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Industrial Development and Renewable Electricity in Morocco: Asymmetric Adjustment and the Role of Water Resources.

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Abstract

The interaction between renewable energy, water resources, and industrial activity has become increasingly relevant for economies undergoing structural transformation. This study examines whether changes in renewable electricity output and water abstraction have different effects on industrial value added in Morocco over the period 1990–2021. Gross domestic product (GDP) and agricultural activity are included as control variables. A Nonlinear Autoregressive Distributed Lag (NARDL) model is used to capture differences between positive and negative changes, complemented by an asymmetric Granger causality analysis. The empirical approach is motivated by the possibility that industrial adjustment to changes in energy supply may be costly and only partly reversible. The bounds test provides evidence of a long-run relationship among the variables. Positive changes in renewable electricity output increase industrial value added, with an estimated coefficient of 2.14. By contrast, negative changes have a considerably stronger adverse effect, with a coefficient of −3.87. This contrast points to a greater sensitivity of industrial activity to reductions in renewable electricity availability than to equivalent increases. Water abstraction shows no statistically significant effect on industrial value added, either in the long run or in the short run, suggesting that aggregate national withdrawals do not capture the specific water-related pressures faced by industrial activities. Agricultural activity and GDP are positively related to industrial value added in the long run. The asymmetric Granger causality test identifies a unidirectional predictive effect running from negative changes in renewable electricity output to industrial activity. The results indicate that interruptions in clean electricity supply may impose substantial costs on Morocco's industrial sector. Maintaining a reliable renewable electricity supply is thus relevant to industrial competitiveness and the country's transition towards a more sustainable production structure. Energy policy should be designed alongside industrial policy, with greater attention to supply reliability and the ability of firms to absorb energy-related disruptions.

Keywords: industrial activity; renewable electricity; water resources; Morocco; NARDL; Asymmetric Adjustment.

1. Introduction

Industrial development remains a central component of economic transformation, structural change, and sustained growth, particularly in developing economies. Its trajectory is closely tied to the availability, reliability, and cost of energy. As countries move towards cleaner energy systems, the relationship between renewable electricity and industrial performance has gained increasing policy relevance. This issue is particularly pertinent in Morocco, where ambitious renewable energy targets are being pursued alongside efforts to strengthen domestic production and deepen industrial value chains.

Water represents another important dimension of this relationship. Manufacturing, mining, and agro-industrial activities require water for cooling, processing, cleaning, and other production operations. At a time when freshwater resources are under growing pressure, the interaction between water availability, energy supply, and industrial activity deserves greater attention. Morocco offers a particularly relevant setting for such an analysis because the expansion of renewable energy is taking place alongside mounting constraints on water resources.

The literature on energy and economic growth, as well as that on the water–energy nexus, has expanded considerably. However, relatively little attention has been given to their joint implications for industrial activity, especially in North African economies. Existing studies also tend to use aggregate economic output rather than sector-specific measures of industrial performance. More importantly, the possibility that positive and negative changes in energy supply may have different consequences remains insufficiently explored. From an adjustment-cost perspective, a reduction in energy availability can disrupt production, investment, and existing production arrangements more rapidly than an equivalent increase can expand productive capacity. The resulting responses may therefore differ in both magnitude and timing.

This study addresses this gap by examining the effects of renewable electricity output and water abstraction on industrial value added in Morocco over the period 1990–2021. The empirical analysis uses the Nonlinear Autoregressive Distributed Lag (NARDL) framework developed by Shin et al. (2014). This approach separates increases and decreases in the explanatory variables into positive and negative partial sums, making it possible to assess whether their effects differ in the short and long run. To complement the dynamic analysis, the asymmetric Granger causality test proposed by Hatemi-J (2012) is used to examine the predictive direction of the relationships. GDP and agricultural value added are included as control variables.

Morocco provides a particularly useful empirical case. The country has considerably expanded its solar and wind capacity over the past decade and has set a target of obtaining 52% of its electricity generation from renewable sources by 2030. Large-scale projects, including the Noor solar complex and the Tarfaya wind farm, have become important elements of this strategy. The expansion of these technologies has strengthened Morocco's position in the regional energy transition, while also raising questions about the implications of changing energy structures for productive activities. Manufacturing, construction, mining, and agro-processing constitute important components of the Moroccan economy, and their performance depends on stable access to energy at competitive cost. Although renewable electricity may reduce environmental pressures and energy costs over time, the transition can also expose firms to temporary infrastructure constraints, supply interruptions, or adjustments in energy markets.

Water constraints add another layer to this challenge. Morocco is experiencing increasing pressure on freshwater resources, with renewable water availability per capita among the lowest in the MENA region. Water-dependent activities are consequently exposed to droughts and interruptions in supply. At the same time, the development of desalination is becoming an important element of national water policy. Desalination, however, requires substantial amounts of energy, creating an additional link between water management and the reliability of the electricity system. This interdependence makes the availability of affordable renewable electricity relevant not only to industrial production but also to the broader sustainability of water supply. Against this background, the study asks : ***to what extent do changes in renewable electricity output exert asymmetric effects on industrial development in Morocco, and what role does water abstraction play alongside this relationship?*** This study pursues two related aims. The first is to identify whether increases and decreases in renewable electricity generate different responses in industrial value added, while assessing water abstraction as an additional explanatory factor. The second is to examine the direction of predictive relationships through asymmetric Granger causality for renewable electricity, providing further evidence on the dynamics linking energy, water, and industrial activity in a water-constrained developing economy.

The study makes four contributions to the literature. First, it examines the asymmetric relationship between renewable electricity output and industrial value added in Morocco while explicitly linking the expected asymmetry to adjustment costs. Second, it combines the NARDL framework with asymmetric Granger causality to distinguish both dynamic effects and predictive directions. Third, water abstraction is incorporated as a substantive explanatory variable rather than being treated merely as a conventional control, allowing its association with industrial value added to be assessed directly alongside the asymmetric renewable-electricity variable. Fourth, the results offer policy implications for economies seeking to expand renewable energy while maintaining industrial performance under increasing resource constraints.

To achieve these aims, the remainder of the paper is structured as follows. Section 2 reviews the relevant literature, develops the theoretical framework, discusses the epistemological positioning of the study, and derives the hypotheses. Section 3 describes the data, sample, and empirical methodology. Section 4 presents the main results. Section 5 discusses the findings in relation to previous research and considers their theoretical and policy implications. Section 6 concludes by outlining policy propositions, limitations, and directions for future research.

2. Literature Review, Theoretical Framework and Hypotheses Development

The links between energy, water resources, and industrial activity have received increasing attention in the economic and sustainability literature. This section first clarifies the main concepts used in the analysis and then develops the theoretical rationale for expecting asymmetric responses. It subsequently presents the epistemological position of the study and reviews the empirical evidence on renewable energy and industrial activity, followed by the literature on water resources and industrial performance. The hypotheses are introduced within the relevant strands of the literature rather than grouped in a separate subsection. This structure connects each proposition directly to its theoretical and empirical basis.

2.1 Key Concepts

Industrial development: Industrial development refers to the expansion of manufacturing, mining, construction, and related productive activities within an economy. It is commonly assessed through industrial value added, either in absolute terms or as a share of GDP (UNIDO, 2020). Beyond its contribution to output, industrial activity is closely associated with structural transformation, productivity gains, and employment creation. For economies such as Morocco, strengthening this productive base remains an important element of long-term development.

Renewable electricity output: Renewable electricity output denotes the share of electricity generated from renewable sources, including solar, wind, hydropower, and biomass, in total electricity generation (IRENA, 2020). In the present study, this indicator captures an important dimension of the energy transition. Within the NARDL framework, it is separated into positive and negative partial sums to determine whether increases and decreases in renewable electricity generation have different implications for industrial value added.

Water abstraction: Water abstraction refers to the total withdrawal of freshwater from surface and groundwater sources for human use (Gleick, 1993). It is considered here as an observable measure of pressure on water resources rather than a direct measure of water scarcity. Movements in abstraction can reflect changes in demand, allocation policies, technological efficiency, production structures, or climatic conditions. This distinction is important because a change in abstraction does not necessarily indicate a corresponding change in physical water availability.

2.2 Theoretical Framework: Why Should the Relationship Be Asymmetric?

The expectation of asymmetric effects in this study is not based solely on the availability of a nonlinear econometric technique. It follows from three related mechanisms that provide an economic rationale for distinguishing between increases and decreases in energy supply.

The first concerns adjustment costs and the irreversibility of investment decisions. Industrial capital is often highly specific and partly sunk, limiting the speed at which firms can adjust their productive capacity (Dixit & Pindyck, 1994). An improvement in energy availability may therefore translate into higher production only gradually, as firms adjust investment, capacity, and production processes. A reduction in energy availability can have a much more immediate consequence. Firms may have to reduce production, leave capacity idle, substitute inputs, or interrupt particular operations. This difference provides a theoretical basis for expecting the absolute effect of negative renewable electricity changes to exceed that of positive changes, expressed as $|\beta RE^{-}| > |\beta RE^{+}|$.

A second mechanism relates to energy security. Reliable access to energy is not simply another production input; it also affects firms' ability to maintain continuous operations and meet contractual and delivery commitments. Energy disruptions can generate costs through production stoppages, input substitution, delays, and uncertainty about future supply. By contrast, an increase in available electricity does not necessarily produce an immediate equivalent expansion in industrial output because firms may face capacity, investment, or demand constraints. The consequences of negative and positive supply shocks can therefore differ even when their initial magnitude is similar (Bhattacharya et al., 2016).

The third mechanism is linked to the notion of hidden cointegration introduced by Granger and Yoon (2002), which provides an important methodological foundation for nonlinear cointegration analysis. A linear specification imposes a common coefficient on positive and negative movements and may consequently conceal distinct long-run processes. Decomposing a variable into cumulative increases and decreases makes it possible to test whether these movements follow different relationships with the dependent variable. The NARDL framework developed by Shin et al. (2014) operationalises this approach by allowing positive and negative changes to enter separately in both the short- and long-run relationships. In the present context, this specification is consistent with the possibility that industrial activity responds differently to an improvement in electricity availability than to a disruption.

The same reasoning can be extended to water resources, although with greater uncertainty. Industries that depend heavily on water for cooling, processing, or other production activities may face substantial adjustment costs when supply becomes constrained. However, aggregate water abstraction in Morocco reflects the requirements of several sectors, particularly agriculture, as well as public allocation decisions and climatic conditions. Its relationship with industrial production is therefore less direct than that of electricity supply. This distinction weakens the theoretical basis for imposing a particular sign on the water coefficient and motivates a more open empirical assessment. For this reason, water abstraction is retained in the empirical model as a linear control variable rather than being separated into positive and negative partial sums. The theoretical mechanisms motivating an asymmetric response, the irreversibility of industrial investment and the energy-security channel, apply specifically to a firm's direct and continuous input. They do not transfer as clearly to an aggregate, multi-sector resource indicator such as WA, whose movements reflect agricultural demand, allocation policy, and climatic conditions as much as industrial pressure.

2.3 Epistemological Approach

The study follows a quantitative, hypothetico-deductive approach consistent with empirical time-series economics. The theoretical mechanisms outlined above are translated into testable hypotheses and evaluated using observable macroeconomic data and formal statistical procedures, including the bounds test, Wald tests, and asymmetric Granger causality.

This approach is suited to the research question because the analysis concerns measurable relationships between industrial value added and a set of economic and resource variables. The single-country time-series design also allows the analysis to remain closely connected to Morocco's specific institutional and resource context. This choice involves a trade-off: it provides greater attention to country-specific dynamics but limits the extent to which the findings can be generalised to other economies. This limitation is considered further in Section6.

2.4 Renewable Energy and Industrial Development

The energy–growth literature has long established the importance of energy availability for economic activity. Early empirical studies reported significant links between energy use and output, with evidence of bidirectional causality in several developing economies (Apergis & Payne, 2010). More recent research has increasingly focused on renewable energy and whether the transition towards cleaner sources can support productive activity without creating new constraints.

Evidence from cross-country studies generally points to a favourable long-run relationship between renewable energy and economic performance. Possible channels include improved energy security, technological progress, investment in green infrastructure, and reductions in exposure to fossil-fuel price fluctuations (Bhattacharya et al., 2016). Renewable energy development may also support innovation and export competitiveness in emerging economies. The transition is not necessarily frictionless, however. Firms may need to adapt production processes, infrastructure, and energy procurement arrangements as the electricity mix changes.

The MENA context adds several structural considerations. Energy subsidies, fossil-fuel dependence, grid constraints, and differences in renewable-energy deployment can shape how clean electricity reaches productive sectors. Recent studies on Morocco and North Africa point to a positive association between renewable energy and broader economic development, while also indicating that the integration of renewable energy into productive systems remains an evolving process (Amayed, 2025; Dahhou et al., 2025).

For Morocco, Dahhou et al. (2025), using a linear ARDL model, report a positive long-run association between renewable energy, green finance, and economic growth. Their framework, however, does not distinguish between increases and decreases in renewable energy. Amayed (2025), using a cross-sectionally augmented ARDL approach for a North African panel, also reports a positive long-run relationship involving digitalisation, energy, and development, but does not decompose the energy variable into positive and negative components. These studies provide useful evidence of the broader energy–development relationship, while leaving open the question of whether industrial activity responds differently to favourable and adverse changes in renewable electricity supply.

The existing evidence therefore supports the expectation of a systematic relationship between renewable electricity and industrial value added:

H1: Changes in renewable electricity output are associated with industrial value added in Morocco.

The theoretical mechanisms developed in Section 2.2 provide a further basis for expecting differences between positive and negative changes. In particular, the immediate production costs associated with energy disruptions may be greater than the short-term gains generated by an equivalent increase in supply. This leads to the following hypothesis:

H2: Positive and negative changes in renewable electricity output exert asymmetric effects on industrial value added in Morocco, with negative changes having a larger absolute effect.

2.5 Water Resources and Industrial Development

Water constitutes a direct input into several industrial processes, including cooling, processing, cleaning, and extraction. Where production depends on substantial volumes of water, restrictions in supply can raise operating costs, reduce productive capacity, and influence investment decisions (Nair et al., 2014). These pressures may become more pronounced as climate change, population growth, and competing demands place additional stress on freshwater resources.

Compared with the energy–industry literature, empirical evidence on water and industrial performance remains relatively limited. The available studies also report heterogeneous results. Kousar et al. (2020), for example, identify a positive relationship between water availability and economic performance in South Asian economies, with effects operating through agricultural and industrial activities. The institutional and resource conditions of these countries differ from those of Morocco, which limits the direct application of their findings to the present context. Chandio et al. (2025) find significant interactions among renewable energy, water resources, and food production in BRICS economies. Their analysis, however, places greater emphasis on agricultural outcomes than on industrial value added. The relevance of their findings to the present study is therefore indirect. More generally, Falkenmark and Rockström (2006) note that aggregate indicators of water withdrawals can conceal important differences in sectoral exposure. A country-level measure of abstraction may consequently fail to capture constraints faced by particular industrial activities. Table 1 summarises the main empirical studies considered in this review and positions the present research in relation to their geographical coverage, methodology, and principal findings.

Table 1. Positioning of the Present Study within the Reviewed Empirical Literature

Study	Context / Sample	Method	Reported relationship
Apergis & Payne (2010)	Commonwealth of Independent States, panel	Panel causality	Bidirectional relationship between energy and growth
Bhattacharya et al. (2016)	38 major renewable-energy countries, panel	Panel cointegration	Positive long-run relationship between renewable energy and output
Dahhou et al. (2025)	Morocco, time series	ARDL	Positive long-run relationship; asymmetry not examined
Amayed (2025)	North Africa, panel	CS-ARDL	Positive long-run relationship; heterogeneous short-run effects; asymmetry not examined
Kousar et al. (2020)	South Asia, panel	Panel regression	Positive relationship between water availability and economic performance
Chandio et al. (2025)	BRICS, panel	Panel NARDL	Significant interaction, mainly through the agricultural channel

Source: compiled by the authors from the reviewed literature.

The comparison highlights two aspects relevant to the present analysis. First, the reviewed studies do not directly examine whether positive and negative changes in renewable electricity or water abstraction have different effects on an industrial outcome. Second, the evidence concerning water is less consistent and is often obtained from settings where agriculture represents an important transmission channel. The Moroccan case therefore warrants separate investigation, particularly because aggregate water abstraction reflects competing sectoral demands and policy-mediated allocation.

Given these considerations, water abstraction is included in the model as a linear control variable, and its relationship with industrial value added is treated as an open empirical question rather than being assigned a predetermined sign:

H3: Changes in water abstraction are associated with industrial value added in Morocco.

3. Data and Methodology

3.1 Variables Description

The empirical analysis examines whether changes in renewable electricity output and water abstraction are associated with different responses in industrial value added in Morocco over the period 1990–2021. The five variables used in the analysis are obtained from the World Bank's World Development Indicators (WDI). Industrial value added (IND), measured as a share of GDP, is used as the dependent variable. Renewable electricity output (RE) represents the main energy variable and is decomposed into positive (RE^{+}) and negative (RE^{-}) partial sums. Unlike RE, water abstraction (WA) enters the model in linear form rather than being decomposed into positive and negative partial sums, since the asymmetry mechanisms discussed in Section 2.2 apply specifically to renewable electricity. Its estimated coefficient is used to test H3. GDP and agricultural value added (AGR) are included as control variables.

All variables enter the empirical specifications in natural logarithms. The same transformation is maintained across the estimators used in Section 4, including NARDL, FMOLS, and DOLS, ensuring consistency when comparing the estimated long-run relationships. Table 2 presents the definitions and sources of the variables.

Table 2. Description of the Variables

Variable	Abbreviation	Definition	Source
Industrial value added to GDP	IND	Industry, including construction, value added (% of GDP)	WDI
Renewable electricity output	RE	Renewable electricity output (% of total electricity output)	WDI
Water abstraction	WA	Annual freshwater withdrawals, total (% of internal resources)	WDI
Gross domestic product	GDP	GDP (constant 2015 US$)	WDI
Agriculture value added to GDP	AGR	Agriculture, forestry, and fishing, value added (% of GDP)	WDI

Source: Authors' compilation based on World Development Indicators.

3.2 Sample and Study Period

The sample consists of 32 annual observations for Morocco covering 1990–2021. The starting point is determined by the availability of continuous and comparable WDI series for renewable electricity output and water abstraction. The 2021 endpoint corresponds to the latest year for which all five variables were simultaneously available when the dataset was compiled. The analysis therefore uses the complete available series rather than selecting a shorter period.

A single-country time-series design is appropriate for the purpose of the study because the analysis focuses on Morocco's specific energy and water conditions. Its renewable energy strategy, industrial structure, and exposure to water stress form part of the economic setting in which the estimated relationships operate. A cross-country panel could provide greater external comparability, but it would also impose a degree of averaging across countries with substantially different institutional and resource conditions. The country-specific approach adopted here is consistent with the epistemological position presented in Section 2.3.

The limited number of annual observations requires particular caution. With only 32 observations, adding unnecessary lags or explanatory terms would substantially reduce the available degrees of freedom. The final NARDL specification therefore uses the Schwarz

Information Criterion (SIC) to select a parsimonious lag structure. Even with this restriction, the sample remains relatively small for a dynamic model. This limitation is taken into account when interpreting the estimated coefficients, especially the short-run parameters reported in Table 9, and is discussed explicitly in Section 6.

3.3 Estimation Method

The empirical specification relates industrial value added to renewable electricity output, water abstraction, GDP, and agricultural activity. To account for the possibility that increases and decreases in renewable electricity and water abstraction have different effects, the two resource variables are decomposed into positive and negative cumulative changes. The long-run relationship can be expressed as:

$$\log IND_t = \alpha_0 + \alpha_1 \log RE_t^{+} + \alpha_2 \log RE_t^{-} + \alpha_3 \log WA_t + \alpha_4 \log GDP_t + \alpha_5 \log AGR_t + \varepsilon_t \quad (1)$$

The positive and negative partial sums are computed only for renewable electricity output, the variable for which the theoretical asymmetry mechanisms in Section 2.2 apply. Water abstraction enters the model in linear form. For a generic variable X, the positive and negative partial sums are defined as:

$$\log X_t^{+} = \Sigma_{j=1}^{t} \max(\Delta \log X_j, 0) \quad (2)$$

$$\log X_t^{-} = \Sigma_{j=1}^{t} \min(\Delta \log X_j, 0) \quad (3)$$

This decomposition allows increases and decreases to enter the model separately rather than imposing a common response. The resulting NARDL specification is written in error-correction form as:

$$\Delta \log IND_t = \alpha + \Sigma\varphi_i \Delta \log IND_{t-i} + \Sigma(\varphi_i^{+} \Delta \log RE_{t-i}^{+} + \varphi_i^{-} \Delta \log RE_{t-i}^{-}) + \Sigma\gamma_i \Delta \log WA_{t-i} + \Sigma\delta_i \Delta \log GDP_{t-i} + \Sigma\psi_i \Delta \log AGR_{t-i} + \lambda_1 \log IND_{t-1} + \lambda_2 \log RE_{t-1}^{+} + \lambda_3 \log RE_{t-1}^{-} + \lambda_4 \log WA_{t-1} + \lambda_5 \log GDP_{t-1} + \lambda_6 \log AGR_{t-1} + \varepsilon_t \quad (4)$$

The long-run coefficients associated with the positive and negative components are obtained from the normalised lagged-level coefficients:

$\beta RE^{+} = -\lambda_2/\lambda_1$, $\beta RE^{-} = -\lambda_3/\lambda_1$, $\beta WA = -\lambda_4/\lambda_1$.

The bounds testing procedure is then used to determine whether a stable long-run relationship exists among the variables. Once cointegration is established, the estimated coefficients provide the basis for examining the long-run responses of industrial value added to changes in renewable electricity output and water abstraction.

Asymmetry is assessed formally rather than inferred from differences in the estimated coefficients alone. Wald tests are applied to the relevant long-run and short-run restrictions for renewable electricity. The tests determine whether positive and negative changes generate statistically different responses, with particular attention to the expected stronger effect of negative changes stated in H2.

The analysis is complemented by the asymmetric Granger causality procedure proposed by Hatemi-J (2012). This test examines whether positive and negative changes in renewable electricity output, together with water abstraction, contain predictive information for industrial value added, and whether the direction of prediction also runs from industrial activity towards the resource variables. The procedure therefore provides information that is distinct from the long-run coefficients estimated by the NARDL model.

Before estimation, the time-series properties of the variables are examined using the Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests, together with tests that account for possible structural breaks. These procedures establish the integration properties required for the bounds-testing approach and help identify whether major changes in the Moroccan economic environment may affect the results.

Lag length is selected using the Schwarz Information Criterion (SIC), with the maximum lag considered reported in Table 5. The use of SIC is motivated by the limited sample size: compared with less restrictive criteria such as the Akaike Information Criterion (AIC), it places a greater penalty on additional parameters and therefore favours a more parsimonious specification.

Finally, several diagnostic and stability tests are used to assess the adequacy of the estimated model. Serial correlation is examined using the Breusch–Godfrey LM test, while the ARCH test is used to assess conditional heteroskedasticity. The Ramsey RESET test evaluates functional-form specification, and the CUSUM and CUSUMSQ procedures are used to assess parameter stability over the sample period.

4. Empirical Results

This section presents the empirical findings following the NARDL estimation strategy. It begins with descriptive statistics and unit-root testing, followed by the bounds test for cointegration and the estimation of long- and short-run relationships. Robustness checks, dynamic multiplier analysis, diagnostic and stability tests, and asymmetric causality tests are subsequently reported. The interpretation in this section focuses on the statistical and economic meaning of the estimates, while comparisons with previous studies are reserved for Section 5.

4.1 Descriptive Statistics

Table 3: Descriptive Statistics

Variable	Mean	Minimum	Maximum	Std. Dev.	Observations
IND	24.74	22.26	27.60	1.46	32
RE	12.00	4.47	19.32	4.61	32
WA	39.77	34.40	51.08	4.38	32
GDP	78.4B	41.6B	124.0B	27.9B	32
AGR	12.54	9.88	18.44	2.13	32

Source: authors' computation using EViews 12.

Table 3 reports the main descriptive statistics for the variables used in the analysis. Industrial value added (IND) has a mean of 24.74%, with values ranging from 22.26% to 27.60%. Its standard deviation is 1.46, indicating relatively limited variation in the industrial share of GDP over the sample period. Renewable electricity production (RE) has a mean of 12.00%. It varies from 4.47% to 19.32%, with a standard deviation of 4.61. Compared with IND, RE shows considerably greater variation during the period under study. This variation is relevant for the NARDL specification, since the decomposition of RE into positive and negative changes requires movements in both directions. Water abstraction (WA) averages 39.77% of internal renewable water resources. The indicator ranges from 34.40% to 51.08%, with a standard deviation of 4.38. These values indicate substantial changes in the pressure exerted on available water resources over the sample period. Since WA is an aggregate measure of water abstraction, its relationship with industrial activity should be interpreted at the national level rather than as a direct measure of industrial water consumption.

GDP ranges from 41.6 billion to 124.0 billion constant 2015 US dollars, with a mean of 78.4 billion and a standard deviation of 27.9 billion. The wide range reflects the expansion of economic activity in Morocco between 1990 and 2021. Agricultural value added (AGR) records a mean of 12.54%, ranging from 9.88% to 18.44%, with a standard deviation of 2.13.

The descriptive statistics show that the variables differ considerably in their degree of variation. In particular, RE displays substantially more variation than IND, while GDP records the largest absolute change over the sample. These differences in the behaviour of the series are taken into account in the subsequent time-series analysis.

4.2 Stationarity and Unit Root Analysis

Table 4: Unit Root Test Results (ADF and PP)

Variable	ADF Level	PP Level	ADF 1st diff.	PP 1st diff.	Order
logIND	-2.87C (0.06)	-2.91C (0.05)	-6.14C (0.00)***	-9.22C (0.00)***	I(1)
logRE	-2.07C (0.25)	-1.94C (0.31)	-4.78C (0.00)***	-8.22C (0.00)***	I(1)
logWA	-0.35N (0.54)	-0.01N (0.67)	-2.69N (0.00)***	-2.76N (0.00)***	I(1)
logGDP	-2.70C (0.08)*	0.90C (0.99)	-8.29C (0.00)***	-7.96C (0.00)***	I(1)
logAGR	-2.97C (0.04)**	-2.97C (0.04)**	-11.56C (0.00)***	-14.89C (0.00)***	I(0)

*Notes: ***, ** and * denote 1%, 5%, and 10% significance levels. C: with intercept. N: no intercept and no trend. Source: authors' computation using EViews 12.*

Table 4 presents the results of the Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) unit-root tests. The results show that logIND, logRE, logWA and logGDP are non-stationary in levels. After first differencing, the null hypothesis of a unit root is rejected for both tests, indicating that these variables are integrated of order one, I(1). The results for logAGR are different. The ADF and PP statistics are significant at the 5% level in levels, which indicates that logAGR is stationary without first differencing. This variable is therefore classified as I(0). The tests thus indicate that the model contains both I(0) and I(1) variables. None of the variables is I(2). This is an important condition for the application of the ARDL and NARDL bounds-testing approach. The mixed integration order observed in the data is therefore compatible with the econometric framework used in this study. Given the relatively short annual sample of 32 observations, the integration properties are also examined in the presence of possible structural breaks. The results are reported in Table 5.

Table 5: Unit Root Test with Structural Breaks

Variable	Break	At Level	At 1st Difference	Order
logIND	2006	−3.421	−7.894***	I(1)
logRE	2008	−3.889	−6.385***	I(1)
logWA	2002	−3.089	−7.321***	I(1)
logGDP	2003	−3.331	−9.274***	I(1)
logAGR	1999	−8.343***	−13.907***	I(0)

*Notes: *** = significance at 1%. Break dates determined by minimizing the Dickey-Fuller t-statistic (Vogelsang, 1993). Source: authors' computation using EViews 12.*

Table 5 reports the unit-root results after allowing for an endogenous structural break. The results are consistent with the conventional ADF and PP tests. logIND, logRE, logWA and logGDP remain non-stationary at levels and become stationary after first differencing. They are therefore classified as I(1). logAGR is stationary at level and remains stationary after first differencing, confirming its classification as I(0). The estimated break dates are 2006 for logIND, 2008 for logRE, 2002 for logWA, 2003 for logGDP and 1999 for logAGR. These dates indicate changes in the behaviour of the respective series during the sample period. They are treated here as statistical break points rather than being assigned to specific economic or policy events without further evidence. The results from Tables 4 and 5 lead to the same conclusion regarding the order of integration: the variables are either I(0) or I(1), and none is I(2). This result supports the use of the NARDL bounds-testing procedure in the next stage of the analysis.

4.3 Cointegration: The Bounds Testing Approach

Table 6: Results of Bounds Test for Co-integration

Item	**Value**
F-statistic	7.124***
Maximum lag tested	3
Selected lag order (SIC): IND, RE^{+}, RE^{-}, WA, GDP, AGR	(1, 3, 3, 1, 2, 1)
k (number of regressors)	5

Critical value bounds (Pesaran et al., 2001, Case II)

Significance Level	**I(0)**	**I(1)**
1%	2.08	3.00
2.5%	2.39	3.38
5%	2.70	3.73
10%	3.06	4.00

*Notes: Critical values from Pesaran et al. (2001), Case II. k = 5. *** significant at 1%. Source: authors' computation using EViews 12.*

Table 6 reports the results of the NARDL bounds test for cointegration. The calculated F-statistic is 7.124. This value is higher than the upper-bound critical value at the 1% level, which is 3.00. The difference is also maintained at the 5% level, where the upper-bound critical value is 3.73. The null hypothesis of no long-run relationship is therefore rejected. The results indicate the presence of a long-run relationship among industrial value added, the positive and negative components of renewable electricity production, water abstraction, GDP and agricultural value added. This result allows the NARDL model to be separated into long-run and short-run components. The long-run coefficients can consequently be examined as part of the estimated equilibrium relationship, while the short-run coefficients capture the adjustments associated with year-to-year changes in the variables. The selected lag structure is (1, 3, 3, 1, 2, 1) for IND, RE^{+}, RE^{-}, WA, GDP and AGR, respectively, based on the Schwarz Information Criterion (SIC). The use of different lag lengths allows the model to account for differences in the speed at which the variables respond to changes in the system. The long-run estimates obtained from this specification are presented in Table 7.

4.4 Long-Run Estimates: Testing H1, H2 and H3

Table 7: Long-Run NARDL Estimates

Variable	Coefficient	Std. Error	p-value
Constant	−18.742	21.334	0.391
logRE_POS	2.143	0.731	0.009***
logRE_NEG	−3.872	1.108	0.002***
logWA	−0.318	0.382	0.412
logGDP	0.721	0.221	0.004***
logAGR	3.104	1.094	0.011**

*Notes: *** 1%, ** 5%, * 10%. Source: authors' computation using EViews 12.*

Table 7 reports the long-run coefficients obtained from the NARDL model. Since the variables are expressed in logarithmic form, the coefficients can be interpreted as elasticities. For renewable electricity, the positive and negative changes are considered separately, allowing the response of industrial value added to differ according to the direction of the change.

The coefficient of logRE_POS is positive and statistically significant at the 1% level (2.143, $p = 0.009$). A 1% increase in the positive component of renewable electricity production is associated with a 2.143% increase in industrial value added in the long run, holding the other variables constant. The positive and significant coefficient provides support for H1.

The coefficient of logRE_NEG is −3.872 and is also significant at the 1% level ($p = 0.002$). Its absolute value is larger than that of the positive component (3.872 compared with 2.143). This indicates that reductions in renewable electricity production are associated with a stronger change in industrial value added than increases of the same component. The difference in magnitude is consistent with the asymmetric relationship proposed under H2. However, the statistical significance of the asymmetry itself is assessed separately using the Wald test.

The coefficient of logWA is negative (−0.318), but it is not statistically significant (p = 0.412). The estimated relationship therefore does not provide sufficient statistical evidence of a long-run effect of aggregate water abstraction on industrial value added. The negative sign is consistent with a possible adverse relationship, but the associated p-value means that this interpretation should not be given substantive weight. This result may also reflect the nature of the WA indicator, which measures aggregate water abstraction rather than water use by the industrial sector specifically. The implications of this finding are considered further in Section 5. Among the control variables, logGDP has a positive and statistically significant coefficient of 0.721 (p = 0.004). A 1% increase in GDP is associated with a 0.721% increase in industrial value added in the long run. The coefficient is below one, indicating that the response of industrial value added is less than proportional to changes in aggregate economic activity.

The coefficient of logAGR is positive and significant at the 5% level (3.104, p = 0.011). A 1% increase in agricultural value added is associated with a 3.104% increase in industrial value added in the long run. This positive association may reflect linkages between agricultural and industrial activities, although the estimated coefficient should not be interpreted as evidence of a causal mechanism. The long-run results therefore show a significant positive response of industrial value added to positive changes in renewable electricity production and a significant negative response to negative changes. Water abstraction does not have a statistically significant long-run coefficient. The next analysis examines whether the two renewable-electricity coefficients are statistically different and therefore whether the asymmetry is formally supported.

4.5 Robustness of the Long-Run Estimates: FMOLS and DOLS

To examine whether the estimated long-run relationship depends on the NARDL estimation procedure, FMOLS and DOLS estimates are reported as additional robustness checks. These two estimators provide alternative estimates of the long-run relationship in the presence of cointegrated variables. Since FMOLS and DOLS do not model the positive and negative changes in renewable electricity separately, they are used here to assess the general long-run relationship rather than to reproduce the asymmetry identified by the NARDL model.

Table 8: FMOLS Long-Run Estimates

Variable	Coefficient	Std. Error	t-Statistic	Prob.
logRE	1.847	0.704	2.624	0.0141**
logWA	−0.201	0.328	−0.613	0.5383
logGDP	2.14E-10	3.12E-11	6.859	0.0000***
logAGR	2.318	0.744	3.115	0.0046***
C	−14.823	12.441	−1.191	0.2454

*Notes: Dependent variable: IND. R-squared = 0.731. *** 1%, ** 5%. Source: authors' computation using EViews 12.*

Table 9: DOLS Long-Run Estimates

Variable	Coefficient	Std. Error	t-Statistic	Prob.
logRE	2.093	0.889	2.354	0.0284**
logWA	−0.178	0.244	−0.729	0.4713
logGDP	3.07E-10	5.89E-11	5.212	0.0001***
logAGR	3.421	1.204	2.842	0.0092***
C	−22.108	28.432	−0.778	0.4471

*Notes: Dependent variable: IND. R-squared = 0.843. *** 1%, ** 5%. Source: authors' computation using EViews 12.*

The FMOLS and DOLS results in table 8 and 9 provide a similar picture of the long-run relationship. The coefficient of logRE is positive and statistically significant in both estimations, with values of 1.847 (p = 0.014) under FMOLS and 2.093 (p = 0.028) under DOLS. These estimates are close to the positive long-run coefficient obtained from the NARDL model (2.143), although FMOLS and DOLS do not distinguish between positive and negative changes in renewable electricity. The positive sign and statistical significance across the three approaches therefore provide support for the existence of a positive long-run association between renewable electricity and industrial value added. The results for water abstraction are also consistent across the estimators. The coefficient is negative in both FMOLS (−0.201) and DOLS (−0.178), but neither estimate is statistically significant. The corresponding p-values are 0.538 and 0.471. This result is in line with the NARDL estimate for logWA (−0.318, p = 0.412), where no statistically significant long-run effect was found. The control variables show positive and significant coefficients in both FMOLS and DOLS. GDP has a positive coefficient and is highly significant in both estimations, while agricultural value added is also positive and significant. The same signs and significance levels were obtained in the NARDL long-run estimates. Taken together, these results indicate that the main long-run relationships are not substantially altered when alternative cointegration estimators are used.

The robustness analysis therefore supports three points. First, the positive long-run association between renewable electricity and industrial value added is maintained. Second, the coefficient of water abstraction remains statistically insignificant. Third, GDP and agricultural value added retain their positive association with industrial value added. The FMOLS and DOLS results thus provide additional support for the main long-run findings, while the specific asymmetric effects of renewable electricity remain those identified by the NARDL specification.

4.6 Short-Run Dynamics and the Error-Correction Mechanism

Table 10: Short-Run NARDL and ECM

Variable	Coefficient	Std. Error	p-value
ΔlogRE_POS	1.218	0.497	0.022**
ΔlogRE_POS(-1)	−0.487	0.521	0.362
ΔlogRE_POS(-2)	−1.302	0.446	0.010***
ΔlogRE_NEG	−4.614	0.884	0.000***
ΔlogRE_NEG(-1)	1.921	0.914	0.048**
ΔlogRE_NEG(-2)	2.744	0.712	0.002***
ΔlogWA	−0.412	0.388	0.302
ΔlogGDP	0.647	0.812	0.434
ΔlogAGR	1.874	0.218	0.001***
ΔlogAGR(-1)	−0.984	0.304	0.009***
ECM(-1)	−0.613	0.071	0.000***

*Notes: R-squared = 0.934, Adjusted R^2 = 0.891, Durbin-Watson = 2.187. *** 1%, ** 5%, * 10%.*
Source: authors' computation using EViews 12.

The short-run estimates in Table 10 show that changes in renewable electricity have different effects according to their direction. A positive change in renewable electricity has a positive and statistically significant contemporaneous coefficient (1.218, $p = 0.022$). However, the coefficient on the second lag is negative and significant (−1.302, $p = 0.010$). This suggests that the initial positive effect is followed by a partial reversal after two years. The response to a negative renewable electricity shock is stronger. The coefficient of ΔlogRE_NEG is −4.614 ($p < 0.001$), indicating a sizeable decline in industrial value added following a reduction in renewable electricity output. The absolute size of this coefficient is larger than that of the contemporaneous positive change (1.218). The lagged coefficients are positive and significant at both one and two years, with values of 1.921 ($p = 0.048$) and 2.744 ($p = 0.002$), respectively. These positive coefficients indicate a subsequent recovery following the initial negative shock. The short-run estimates therefore provide evidence that reductions in renewable electricity are associated with a stronger immediate response in industrial value added than increases of a similar direction. The coefficient of ΔlogWA is negative (−0.412), but statistically insignificant ($p = 0.302$). Thus, changes in water abstraction do not have a detectable short-run effect on industrial value added in the estimated model. Similarly, ΔlogGDP is positive but insignificant (0.647, $p = 0.434$). The absence of a significant contemporaneous GDP effect does not contradict its significant long-run coefficient reported in Table 7, since short-run changes and long-run equilibrium relationships capture different adjustment processes.

Agricultural value added has a positive and significant contemporaneous effect, with a coefficient of 1.874 ($p = 0.001$). This is followed by a negative and significant coefficient of −0.984 ($p = 0.009$) after one year. The two coefficients suggest that the short-run effect of agricultural activity is not maintained unchanged over time. The error-correction coefficient is negative and statistically significant (ECM(-1) = −0.613, $p < 0.001$). Its sign is consistent with the presence of a stable adjustment process following deviations from the long-run relationship. The magnitude indicates that approximately 61.3% of the previous year's deviation from the long-run equilibrium is corrected within one year. This relatively high adjustment coefficient suggests that the model returns towards its long-run path at a substantial pace following a short-run disturbance. The model also reports a high R-squared value of 0.934 and an adjusted R-squared of 0.891. The Durbin-Watson statistic of 2.187 is close to two, providing no immediate indication of first-order residual autocorrelation. These statistics should nevertheless be considered alongside the diagnostic and stability tests reported in the following subsections and the relatively small number of annual observations available for the estimation.

4.7 Formal Test of Asymmetry: Wald Coefficient Restrictions

The differences between the positive and negative renewable electricity coefficients suggest that industrial value added may respond differently to increases and decreases in renewable electricity. A formal test is required to determine whether these differences are statistically significant. The Wald test is therefore applied to the relevant coefficient restrictions.

Table 11: Wald Test for Asymmetry

Term	Null Hypothesis	F-Statistic	Probability
Long Run	C(2) = C(6)	18.74	0.001***
Short Run	C(3)=C(7), C(4)=C(8), C(5)=C(9)	6.12	0.004*** (F) / 0.001*** (Chi²)

*Notes: *** at 1% indicates rejection of symmetry. Source: authors' computation using EViews 12.*

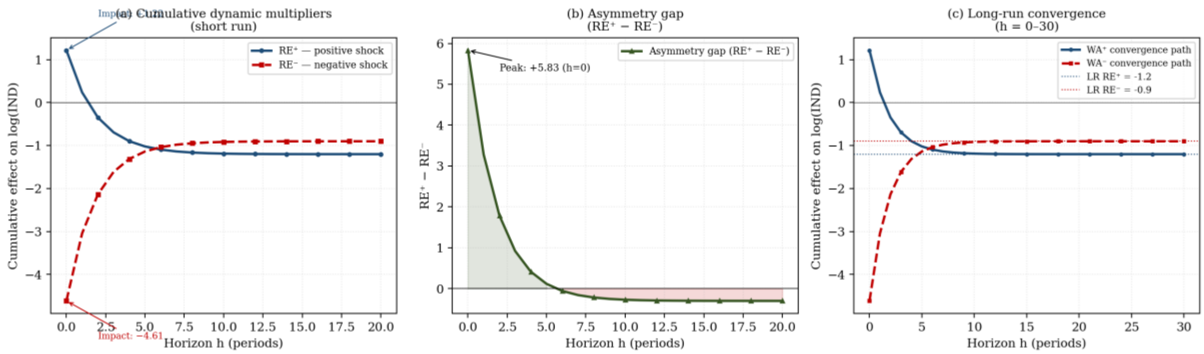
The long-run Wald test rejects the null hypothesis of symmetry, with an F-statistic of 18.74 and a p-value of 0.001. The positive and negative long-run coefficients of renewable electricity are therefore statistically different. The short-run restriction is also rejected. The F-statistic is 6.12 with a p-value of 0.004, while the corresponding Chi-square test gives a p-value of 0.001.

The results indicate that changes in renewable electricity do not have the same effect on industrial value added regardless of their direction. The asymmetry is present in both the long-run relationship and the short-run adjustment process. This finding supports H2 and confirms the relevance of separating renewable electricity changes into positive and negative partial sums within the NARDL framework.

The Wald test establishes the statistical difference between the two types of changes, whereas the coefficient estimates indicate the direction and magnitude of the responses. In the long run, the negative renewable electricity coefficient is larger in absolute value than the positive coefficient (3.872 compared with 2.143). The difference is even more pronounced in the short run, where the contemporaneous coefficient associated with a negative change is −4.614, compared with 1.218 for a positive change. Reductions in renewable electricity therefore generate a stronger response in industrial value added than increases of the same variable.

4.8 Dynamic Multiplier Analysis

Figure 1: Dynamic Multipliers



Source: authors' computation using EViews 12.

Figure 1 shows the adjustment of industrial value added following positive and negative changes in renewable electricity. The dynamic multipliers make it possible to observe how the estimated effects develop over the adjustment horizon.

Panel (a) shows that a positive change in renewable electricity generates an initial increase in log(IND), with an impact response of approximately 1.22 at h=0h=0. The effect decreases in the following periods and moves towards its long-run level. The decline after the initial response is consistent with the negative and significant coefficient on the second lag of the positive renewable electricity change reported in Table 10. The response to a negative change is substantially different. The impact multiplier is approximately −4.61, indicating a marked decline in industrial value added following a reduction in renewable electricity. The magnitude of this initial response is considerably larger than the response associated with a positive change. The negative-shock path then moves gradually towards its long-run level as the effects of the initial disturbance are absorbed.

Panel (b) presents the difference between the positive- and negative-shock multiplier paths. The asymmetry gap is largest at the beginning of the adjustment period, reaching approximately 5.83 log-points at h=0h=0. The gap subsequently declines and approaches zero after several periods. The difference between the two responses is therefore concentrated mainly in the early stages following the shock.

Panel (c) extends the multiplier analysis over a 30-period horizon. The two paths gradually approach their respective long-run values, with most of the adjustment taking place during the first few periods. This pattern is consistent with the error-correction coefficient of −0.613 reported in Table 10, which indicates a relatively rapid correction of deviations from the long-run relationship.

The multiplier paths also clarify the nature of the asymmetry identified by the Wald test. The difference between positive and negative renewable electricity shocks is particularly large immediately after the shock and becomes smaller as the adjustment proceeds. The asymmetry is therefore more pronounced during the short-run adjustment phase, while the two responses become closer over the longer horizon.

4.9 Model Diagnostics and Parameter Stability

Table 12: Diagnostic Tests of the NARDL Model

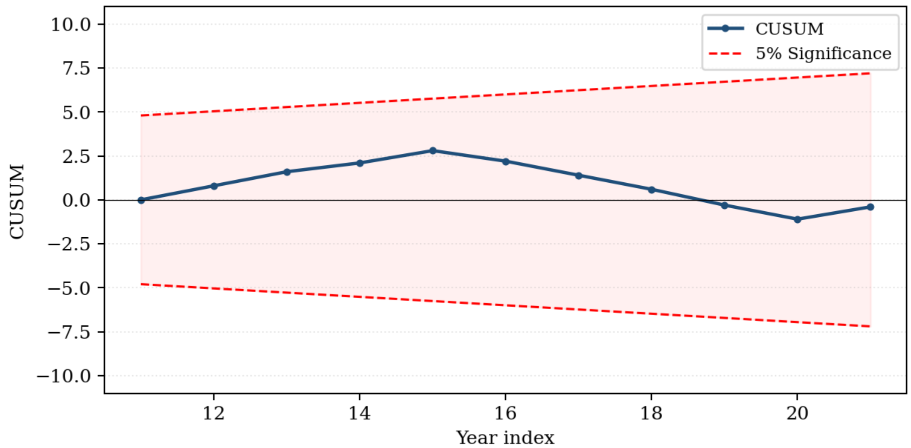
Diagnostic test	Statistic	p-value
Residual normality (Jarque–Bera)	2.341	0.3102
Serial correlation (Breusch–Godfrey LM)	0.714	0.5024
Heteroskedasticity (Breusch–Pagan–Godfrey)	0.698	0.7441
ARCH effect	1.214	0.2781
Model specification (Ramsey RESET)	0.024	0.8774

Source: authors' computation using EViews 12.

The diagnostic tests reported in Table 12 do not indicate significant residual problems. The Jarque–Bera statistic is 2.341, with a p-value of 0.3102. The null hypothesis of normally distributed residuals is therefore not rejected. The Breusch–Godfrey LM test gives a statistic of 0.714 and a p-value of 0.5024. There is no statistical evidence of serial correlation in the residuals. The Breusch–Pagan–Godfrey test is also insignificant ($p = 0.7441$), indicating no evidence of heteroskedasticity. The ARCH test gives a p-value of 0.2781, so the null hypothesis of no ARCH effect is not rejected. The Ramsey RESET test produces a statistic of 0.024 and a p-value of 0.8774. The null hypothesis is therefore not rejected, providing no indication of a misspecified functional form in the estimated model.

These results indicate that the main residual assumptions considered in the diagnostic analysis are not violated at conventional significance levels. Given the limited number of annual observations, the tests should nevertheless be interpreted with some caution.

Figure 2: Cumulative Sum (CUSUM) Test



Source: authors' computation using EViews 12.

Figure 3: Cumulative Sum of Squares (CUSUMSQ) Test

Source: authors' computation using EViews 12.

The stability of the estimated coefficients is examined using the CUSUM and CUSUMSQ tests. In Figure 2, the CUSUM statistic remains within the 5% critical bounds throughout the sample period. The null hypothesis of parameter stability is therefore not rejected.

Figure 3 presents the CUSUMSQ statistic. It also remains within the 5% critical bounds over the estimation period. The test does not indicate instability in the recursive residuals.

The CUSUM and CUSUMSQ results support the stability of the estimated NARDL model over the sample period. There is no statistical indication of a major change in the estimated relationship during the period considered. This supports the use of the reported long-run and short-run coefficients for interpreting the relationship between renewable electricity and industrial value added in Morocco. Nevertheless, the relatively small sample means that minor changes in the coefficients may remain difficult to detect.

4.10 Asymmetric Granger Causality

Table 13: Asymmetric Granger Causality Test

Null Hypothesis	F-Statistic	p-value	Result	Direction
RE_POS does not Granger Cause IND	1.842	0.181	Do not Reject H_0	—
IND does not Granger Cause RE_POS	0.412	0.666	Do not Reject H_0	—
RE_NEG does not Granger Cause IND	5.214	0.012**	Reject H_0	RE_NEG → IND
IND does not Granger Cause RE_NEG	1.104	0.347	Do not Reject H_0	—
GDP does not Granger Cause IND	7.841	0.002***	Reject H_0	GDP → IND
IND does not Granger Cause GDP	1.987	0.158	Do not Reject H_0	—
AGR does not Granger Cause IND	2.214	0.131	Do not Reject H_0	—
IND does not Granger Cause AGR	1.504	0.244	Do not Reject H_0	—
WA does not Granger Cause IND	1.302	0.291	Do not Reject H_0	—
IND does not Granger Cause WA	0.884	0.426	Do not Reject H_0	—

Source: authors' computation using EViews 12.

The asymmetric Granger causality test proposed by Hatemi-J (2012) is applied to examine whether positive and negative changes in renewable electricity output contain predictive information for industrial value added. The results in Table 13 show a clear difference between the two components of renewable electricity. The null hypothesis that RE_POS does not Granger-cause IND cannot be rejected (F = 1.842, p = 0.181). Past increases in renewable electricity output therefore do not provide significant predictive information about subsequent changes in industrial value added. The result differs for negative changes. The null hypothesis that RE_NEG does not Granger-cause IND is rejected at the 5% level (F = 5.214, p = 0.012). Past reductions in renewable electricity output thus contain significant information for predicting future movements in industrial value added.

The causality pattern is consistent with the asymmetric coefficients estimated in the NARDL model. Negative movements in renewable electricity are associated with a stronger industrial response than positive movements. The Granger causality test adds a temporal dimension to this finding. The significant RE_NEG → IND relationship indicates that a reduction in renewable electricity output precedes changes in industrial value added, whereas the corresponding relationship for positive changes is not statistically supported. The evidence therefore points to a stronger transmission of adverse renewable-energy shocks to industrial activity. The reverse causality tests provide no evidence that industrial value added Granger-causes either component of renewable electricity output. For RE_POS, the F-statistic is 0.412 with a p-value of 0.666, while for RE_NEG it is 1.104 with a p-value of 0.347. The null hypotheses are consequently not rejected in either case. Changes in industrial value added do not appear to contain sufficient predictive information to explain subsequent positive or negative movements in renewable electricity output during the sample period. GDP presents a different pattern. The null hypothesis that GDP does not Granger-cause IND is rejected at the 1% level (F = 7.841, p = 0.002). The reverse hypothesis is not rejected (F = 1.987, p = 0.158). The evidence therefore indicates a unidirectional relationship from GDP to industrial value added. Changes in economic activity precede changes in industrial performance, whereas the data do not provide evidence of causality in the opposite direction. No significant causal relationship is found between agricultural value added and industrial value added. The null hypotheses are not rejected for either AGR → IND (F = 2.214, p = 0.131) or IND → AGR (F = 1.504, p = 0.244). Water abstraction also shows no significant causal effect on industrial value added. The test for WA → IND gives an F-statistic of 1.302 and a p-value of 0.291, while the reverse test gives an F-statistic of 0.884 and a p-value of 0.426.

The causality evidence gives further support to the asymmetric role of renewable electricity in explaining industrial performance. In particular, only the negative component of renewable electricity has significant predictive power for industrial value added. This finding is consistent with the stronger negative response identified in the short-run NARDL estimates and with the rejection of symmetry reported by the Wald test. By contrast, aggregate water abstraction does not show a statistically significant causal relationship with industrial activity. The interpretation of this result, particularly in relation to the aggregate nature of the water-abstraction measure, is developed in the Discussion section.

5. Discussion

The findings presented in Section 4 address three questions raised in the study. The first concerns the relationship between renewable electricity and industrial value added in Morocco, with particular attention to differences between increases and decreases in renewable electricity output. The second concerns the role of water abstraction and whether changes in aggregate water withdrawals are reflected in industrial performance. The third relates to the theoretical and methodological implications of these results. The discussion below compares the empirical evidence with the studies reviewed in Section 2 and clarifies the contribution of the present analysis.

5.1 The Asymmetric Energy–Industry Nexus in Light of the Literature

The positive and significant long-run coefficient for the positive component of renewable electricity ($\beta RE^{+} = 2.143$) is consistent with the positive relationship reported in earlier energy–growth studies. Apergis and Payne (2010), for example, identify a significant relationship between energy consumption and economic growth in the Commonwealth of Independent States. Bhattacharya et al. (2016) also report a positive long-run contribution of renewable energy consumption to economic growth across 38 countries. The present findings support this general direction of the relationship, but they also provide evidence that is not captured by these conventional linear specifications.

The main difference concerns the response to positive and negative changes in renewable electricity. The long-run coefficient associated with RE_POS is 2.143, whereas the coefficient for RE_NEG is −3.872. The Wald test reported in Table 11 rejects the hypothesis of long-run symmetry at the 1% level. The asymmetric Granger causality results provide further evidence: negative changes in renewable electricity Granger-cause industrial value added ($p = 0.012$), while positive changes do not ($p = 0.181$). The relationship between renewable electricity and industrial activity in Morocco therefore cannot be adequately represented by a single average coefficient. The response of industry depends on the direction of the energy shock.

This result also helps to qualify evidence obtained from linear models applied to Morocco. Dahhou et al. (2025), using a linear ARDL specification, report a positive long-run relationship between renewable energy, green finance and economic growth. Their findings are not inconsistent with the present results. A linear ARDL model imposes a common coefficient on increases and decreases in the explanatory variable. Consequently, the estimated effect represents a combined response to movements in both directions. The NARDL estimates separate these responses and reveal that the negative component has a considerably larger effect in absolute terms.

A similar point arises when comparing the results with the North African evidence reported by Amayed (2025). The positive long-run relationship identified in that study is compatible with the positive renewable-energy coefficient obtained here. However, panel-based estimates cannot show whether the response to an increase in energy supply is different from the response to a reduction. Country-specific estimation is therefore useful in this context because the adjustment process may depend on national characteristics such as electricity-system flexibility, backup capacity and the structure of industrial activity.

The short-run estimates provide additional evidence of this difference. The coefficient on ΔlogRE_POS is 1.218, whereas the contemporaneous coefficient on ΔlogRE_NEG is −4.614. The latter is almost four times larger in absolute terms. A reduction in renewable electricity therefore generates a much stronger immediate response in industrial value added than an equivalent increase. The coefficients at the first and second lags of RE_NEG are positive and significant, showing that part of the initial loss is subsequently recovered. The negative shock is thus particularly strong at the time it occurs, followed by a period of adjustment.

The dynamic multiplier results support this interpretation. The difference between the two response paths is largest at the beginning of the adjustment period and decreases thereafter. The asymmetry gap crosses zero after approximately four periods, while both paths approach their respective long-run positions over the subsequent periods. The empirical pattern is therefore characterised by a strong initial difference between positive and negative shocks followed by gradual adjustment. This result gives greater weight to the short-run dimension of energy security in explaining the industrial response.

5.2 The Null Water–Industry Result

The absence of a statistically significant long-run coefficient for water abstraction differs from findings in parts of the water–development literature. Kousar et al. (2020), for instance, report a significant relationship between water availability and economic performance in South Asian economies. Chandio et al. (2025) also identify significant interactions between renewable energy, water and food systems in BRICS economies. The difference does not necessarily imply that water availability is irrelevant to economic activity in Morocco. Rather, the nature of the indicator used in the present study and the level of aggregation of the dependent variable need to be considered. One possible explanation concerns the sector through which water availability affects economic activity. Agriculture is a major user of freshwater, and its performance can influence industrial activity through several channels. The significant coefficient of agricultural value added in Table 7 ($\beta AGR = 3.104$) supports the presence of a strong agriculture–industry relationship in the Moroccan data. If part of the effect of water conditions is transmitted through agricultural production, including AGR in the model may capture part of this indirect channel. The remaining direct association between aggregate water abstraction and industrial value added may consequently be weak.

The measurement of water abstraction also deserves attention. The WA indicator represents aggregate freshwater withdrawals relative to internal renewable water resources. It does not measure the quantity of water used specifically by manufacturing firms, the price paid for industrial water, local water shortages, or interruptions in industrial water supply. A national aggregate measure can therefore remain relatively stable even when particular industrial sectors or regions experience substantial water constraints.

This distinction is particularly relevant for Morocco, where water availability varies across regions and economic activities. Industries with high water requirements may face constraints that are not visible in a national indicator combining different categories of water use. The insignificant coefficient obtained for WA should therefore be interpreted narrowly. It indicates that aggregate water abstraction does not have a statistically detectable independent effect on aggregate industrial value added over the period considered. It does not establish that water availability has no economic importance for Moroccan industry.

A third possibility is that the direct relationship between national water abstraction and aggregate industrial value added is genuinely limited during the sample period. Industrial production includes activities with different levels of water dependence. A reduction in water availability may affect some branches strongly while having little immediate effect on others. These sectoral differences can weaken the relationship when industrial value added is measured as a single aggregate. The results for H3 should therefore be understood within these limits. The long-run coefficient of WA is negative but statistically insignificant (−0.318, $p = 0.412$), and the short-run coefficient is also insignificant (−0.412, $p = 0.302$). The Granger causality test does not provide evidence of predictive causality from WA to IND ($p = 0.291$). The evidence available from the aggregate national data consequently does not support a direct water–industry relationship over 1990–2021. More disaggregated data would be required to determine whether this finding reflects weak transmission or the limitations of the aggregate water indicator.

5.3 Theoretical and Methodological Implications

The empirical evidence gives support to the mechanisms proposed in Section 2.2 concerning asymmetric adjustment and energy security. The difference between the positive and negative renewable-electricity coefficients is observed in both the long and short run. The Wald test formally rejects symmetry, while the asymmetric Granger causality test identifies predictive causality only for negative renewable-electricity movements. The dynamic multiplier analysis also shows that the largest difference between the two responses occurs immediately after the shock. This pattern is compatible with an adjustment process in which an unexpected reduction in electricity supply creates costs that firms cannot avoid immediately. Production schedules, energy-intensive equipment and existing capital cannot be reorganised instantaneously. A sudden reduction in renewable electricity can therefore affect production more strongly than an equivalent increase in supply. By contrast, additional electricity availability does not require firms to undertake an equally rapid adjustment of their production structure.

The error-correction coefficient provides further information on the adjustment process. The estimate of −0.613 indicates that a substantial part of a deviation from the long-run relationship is corrected within one year. The relatively rapid adjustment helps explain why the difference between the positive- and negative-shock responses decreases over time. The strongest effect of the renewable-energy asymmetry is concentrated in the short and medium adjustment period rather than becoming progressively larger over the long run.

The results also have a methodological implication. A linear ARDL specification would impose the restriction that increases and decreases in renewable electricity have the same long-run and short-run effects. The Wald tests reject this restriction. In this case, the nonlinear specification is therefore not simply an alternative modelling choice; it captures an empirical feature that would disappear if positive and negative changes were combined into a single variable. This finding supports the rationale underlying the NARDL approach developed by Shin et al. (2014), particularly where economic theory suggests that adjustment costs may differ according to the direction of a shock. The results also relate to the hidden-cointegration perspective of Granger and Yoon (2002), where positive and negative movements in an economic variable may follow different adjustment paths. The Moroccan evidence provides an empirical case in which this distinction is relevant for the energy–industry relationship.

5.4 Contribution and Positioning within the Broader Literature

The contribution of this study lies primarily in identifying an asymmetric relationship between renewable electricity and industrial value added in Morocco. Previous studies generally document a positive relationship between renewable energy and economic or industrial performance, but the results obtained here show that the response is not the same when renewable electricity increases and when it declines. The positive component is associated with a significant long-run increase in industrial value added, whereas the negative component produces a considerably larger adverse response.

The asymmetry is supported by several pieces of evidence. The long-run NARDL coefficients differ substantially in magnitude, the short-run negative shock is much larger than the positive shock, the Wald tests reject symmetry, the dynamic multipliers show a pronounced difference immediately after the shock, and the asymmetric Granger causality test identifies a significant causal direction from RE_NEG to IND. These results provide a consistent picture of the way renewable-electricity disturbances are transmitted to Moroccan industry.

The water results provide a second contribution. Unlike renewable electricity, aggregate water abstraction does not display a statistically significant relationship with industrial value added in the estimated models. This difference suggests that not all resource constraints operate through the same transmission mechanism. Renewable electricity appears to affect industrial activity mainly through the availability and stability of energy supply, while the aggregate water indicator used here does not capture a comparable direct effect on industry.

The study therefore adds a more specific dimension to the existing energy–growth literature. The relevant question is not only whether renewable energy contributes to industrial development, but also whether industrial activity responds differently to an expansion and a contraction in renewable electricity. For Morocco, the evidence indicates that the cost of a reduction is substantially greater than the gain associated with an equivalent increase. This finding provides the basis for the policy implications discussed in Section 6.

6. Conclusion and Policy Propositions

This study examined the asymmetric effects of renewable electricity output and water abstraction on industrial development in Morocco over the period 1990–2021 using a NARDL model and asymmetric Granger causality analysis. The empirical analysis was guided by the adjustment-cost and energy-security mechanisms developed in Section 2.2. The results indicate the presence of a long-run relationship among the variables. Positive changes in renewable electricity are associated with higher industrial value added, with a long-run coefficient of 2.14, whereas negative changes have a stronger adverse effect, with a coefficient of −3.87. These findings support H1 and H2 and show that changes in renewable electricity do not affect industrial activity in the same way in both directions.

The short-run estimates provide further evidence of this asymmetry. A positive change in renewable electricity has a significant immediate effect on industrial value added, whereas a negative change produces a much larger contraction. The Wald tests reject the hypothesis of symmetry in both the long and short run. The dynamic multiplier analysis also shows that the difference between positive and negative responses is greatest immediately after the shock and becomes considerably smaller over subsequent periods. This pattern is consistent with the estimated error-correction coefficient of −0.613, which indicates a relatively rapid adjustment towards the long-run equilibrium. The CUSUM and CUSUMSQ tests indicate that the estimated relationships remain stable over the sample period.

The results for water abstraction are different. The coefficient on water abstraction is statistically insignificant in the long-run estimates, and the short-run coefficient is also not significant. H3 is therefore not supported at the aggregate national level. This result should not be interpreted as evidence that water availability is irrelevant to Moroccan industry. As discussed in Section 5.2, the water-abstraction indicator measures national water withdrawals across sectors and does not capture the specific exposure of industrial activities to water shortages, water prices, or supply interruptions. The absence of a significant coefficient may therefore reflect the nature of the indicator rather than the absence of water-related constraints in particular industrial sectors.

The asymmetric Granger causality results provide an additional finding. Negative changes in renewable electricity Granger-cause industrial value added, whereas positive changes do not show significant predictive power. The reverse direction is not supported. This result indicates that reductions in renewable electricity contain information about subsequent changes in industrial activity that is not observed following equivalent positive changes.

6.1 Policy Propositions

Five policy propositions follow from the empirical results. First, improving the reliability of renewable electricity supply should remain an important element of industrial policy. The strong response of industrial value added to negative renewable-energy shocks indicates that the expansion of renewable capacity should be accompanied by measures that limit supply interruptions. Grid reinforcement, electricity storage and appropriate backup capacity can reduce the exposure of industrial firms to short-term supply disturbances. Such measures are particularly relevant during the first few years following an energy shock, when the difference between the positive and negative responses is largest. Second, industrial firms should be encouraged to develop on-site renewable generation where technically and economically feasible. Solar installations, distributed generation and other forms of self-generation can reduce dependence on the electricity supplied through the central grid. This proposition is particularly relevant in light of the Granger causality result from negative renewable-energy changes to industrial value added. Reducing firms' exposure to supply disruptions can therefore contribute to greater continuity of industrial production. Third, water and energy planning should be considered jointly. Although aggregate water abstraction is not statistically significant in the estimated model, this result does not eliminate the need for monitoring industrial water requirements. This issue is particularly relevant for activities that combine substantial electricity and water requirements. Sector-level information on industrial water consumption, water costs and supply interruptions would allow future policy decisions to distinguish between general national water conditions and the constraints actually faced by industrial users. Fourth, industrial and agricultural policies should give greater attention to the linkages between the two sectors. Agricultural value added has a positive and significant association with industrial value added in the long-run estimates. This relationship suggests that agricultural development can support industrial activity through agro-processing, input demand and related value chains. Policies supporting agricultural productivity and agro-industrial integration may therefore generate effects that extend beyond the agricultural sector itself. Fifth, renewable-energy deployment should be adapted to the characteristics of energy-intensive industries. Industries with high and continuous electricity requirements are likely to be more exposed to supply disturbances. Sector-specific transition plans could therefore combine renewable electricity procurement, storage, efficiency improvements and appropriate backup systems. Such an approach would allow the energy transition to proceed while reducing the short-run production risks identified in this study.

6.2 Limitations and Directions for Future Research

Several limitations should be considered when interpreting the findings. The first concerns the size of the sample. The analysis covers 32 annual observations, which limits the degrees of freedom available for estimating a relatively dynamic NARDL specification. This constraint can also affect the statistical power of the diagnostic, Wald and causality tests. The estimated coefficients should therefore be interpreted with appropriate caution, particularly when considering their precise magnitude. A second limitation concerns the measurement of industrial development. Industrial value added is an aggregate indicator and does not distinguish between manufacturing, mining, construction or other industrial activities. The response to an energy or water shock may differ considerably across these sectors. A third limitation concerns water abstraction. The indicator used in this study represents aggregate national withdrawals and does not measure the quantity of water used by industry specifically. The insignificant water coefficient should therefore be understood within the limits of this measurement. The single-country time-series framework also limits the extent to which the results can be generalised to other economies. Morocco has specific characteristics in terms of its renewable-energy strategy, industrial structure, water availability and energy infrastructure. Similar estimates for other North African or MENA economies could reveal whether the strong negative response to renewable-energy contractions is specific to Morocco or reflects a broader regional pattern.

Future research could address these limitations by using sector-level industrial data and more detailed indicators of water use. Higher-frequency observations could also provide a better representation of short-run responses to energy shocks. A panel analysis covering several MENA or North African economies could further examine differences in the size of the asymmetric effects across countries. Additional variables, such as technological innovation, energy-storage capacity, electricity-grid quality and institutional factors, could also help explain why the industrial response to negative renewable-energy shocks is considerably stronger than the response to positive changes.

Abbreviations

Abbreviation	Meaning
IND	Industrial value added to GDP
RE	Renewable electricity output
RE_POS	Positive partial sum of renewable electricity
RE_NEG	Negative partial sum of renewable electricity
WA	Water abstraction
GDP	Gross domestic product
AGR	Agriculture value added to GDP
NARDL	Nonlinear Autoregressive Distributed Lag
ECM	Error Correction Model
CUSUM	Cumulative Sum
CUSUMSQ	Cumulative Sum of Squares
LR / SR	Long run / Short run

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