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BUDGET DEFICIT AND CO_2 EMISSIONS IN MOROCCO: AN ASYMMETRIC NARDL-BASED ANALYSIS

Abstract

In emerging economies, the integration of environmental considerations into fiscal policy analysis has emerged as a priority of sustainable development strategies. This paper seeks to investigate the asymmetric short- and long-term impacts of the budget deficit on CO_2 emissions per capita in Morocco from 1974 to 2022. A nonlinear ARDL model is employed to identify asymmetric fiscal dynamics over the period under study. The estimation results indicate that, in the short run, an increase in the budget deficit immediately and significantly reduces CO_2 emissions per capita (−0.0046; $p < 0.05$), while the delayed effect of this increase significantly increases emissions in the following period (0.0068; $p < 0.05$), revealing opposing dynamics and instability in the short-term adjustment process. Conversely, the immediate and delayed effects of negative changes in the deficit do not exert statistically meaningful short-run effects ($p > 0.10$). In the long run, both increases and decreases in the budget deficit reduce emissions (−0.0075; $p < 0.05$; −0.0171; $p < 0.01$, respectively), with a stronger effect associated with deficit reductions. The results also show that urbanization significantly reduces emissions (−0.0168; $p < 0.05$), whereas fossil fuel consumption increases them (0.0003; $p < 0.05$). In contrast, GDP per capita, along with inward FDI inflows, fails to demonstrate statistical significance over the long-term horizon ($p > 0.05$). These results underscore the nonlinear and asymmetric nature of the fiscal policy and environmental quality nexus, suggesting that prudent budget management can promote sustainable environmental outcomes.

Keywords budget deficit, CO_2 emissions, NARDL approach, asymmetric effects, environmental policy, energy transition

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INTRODUCTION

In recent years, concerns about climate change and environmental degradation have placed the issue of carbon dioxide (CO_2) emissions at the heart of debates on sustainable development. In this context, public policies, and more specifically fiscal policies, play a strategic role in shaping countries' economic and environmental trajectories.

Indeed, the allocation of public resources, the structure of investments, infrastructure financing and the implementation of energy policies are directly influenced by budgetary choices, which can have a significant impact on environmental quality.

In developing economies, this issue is particularly important due to persistent budget deficits and increasing environmental pressures. Recurring budget deficits are often linked to development policies based on public investment, urbanisation and structural transformation, which can influence CO_2 emission levels. Thus, reconciling balanced public finances with environmental sustainability objectives is a major challenge for public policymakers.

In Morocco, public finances are an important lever for supporting economic growth, social programmes and infrastructure projects. However, the Moroccan economy has experienced persistent budget deficits in recent decades, alongside growing environmental challenges, including CO_2 emissions reduction and energy transition. Indeed, this situation highlights a major issue concerning the role of fiscal imbalances in the environmental dynamics of a developing country committed to a path of growth and economic transition.

Thus, the coexistence of recurring budget deficits and growing demands for environmental sustainability raises a key question about the role of public finances in environmental preservation. Understanding this issue is essential in the Moroccan context, where reconciling economic development, budget management and environmental protection is a major strategic challenge.

Based on the above considerations, the following research question arises: to what extent do variations in the budget deficit have asymmetric effects on carbon dioxide (CO2) emissions?

1. LITERATURE REVIEW AND HYPOTHESES

The link between fiscal policy and the quality of the environment has been the subject of growing interest in recent economic literature. Several empirical studies highlight the role of macroeconomic factors, such as fossil fuel consumption, economic growth, urbanization, and inward FDI inflows, in shaping environmental outcomes, particularly carbon dioxide (CO_2) emissions. Within this framework, fiscal policy has emerged as a potentially influential instrument affecting environmental quality through public spending, taxation, and budgetary balances.

Numerous studies have analyzed the link between budget deficits and carbon dioxide (CO_2) emissions worldwide. In the Indian context, Asif et al. (2023) examined in depth the relationship between budget deficits and environmental quality, measured by carbon dioxide (CO_2) emissions, using ARDL, NARDL, and MTNARDL models from 1972 to 2021. The results of the ARDL model show that the budget deficit has a positive and significant effect on CO_2 emissions in the long run, implying that an increase in the deficit exacerbates environmental degradation. The NARDL model reveals an asymmetry in this relationship, whereby an increase in the deficit leads to a sharp rise in emissions, while a reduction in the deficit leads to a more moderate decline in emissions. The MTNARDL model identifies several threshold regimes and confirms that small reductions in the budget deficit can lead to significant improvements in air quality, while large increases in the deficit do not proportionally amplify pollution, reflecting a non-linear relationship.

Liu et al. (2017b) sought to determine whether fiscal policy can play a structural role in reducing CO_2 emissions by mobilizing hybrid fiscal instruments combining carbon taxes and subsidies. Their model, applied to the taxi sector in Beijing, is based on a budget-neutral system in which taxes levied on high-emission companies are fully redistributed to more virtuous companies in the form of allowances. The results show that this incentive mechanism promotes the adoption of clean technologies while maintaining budgetary balance.

From a Turkish perspective, Sa. Katircioğlu and Se. Katircioğlu (2017) highlighted the nature of the relationship between fiscal policy and environmental degradation. The results show that, in the long term, fiscal measures contribute to reducing CO_2 emissions, thus indicating a beneficial effect on the environment. In the Chinese context, Yuelan et al. (2019) examined the link between fiscal policy instruments and environmental degradation, with a particular focus on CO_2 emissions. The results reveal that fiscal policy, particularly through public spending and government revenues, plays a major role in long-term environmental degradation. Accordingly, expansionary fiscal policies, such as increased public spending, are associated with higher CO_2 emissions and more pronounced environmental degradation.

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Beyond fiscal variables, fossil fuel consumption is widely identified as one of the primary drivers of CO_2 emissions. Numerous studies confirm a strong positive relationship between fossil-fuel-based energy use and environmental degradation across different regions. According to Asif et al. (2023), fossil fuel consumption is identified as a key positive and significant determinant of CO_2 emissions in India. This highlighted India's heavy energy dependence on non-renewable sources.

Yuelan et al. (2019) highlighted the major role of energy consumption in environmental degradation in China. They found that increased energy consumption is directly linked to increased CO_2 emissions. The results indicate that a 1% increase in energy consumption leads to a 0.68% increase in CO_2 emissions. Further, Behera and Dash (2017) found that primary energy consumption and fossil fuel use increase carbon dioxide emissions in middle-income countries in the SSEA region. In the same Asian context, Qingquan et al. (2020) confirmed that fossil fuel consumption is a major determinant of CO_2 emissions. In their study, a 1% increase in fossil fuel consumption leads to a significant increase in CO_2 emissions. In Sri Lanka, Gasimli et al. (2019) found that energy consumption leads to carbon emissions in both the short and long terms.

The relationship between economic growth and environmental quality has also been the subject of numerous studies, particularly within the framework of this approach. One of the main contributions to the analysis of this relationship is the famous Kuznets curve. This curve suggests an inverted U-shaped relationship between per capita income and environmental degradation. Inspired by Kuznets' (1955) work on inequality, this hypothesis was transposed to the environment by Grossman and Krueger (1991, 1995). According to this model, economic growth is accompanied by an increase in pollutant emissions due to industrialization and weak environmental regulations. However, above a certain income threshold, environmental awareness, technological advances, and environmental policies lead to a gradual reduction in pollution.

For G7 countries, Nathaniel (2021) showed that economic growth has a positive effect on the ecological footprint. However, the negative coefficient of the squared GDP variable suggests the presence of an Environmental Kuznets Curve (EKC) in the UK, USA, Germany, and Japan. In the same vein, Munir and Ameer (2018) sought to validate the Kuznets environmental curve hypothesis across 11 emerging Asian economies. The results confirm the existence of an inverted U-shaped relationship between GDP and sulfur dioxide (SO_2) emissions. Initially, economic growth increases emissions, but as growth continues, stricter environmental policies and technological improvements help to reduce them.

Similarly, Nasir et al. (2019) examined the impact of economic growth on CO_2 emissions using panel data covering the period 1982–2014. Empirical results show that economic growth significantly increases CO_2 emissions, reflecting intensified environmental pressures in the early stages of development. However, the introduction of the quadratic income term reveals a negative effect, confirming the validity of the Environmental Kuznets Curve (EKC) hypothesis, according to which CO_2 emissions decline beyond a certain income threshold.

In China, Yuelan et al. (2019) showed that GDP growth has a direct and significant impact on environmental degradation through increased CO_2 emissions. The results indicate that sustained economic growth is linked to increased energy demand in the industrial and transportation sectors, which are the main sources of CO_2 emissions. In the same Chinese context, Sung et al. (2018) examined the impact of industrial GDP on CO_2 emissions in the Chinese manufacturing sector. The study concludes that industrial GDP contributes to improving environmental quality by reducing CO_2 emissions.

In an Arab context, Shahbaz et al. (2014) revealed an inverted U-shaped relationship between economic growth (GDP) and CO_2 emissions in the United Arab Emirates. The results indicate that emissions increase with economic growth up to a certain income threshold. Beyond this threshold, continued economic growth reduces CO_2 emissions, suggesting a decoupling effect between growth and environmental degradation.

Urbanization represents another key determinant of environmental outcomes, though its ef-

fects remain ambiguous. Many empirical studies have identified a significant link between urban growth and environmental degradation, particularly through increased CO_2 emissions. Asif et al. (2023) examined the relationship between urbanization and environmental quality in India using the ARDL approach. Their findings indicate that the effects of urbanization are nuanced. While it tends to increase CO_2 emissions in the short run, it appears to exert a moderating effect in the long run.

Nathaniel (2021) showed that urbanization has a variable impact on environmental quality. Its effect is minimal in countries such as Canada, Japan, and the UK, but highly detrimental in the United States, Germany, Italy, and France. In Asian economies, Qingquan et al. (2020) confirmed that urbanization is an important factor in the rise of CO_2 emissions. The study reveals that urbanization has a significant impact on emission levels and contributes to the increase in CO_2 emissions.

Gasimli et al. (2019) found that urbanization has a negative and statistically significant effect on carbon emissions in Sri Lanka. Xu et al. (2018) analyzed the impact of urbanization on carbon emissions in the Pearl River Delta region between 1990 and 2014, examining three aspects of urbanization: land urbanization, demographic urbanization, and economic urbanization. The results showed that economic urbanization and land urbanization follow a Kuznets environmental curve. Their effects on carbon emissions are positive up to a certain level of urbanization, after which they become negative, leading to a decrease in emissions. In contrast, demographic urbanization has an insignificant effect on carbon emissions.

Munir and Ameer (2018) analyzed the short- and long-run effects of economic growth and urbanization on sulfur dioxide (SO_2) using an augmented STIRPAT model and panel cointegration and causality tests for 11 Asian emerging economies over the period 1980–2014. Results show that urbanization plays a positive role in reducing SO_2 emissions in the long term in emerging Asian economies.

In Africa, Çetin and Ecevit (2015) analyzed the relationship between urbanization and CO_2 emissions for 19 Sub-Saharan African countries over the period 1985–2010, using the Pedroni and Kao cointegration tests and Granger causality tests based on a Vector Error Correction Model (VECM). The results identify urbanization as a major contributor to environmental degradation. In the case of the United Arab Emirates (UAE), Shahbaz et al. (2014) examined the relationship between economic growth, urbanization, and CO_2 emissions using quarterly data over the period 1975–2011. Applying the ARDL bounds testing approach with structural breaks and VECM-based Granger causality tests, the results confirm the existence of cointegration and indicate that urbanization increases CO_2 emissions.

Al-Mulali et al. (2013) examined the relationship between urbanization and CO_2 emissions in the MENA region using panel data over the period 1980–2009. Applying the Pedroni cointegration test, Dynamic OLS, and Granger causality analysis, the results confirm the existence of a long-run cointegration relationship and reveal positive bi-directional relationships in both the long run and the short run between urbanization and CO_2 emissions, with the magnitude of these effects varying across countries according to their income and development levels.

Martínez-Zarzoso and Maruotti (2011) analyzed the impact of urbanization on CO_2 emissions between 1975 and 2003 using a panel of developing countries. The results reveal an inverted U-shaped relationship between urbanization and CO_2 emissions. The elasticity of emissions with respect to urbanization is positive at low levels of urbanization. The study classified countries into three homogeneous groups, each showing a different impact of urbanization on CO_2 emissions. For two of these groups, a threshold was identified beyond which the elasticity of emissions with respect to urbanization becomes negative, meaning further urban growth no longer leads to increased emissions. For the third group, urbanization has no significant effect.

Finally, the environmental impact of foreign direct investment remains highly debated. In the context of China and the Belt and Road Initiative (BRI) countries, Mahadevan and Sun (2020) analyzed the effects of foreign direct investment on carbon emissions, both in the Chinese domestic economy

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and in recipient countries. The results show that FDI inflows into China reduce carbon emissions in the eastern and western regions, while their effect remains insignificant in the central region. In contrast, FDI outflows from China, particularly those from the eastern region, contribute to reducing emissions within China. Furthermore, the impact of Chinese FDI on carbon emissions in BRI countries is reducing in low-income countries and increasing in lower-middle-income countries, while remaining insignificant in high-income and upper-middle-income countries.

Focusing on the Chinese manufacturing sector, Sung et al. (2018) analyzed the impact of foreign direct investment flows on carbon dioxide (CO_2) emissions using panel data covering 28 manufacturing sub-sectors over the period 2002–2015. Using the generalized method of moments (GMM) approach, the results indicate that FDI reduces CO_2 emissions, suggesting that foreign investment improves the environmental performance of China's manufacturing sector. In another study focusing on China, Liu et al. (2017a) examined the impact of foreign direct investment on environmental pollution in 285 Chinese cities, adopting a spatial econometric perspective. The study showed that foreign direct investment has mixed effects on environmental quality. Although FDI reduces pollution caused by ash, soot, and dust, it increases pollution caused by wastewater and sulphur dioxide. These results validate the 'pollution haven' and 'pollution halo' hypotheses and highlight the complex effects of FDI on the environment.

In the context of emerging ASEAN economies, Nasir et al. (2019) analyzed the impact of foreign direct investment on CO_2 emissions using panel data covering the period 1982–2014. Using Dynamic Ordinary Least Squares (DOLS) and Fully Modified OLS (FMOLS) methods, the results highlight a long-term cointegration relationship between FDI and CO_2 emissions. The estimates show that FDI contributes significantly to the increase in CO_2 emissions.

Behera and Dash (2017) examined the influence of foreign direct investment (FDI) on carbon dioxide (CO_2) emissions in 17 South and Southeast Asian (SSEA) countries between 1980 and 2012. Using Pedroni and Westerlund cointegration tests, the results reveal differentiated impacts depending on the level of economic development of the countries. The results showed that FDI contributes to an increase in CO_2 emissions in high-income countries. However, in middle-income countries such as India and Indonesia, the impact of FDI on CO_2 emissions is most pronounced. In contrast, the impact of FDI on CO_2 emissions remains limited in low-income countries.

In the context of emerging economies, Paramati et al. (2016) analyzed the role of foreign direct investment (FDI) in CO_2 emissions dynamics using a balanced panel of 20 emerging economies over the period 1991–2012. Empirical results show that FDI flows significantly promote the use of clean energy, thereby indirectly contributing to the reduction of CO_2 emissions. These results suggest that FDI can play a key role in carbon emission mitigation.

Drawing on the existing empirical literature, this study seeks to investigate the asymmetric nexus between the budget deficit and economic growth in the Moroccan context and thus develops the following hypotheses:

H1: Budget deficit has a significant influence on carbon dioxide (CO_2) emissions.

H2: Budget deficit has asymmetric effects on carbon dioxide (CO_2) emissions.

H3: GDP has a significant influence on carbon dioxide (CO_2) emissions.

H4: FDI has a significant influence on carbon dioxide (CO_2) emissions.

H5: Urbanization has a significant influence on carbon dioxide (CO_2) emissions.

H6: Fossil fuel consumption has a significant influence on carbon dioxide (CO_2) emissions.

2. METHODOLOGY

To analyze the asymmetric effects of the budget deficit on environmental quality, specifically CO_2 emissions, we adopt a Nonlinear Autoregressive

Distributed Lag approach. This econometric framework is particularly well-suited for examining nonlinear and dynamic relationships between variables.

2.1. Econometric model specification

The NARDL framework allows for the assessment of the differentiated impact of positive and negative shocks in the budget deficit on CO_2 emissions by capturing asymmetries in temporal dynamics.

$$CO2PC_t = \varphi + \sum_{i=1}^{p} \alpha_i CO2PC_{t-i} + \sum_{j=0}^{q} \beta_j FD_{t-j}^{+} + \sum_{k=0}^{r} \gamma_k FD_{t-k}^{-} + \sum_{l=0}^{s} \theta_l X_l + \varepsilon_t, \quad (1)$$

where $CO2PC$ represents carbon dioxide emissions per capita; FD^+ represents the positive component of the budget deficit; FD^- represents the negative component of the budget deficit; X represents a vector of control variables comprising gross domestic product per capita (GDPPC), inward foreign direct investment (FDI), urbanization rate (URB), and fossil fuel consumption per capita (FFCPC); φ represents the constant term of the model; α, β, γ and θ capture the estimated impacts of the associated explanatory variables; ε represents the stochastic error term.

In this study, we examine the asymmetric effects of the budget deficit (FD); our variable of interest is carbon dioxide emissions per capita (CO_2PC), while controlling for the influence of other explanatory variables, namely gross domestic product per capita (GDPPC), inward foreign direct investment (FDI), urbanization rate (URB), and fossil fuel consumption per capita (FFCPC).

2.2. Nature and source of the data

This empirical analysis relies on annual time-series data covering the period 1974–2022. The dataset was collected from several sources, including the World Bank's World Development Indicators (WDI) database, the Our World in Data (OWID) platform, and the Ministry of Economy and Finance of Morocco. Table 1 presents a summary description of the model variables.

Table 1. Description of model variables

Variable	Description	Source
CO2PC	Carbon dioxide emissions per capita	Our World in Data (OWID) platform
FD	Budget deficit as a percentage of Gross Domestic Product	Ministry of Economy and Finance of Morocco
GDPPC	Gross domestic product per capita	World Bank, World Development Indicators (WDI)
FDI	Inward foreign direct investment	World Bank, World Development Indicators (WDI)
URB	Urbanization rate	World Bank, World Development Indicators (WDI)
FFCPC	Fossil fuel consumption per capita	Our World in Data (OWID) platform

3. RESULTS AND DISCUSSION

Before proceeding with the estimation of the model, several preliminary tests are performed to ensure the validity and adequacy of the empirical framework.

3.1. Stationarity and unit root diagnostics

Prior to estimating the model assessing the asymmetric impact of the budget deficit (the main explanatory variable) on carbon dioxide (CO_2) emissions per capita, it is necessary to examine the stationarity properties of the time-series data. Indeed, checking for stationarity is necessary to ensure the robustness of econometric estimates and to avoid spurious regressions arising from nonstationary series.

The unit root test results reported in Table 2 indicate that CO_2PC, FD, GDPPC, FDI, and FFCPC are stationary in first differences – that is, they are integrated of order I(1) at the 1% significance level. Regarding the variable URB, although stationarity is not confirmed at the conventional 5% level, the ADF test with constant and trend rejects the unit root hypothesis at the 10% level (ADF statistic = –3.39; p-value = 0.0629). Thus, we consider this variable as weakly stationary in levels, or integrated of order I(0).

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Table 2. Results of the unit root tests (ADF)

Variables	Level	First Difference	Order of Integration
CO2PC	−0.0330	−11.2070	I(1)
	(−0.9507)	(0.0000)***	
FD	−2.4455	−7.5930	I(1)
	(−0.1346)	(0.0000)***	
GDPPC	1.1096	−11.6323	I(1)
	−0.9971	(0.0000)***	
FDI	−1.9180	−16.9427	I(1)
	−0.3216	(0.0000)***	
URB	−3.3974	–	I(0)
	(0.06297)*	–	
FFCPC	0.0453	−11.4785	I(1)
	−0.9581	(0.0000)***	

Note: Probability (p-value); * stationary at 10%; ** stationary at 5%; *** stationary at 1%.

The findings indicate that the variables are stationary either at level, I(0), or after first differencing, I(1), which justifies the application of the NARDL modelling framework in this study.

3.2. Selection of optimal lag length

Before estimating the NARDL model examining the asymmetric impact of the budget deficit on CO_2 emissions in Morocco, it is essential to determine the optimal number of lags for each variable. This step is carried out using the Akaike Information Criterion (AIC), which allows the identification of the most appropriate lag structure while preserving model parsimony.

Figure 1 shows that, following the imposed order of variables (CO_2PC, GDPPC, FDI, URB, FFCPC, FD), the most parsimonious model is a NARDL (2,0,0,0,0,2).

3.3. NARDL model estimation and diagnostic validation

Once the optimal lag structure has been identified, the NARDL (2,0,0,0,0,2) specification is estimated, with the estimation results displayed in Table 3.

Table 3. NARDL model estimation

Selected model: NARDL(2,0,0,0,0,2)				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
CO2PC(−1)	−0.6886	0.1039	−6.6265	0.0000
GDPPC	0.0000	0.0000	−0.5972	0.5541
FDI	−0.0069	0.0054	−1.2937	0.2040
URB	−0.0116	0.0043	−2.6791	0.0111
FFCPC	0.0002	0.0000	7.8053	0.0000
@CUMDP(FD(−1))	−0.0052	0.0022	−2.3457	0.0246
@CUMDN(FD(−1))	−0.0118	0.0028	−4.2663	0.0001
C	0.4688	0.1543	3.0381	0.0044
D(CO2PC(−1))	−0.1540	0.0980	−1.5714	0.1248
@DCUMDP(FD)	−0.0046	0.0033	−1.3979	0.1707
@DCUMDN(FD)	−0.0026	0.0052	−0.4945	0.6240
@DCUMDP(FD(−1))	0.0068	0.0035	1.9572	0.0581
@DCUMDN(FD(−1))	−0.0024	0.0045	−0.5452	0.5890
R−squared	0.7986	–	–	–

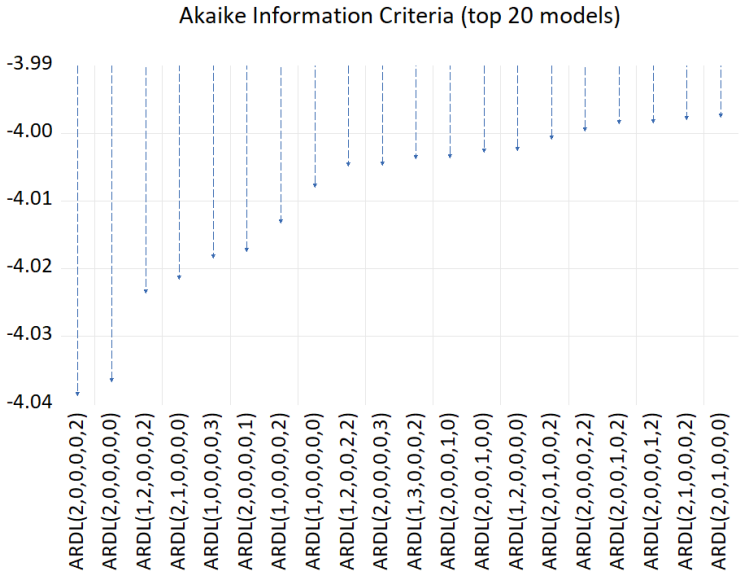


Figure 1. Akaike Information Criterion (AIC)

Subsequent to model estimation, several post-estimation diagnostic checks are carried out to evaluate the robustness and overall validity of the NARDL model.

3.4. Error autocorrelation: Residual correlogram

Figure 2 indicates a complete absence of error autocorrelation. Indeed, both the autocorrelation and partial autocorrelation coefficients remain within the confidence bounds, leading to the acceptance of the null hypothesis of no serial correlation. Hence, the error terms can be considered free from autocorrelation.

3.5. Breusch-Pagan-Godfrey test of heteroskedasticity

Table 4. Breusch-Pagan-Godfrey test

Heteroskedasticity Test: Breusch-Pagan-Godfrey			
Null hypothesis: Homoskedasticity			
F-statistic	1.02884	Prob, F(12,36)	0.4448
Obs*R-squared	12.51305	Prob, Chi-Square(12)	0.4054
Scaled explained SS	4.6793	Prob, Chi-Square(12)	0.9678

As reported in Table 4, the *p*-value associated with the *F*-statistic exceeds the 5% significance level, indicating the absence of heteroskedasticity. Consequently, the residuals can be regarded as homoscedastic.

3.6. Normality of the errors: Jarque–Bera test

Figure 3 confirms that the residuals follow a normal distribution, as the Jarque–Bera probability value is higher than the 5% threshold. This result supports the normality assumption of the error term.

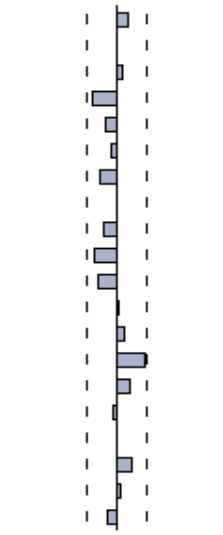
3.7. Model stability: CUSUM and CUSUM of squares tests

The CUSUM and CUSUMSQ plots displayed in Figures 4 and 5 remain within the 5% critical bounds, indicating the stability of both the model coefficients and the variance of the residuals over the sample period. Accordingly, the estimated model is structurally stable.

3.8. Bounds cointegration test

To examine the existence of a cointegration relationship, we will use the test developed by Pesaran

Sample: 1974 2022
Q-statistic probabilities adjusted for 12 dynamic regressors



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob*
		1	0.114	0.114	0.6720	0.412
		2	0.005	-0.008	0.6731	0.714
		3	0.046	0.048	0.7905	0.852
		4	-0.234	-0.248	3.8204	0.431
		5	-0.104	-0.049	4.4294	0.489
		6	-0.054	-0.046	4.6019	0.596
		7	-0.168	-0.141	6.2874	0.507
		8	-0.005	-0.023	6.2892	0.615
		9	-0.128	-0.179	7.3174	0.604
		10	-0.221	-0.232	10.433	0.403
		11	-0.176	-0.280	12.471	0.329
		12	0.011	-0.036	12.479	0.408
		13	0.070	-0.061	12.816	0.462
		14	0.274	0.131	18.181	0.199
		15	0.123	-0.090	19.290	0.201
		16	-0.040	-0.198	19.410	0.248
		17	-0.002	-0.163	19.411	0.305
		18	0.134	0.153	20.865	0.286
		19	0.025	0.032	20.919	0.341
		20	-0.087	-0.257	21.567	0.364

*Probabilities may not be valid for this equation specification.

Figure 2. Correlogram of residuals

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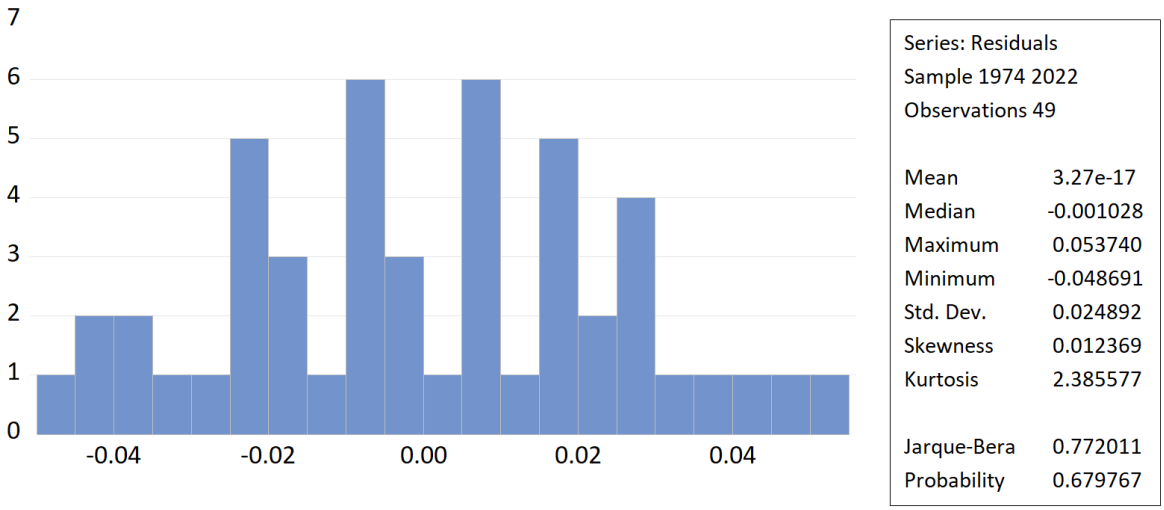

Figure 3. Jarque–Bera test

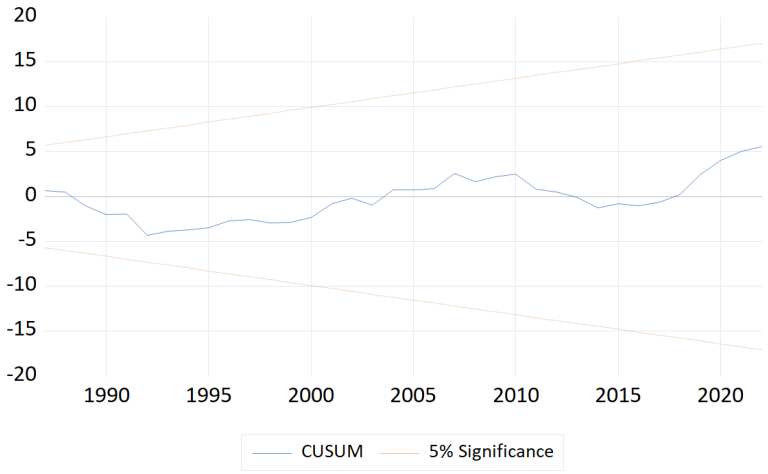

Figure 4. CUSUM test

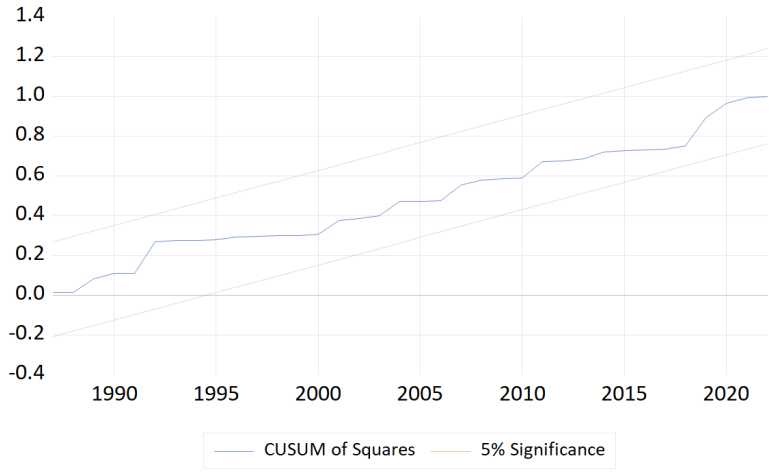

Figure 5. CUSUM of squares test

Table 5. Bounds cointegration test

F-Bounds Test						
Null Hypothesis: No levels relationship Number of cointegrating variables: 6 Trend type: Rest, constant (Case 2) Sample size: 49						
F-statistic	**14.7511**					
Sampl Size	**45**		**50**		**Asymptotic**	
Signif.	**I(0)**	**I(1)**	**I(0)**	**I(1)**	**I(0)**	**I(1)**
10%	2.188	3.254	2.17	3.22	1.99	2.94
5%	2.591	3.766	2.55	3.708	2.27	3.28
1%	3.54	4.931	3.424	4.88	2.88	3.99

et al. (2001). More precisely, the calculated *F*-statistic is compared with the lower and upper critical bound values.

The results of the bounds cointegration test (Table 5) robustly confirm the existence of a long-term relationship among the model's variables. The *F*-statistic (14.751) significantly exceeds all the upper critical bounds (I(1)) at all significance levels (1%, 5%, and 10%). This strong statistical evidence validates the presence of a cointegration relationship.

This result fully justifies the use of a NARDL model, which allows us to estimate the long-term effects of the explanatory variables (GDPPC, FDI, URB, FFCPC) on carbon dioxide emissions per capita (CO_2PC) under a classical linear framework, thus providing insights into their environmental impact, and to specifically analyze the asymmetric effects of the budget deficit (FD, decomposed into FD^+ and FD^-) on CO_2PC. This captures the differentiated responses to positive and negative shocks of FD, as well as the nonlinear dynamics in the impact of FD variations on carbon dioxide emissions per capita.

3.9. Coefficient symmetry tests

The symmetry tests in Table 6 reveal the existence of a significant long-run asymmetry in the effect of the budget deficit on CO_2 emissions, while the short-run effects appear to be largely symmetric. These results fully justify our asymmetric NARDL approach to analyze the differentiated impacts of fiscal policies, through budget deficits, on environmental quality.

Table 6. Coefficient symmetry tests

Coefficient symmetry tests			
Null hypothesis: Coefficient is symmetric			
Variable	**Statistic**	**Value**	**Probability**
Long-run			
FD	F-statistic	5.3214	0.0269
Short-run			
FD	F-statistic	0.8268	0.3692

3.10. Discussion of short- and long-term results

Table 7. Short-term coefficients

Short-term coefficient				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
D(CO2PC(-1))	–0.15401478	0.0671	–2.2958	0.0266
@DCUMDP(FD)	–0.00464488	0.0022	–2.0761	0.0439
@DCUMDN(FD)	–0.00256065	0.0039	–0.6619	0.5115
@DCUMDP(FD(–1))	0.00683637	0.0027	2.5179	0.0156
@DCUMDN(FD(–1))	–0.00243106	0.0034	–0.7075	0.4831
COINTEQ*	–0.68857761	0.0580	–11.8725	0.0000
R-squared	0.7986	–	–	–

Table 8. Long-term coefficients

Long-term coefficient				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
GDPPC	–0.0000043775	0.0000	–0.5767	0.5672
FDI	–0.0100528868	0.0079	–1.2797	0.2077
URB	–0.0168950086	0.0066	–2.5500	0.0145
FFCPC	0.0003016842	0.0000	6.8570	0.0000
@CUMDP(FD(–1))	–0.0074848812	0.0037	–2.0213	0.0497
@CUMDN(FD(–1))	–0.0171309679	0.0044	–3.9155	0.0003
C	0.6808024777	0.2356	2.8901	0.0061

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The estimated short-run and long-run parameters are summarized in Tables 7 and 8, respectively. The results reveal that the error correction term is negative and statistically significant, which indicates the existence of a valid error correction mechanism and confirms the presence of a long-run cointegration relationship among the variables. This implies that any short-run deviation from the long-run equilibrium is corrected at a speed of approximately 68.86% per year following a shock.

The results reveal marked asymmetric effects of the budget deficit (FD) on CO_2 emissions, both in the short and long term. In the short term, the asymmetry exhibits an opposite dynamic. The current budget deficit has a negative and statistically significant effect on carbon dioxide emissions, meaning that an expansionary fiscal shock temporarily reduces emissions. Conversely, the lagged effect of a positive deficit shock exerts a positive and statistically significant impact, indicating that a deficit recorded in the previous year contributes to an increase in CO_2 emissions per capita, reflecting a delayed polluting effect. However, both the immediate and lagged effects of deficit reductions do not have a statistically significant impact in the short term, suggesting a limited environmental responsiveness to fiscal austerity over short horizons. In the long term, both fiscal shocks exhibit negative and significant effects on CO_2 emissions, confirming the existence of a structural asymmetry in the relationship between the budget deficit and environmental quality. A persistent increase in the budget deficit leads to a moderate and significant reduction in CO_2 emissions, while a decrease in the deficit generates a stronger and highly significant reduction. Thus, although both types of fiscal shocks contribute to improving environmental quality in the long run, the impact of restrictive fiscal policies (FD^-) proves to be more pronounced than that of expansionary measures (FD^+).

Regarding GDP per capita, the results reveal no significant effect, either in the short or long term, on carbon dioxide emissions per capita. In the long run, the estimated coefficient is negative but statistically insignificant, suggesting that changes in GDP per capita do not have a decisive influence on the dynamics of CO_2 emissions. In the short run, this variable is not among the significant explanatory variables, confirming the weakness of its transitional impact. Economically, this neutrality can be explained by several factors. On the one hand, the observed economic growth may be driven by less carbon-intensive sectors, thereby weakening the traditional link between growth and pollution. On the other hand, it is possible that the potential effects of GDP on emissions are absorbed or offset by other variables such as fossil fuel consumption or the level of urbanization.

As for the FDI variable, the results show no significant effect in either the short or long term. In the long term, although the coefficient associated with the impact of foreign direct investment (FDI) on CO_2 emissions is negative, it remains statistically insignificant, suggesting that FDI has not had a measurable influence on Morocco's environmental quality. In the short term, the absence of this variable among the relevant regressors also confirms the weakness of its immediate impact. The statistical insignificance of the results indicates, however, that the environmental impact of FDI remains marginal, likely due to its sectoral orientation toward low-pollution activities or to its insufficient volume to significantly alter the national energy mix.

The URB variable has a significant long-term effect but no short-term impact on carbon dioxide emissions per capita. The long-term coefficient is negative and statistically significant, suggesting that an increase in the urbanization rate contributes to a reduction in pollutant emissions. This result may seem counterintuitive, but it can be explained by the potential effects of urban concentration: urban areas, especially in emerging contexts, tend to benefit from better infrastructure, broader access to public transportation, and economies of scale in resource and service management.

In the short term, urbanization does not have an impact on CO_2 emissions per capita. This lack of immediate effect can be explained by the gradual nature of urban transformations, the time required for infrastructure implementation, and the slow pace of behavioral changes related to mobility, housing, or energy consumption.

Economically, these results highlight the importance of sustainable urban policies in the long run.

Well-planned urbanization supported by investments in green infrastructure can be an effective lever to improve environmental quality.

The FFCPC variable has a positive and highly significant long-term effect on carbon dioxide emissions per capita, while in the short term, it does not appear among the selected explanatory variables. This suggests an essentially structural and non-immediate impact. The long-term estimated coefficient indicates that the increase in fossil fuel consumption is a major factor in environmental degradation in Morocco. This positive relationship reflects a marked energy dependence on carbon-based sources, such as oil, coal, or natural gas, whose combustion is directly linked to CO_2 emissions. These results confirm the existence of a direct and robust link between fossil energy consumption and environmental quality and highlight the limitations of Morocco's current energy model. The absence of a significant short-term effect can be explained by the inertia of energy systems, which means that adjustments to consumption habits or production structures happen slowly.

In view of the empirical evidence obtained, it can be concluded that hypotheses *H1*, *H2*, *H5,* and *H6* are confirmed, while hypotheses *H3* and *H4* are not validated. On the one hand, the estimates show that changes in the budget deficit have statistically significant long-term asymmetric effects on CO_2 emissions, confirming hypothesis *H1*, in line with Asif et al. (2023) and Yuelan et al. (2019), as well as hypothesis *H2*, consistent with the results of Asif et al. (2023) and Sa. Katircioğlu and Se. Katircioğlu (2017). On the other hand, urbanization is associated with a reduction in CO_2 emissions, which validates hypothesis *H5*, in line with the conclusions of Gasimli et al. (2019), Munir and Ameer (2018), and Martínez-Zarzoso and Maruotti (2011). Finally, fossil fuel consumption contributes significantly to the increase in CO_2 emissions, thus validating hypothesis *H6* and corroborating the results of Asif et al. (2023), Yuelan et al. (2019), Behera and Dash (2017), and Qingquan et al. (2020). On the other hand, the absence of a statistically significant effect of GDP per capita and foreign direct investment leads to the rejection of hypotheses *H3* and *H4*.

CONCLUSION

This paper seeks to assess how changes in the budget deficit asymmetrically influence environmental quality in Morocco, as measured by carbon dioxide (CO_2) per capita emissions in a dynamic short- and long-term framework.

The results highlight the existence of a significant asymmetric relationship between the budget deficit and CO_2 emissions. The estimates indicate that an increase in the budget deficit is associated with an immediate decline in emissions, whereas the lagged effect of a positive deficit shock leads to an increase in emissions. By contrast, negative deficit variations do not exert a statistically significant impact in the short term. In the long run, both positive and negative variations in the deficit contribute to reducing emissions, but with a significantly stronger impact in the case of restrictive budgetary adjustments. With regard to control variables, fossil fuel consumption is the main determinant of environmental degradation in Morocco, while urbanization contributes to reducing CO_2 emissions. On the other hand, GDP per capita and foreign direct investment have no significant effect.

These findings offer implications for public policy. On the one hand, fiscal policy should be designed as an instrument of ecological transition, prioritizing public resources for low-carbon investments and limiting the deferred polluting effects of expansionary policies. On the other hand, fiscal consolidation, when gradual and well-targeted, can be an effective lever for reducing emissions while strengthening the sustainability of public finances, provided that blind adjustments to the detriment of strategic environmental spending are avoided.

Future extensions of this study could rely on a more disaggregated fiscal analysis to better capture the differentiated environmental implications of specific public spending and revenue streams.

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Funding acquisition: Mohammed Hennach.
Investigation: Mohammed Hennach.
Methodology: Mohammed Hennach.
Project administration: Mohammed Hennach, Abdellah Echaoui.
Resources: Mohammed Hennach.
Software: Mohammed Hennach.
Supervision: Abdellah Echaoui.
Validation: Abdellah Echaoui.
Visualization: Mohammed Hennach.
Writing – original draft: Mohammed Hennach.
Writing – review & editing: Mohammed Hennach, Abdellah Echaoui.

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