






“Empirical analysis of the relationship between renewable energy consumption and long-term economic growth in Morocco”

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EMPIRICAL ANALYSIS OF THE RELATIONSHIP BETWEEN RENEWABLE ENERGY CONSUMPTION AND LONG-TERM ECONOMIC GROWTH IN MOROCCO

Abstract

The objective of this study is to assess the potential long-term impact of continued and increasing consumption of renewable energy on Morocco's economic growth. Employing a Cobb-Douglas production function, the study investigates the influence of renewable energy on GDP over the period from 1990 to 2023. In order to consider a possible non-linear dynamic, the squared term of renewable energy consumption is included among the explanatory variables, and the analysis is conducted using the autoregressive distributed lag (ARDL) bounds testing approach. The findings reveal a non-linear, inverted U-shaped relationship between renewable energy use and economic growth. Specifically, the analysis identifies a critical consumption threshold of 9%, beyond which the effect on growth turns negative. Given that Morocco's current energy strategy, adopted in 2009, targets a substantial increase in renewable energy use over the long term, the results suggest that unchecked expansion may hinder economic performance. Therefore, optimizing renewable energy use is essential, and a revision of 2009 energy policy appears warranted to ensure it aligns with long-term economic sustainability.

Keywords

GDP, renewable energies, Morocco, threshold, energy strategy, ARDL

JEL Classification

Q42, Q01, Q48

INTRODUCTION

While renewable energy initiatives aim to curb fossil fuel consumption without hampering productivity, available evidence indicates that economic expansion correlates strongly with increases in energy usage. Indeed, history shows that economic growth has always been accompanied by the use of conventional fuels.

Non-renewable energy sources are a finite resource that will eventually diminish, a fact that researchers continue to highlight, like Hubbert (1956), Laherrère (2004), and Campbell (2013, 2015). Additionally, burning oil, coal, and gas exacerbates climate change through greenhouse gas emissions. These issues raise serious questions about the long-term sustainability of our current energy model. Transitioning to renewable sources like solar, wind, and hydro is now seen as necessary. This energy transformation involves moving away from coal, oil, and gas extraction over time and harnessing renewable energy sources such as solar, wind, and geothermal power.

While political leaders express interest in lessening dependence on fossil fuels, renewable technologies remain insufficiently developed to satisfy escalating energy demands from infrastructure and population growth. Numerous countries, therefore, continue to heavily consume conventional energy sources. Despite leaders' rhetoric, fossil fuels uniquely provide intensely concentrated energy and deliver more net power to economies than intermittent alternatives. The technical difficulties of renewable sources worsen as energy needs amplify, necessitating sustained reliance on carbon-intensive options in the absence of revolutionary scientific advances. This mismatch between expressed aspirations and fossil fuel realities is likely to prolong unbalanced energy systems until innovation enables renewables to effectively substitute for fossil fuels.

In 2009, Morocco introduced an ambitious national energy strategy designed to enhance the efficiency of renewable energy sources, with the dual objective of supporting strong economic growth and reducing carbon dioxide emissions. The strategy centered on gradually integrating renewable energy into the national energy mix, with clearly defined goals across short-, medium- and long-term horizons. Specifically, it aimed to increase the share of renewables to 42% of total installed electricity capacity by 2020 and further to 52% by 2030. Despite these objectives, the 2024 National Inventory Report submitted to the United Nations Framework Convention on Climate Change (UNFCCC, 2024) reveals that Morocco's energy dependency rate stood at 91.2% in 2022.

The above considerations raise the following research question: Is the sustained consumption of renewable energy a significant driver of economic growth in Morocco?

1. LITERATURE REVIEW AND HYPOTHESES

Economic progress has long been linked to fossil fuels. However, after the 1978 oil shock, which precipitated an energy catastrophe and slowed output, consideration shifted toward different energy sources, particularly renewable energies. That is why numerous empirical studies have analyzed the relationship between renewable energy consumption and economic growth, aimed toward assessing their ability to maintain the manufacturing pace traditionally assured by fossil fuels, with mixed results depending on the context, the period, and the methodology applied. In this context, our study aims to analyze how GDP is impacted by the massive consumption of renewable energy in Morocco, which can take different forms of response.

We begin our analysis with cases where the impact is positive, such as that of Cetin (2016), who, based on heterogeneous panel data for seven emerging economies between 1992 and 2012, confirmed that renewable energy has a positive effect on GDP. In the same context, Mahjabeen et al. (2020) used a Cobb-Douglas production function and an ARDL model for eight developing countries over

the period 1990–2016 and found a positive effect. Similarly, Inglesi-Lotz (2016) used a panel cointegration test across four OECD countries from 1990 to 2010 and also confirmed this positive relationship. Fang (2011) showed that an increase of 1% in the use of renewable energy was responsible for an increase of 0.12% in GDP for China between 1978 and 2008. Equally, employing long-run causality tests over the period 1990–2012 and a sample of 80 countries, Apergis and Danuletiu (2014) found a long-run positive causal relationship between renewable energy consumption and GDP. In the same context of analysis, Hamit-Hagggar (2016) showed, for eleven Sub-Saharan African countries and over the period of 1970–2007, a unidirectional positive causality from renewable energy to GDP. Analogously, exploiting panel data for 42 developing countries from 1990 to 2012, Fotourehchi (2017) also found a positive long-run nexus in an asymmetric analysis based on the NARDL model. A similar finding was confirmed for Gabon and Egypt by Awodumi and Adewuyi (2020), for the timeframe of 1980–2015, using the NARDL model. Likewise, Wang et al. (2023) analyzed a panel of 24 countries between 2001 and 2020, and highlighted the respective influence of fossil fuels and renewable energy consumption on gross domestic product and carbon emissions. The conclusions from

Dumitrescu and Hurlin's heterogeneous causality test indicated a positive relationship between renewable energy use and economic growth, a trend observed across all the countries examined, with the notable exception of Russia. The positive impact is also supported by Hieu and Mai (2023), who draw on panel data from 80 developing countries, covering countries with different income levels, collected between 1990 and 2020. Granger's causality approach shows that renewable energy sources have a positive effect on GDP.

Conversely, some research has highlighted negative effects, such as that of Afonso et al. (2017), who identified a negative effect of renewable energy consumption on GDP in 28 countries between 1995 and 2013 using an ARDL panel model. Likewise, Yazidi and Shakouri (2017) demonstrated a unidirectional negative correlation in Iran during 1979 and 2014, indicating a 0.89% loss in GDP for every 1% rise in renewable energy usage. Similarly, Ocal and Aslan (2013), using the ARDL model and the Toda-Yamamoto Causality test, identified negative effects in Turkey between 1990 and 2010. While Magazzino (2017), examining Italy during the period 1970–2007, revealed a 0.23% GDP decrease for each 1% growth in renewable energy sources. Equally, Namahoro et al. (2021) examined the situation in Rwanda across the years 1990–2015 using the NARDL model and causality tests, demonstrating a favorable short-term impact but a negative long-term effect. Similarly, Somoye et al. (2022) showed that certain forms of renewable energy in Nigeria could have negative effects on GDP, using NARDL to analyze the period from 1990 to 2019. In an identical framework, Sasana and Ghozali (2017) stated that fossil fuels facilitated growth in BRICS countries between 1995 and 2014, while renewable energy sources slowed it down using multiple linear regressions with fixed effects. In the same context of analysis, the negative impact was observed in Angola by Telly and Liu (2023) using the ARDL model for the period between 1990 and 2020, as well as in Tunisia by Brini et al. (2017), where the ARDL models highlighted negative effects based on the period between 1980 and 2011. The negative impact was also supported by Bhattacharya et al. (2016), who studied the impact of renewable energy consumption on GDP in several countries around the world using heterogeneous panel es-

timation between 1990 and 2012. Among the results obtained was a negative impact in India, the United States, Ukraine, and Israel.

Nevertheless, other studies have identified neutral or negligible effects, such as that by Apergis and Payne (2010), who found long-term neutrality in their examination of twenty OECD countries between 1985 and 2005 using panel cointegration and the VECM model. Similarly, another study using cointegration and causality tests conducted by Bulut and Muratoglu (2018) found no significant association for Turkey over the interval 1990–2015. In the same framework of analysis, Menegaki (2011), using Granger causality tests for 27 European nations within the timeframe 1997–2007, also showed no substantial influence. Equally, Omri et al. (2015), employing dynamic simultaneous-equation models across 17 developed and developing nations, identified neutral outcomes for Finland, Switzerland, and Brazil. Okumus et al. (2021) examined the G7 across the years 1980–2016 using a new panel data estimator, which indicated neutrality for France, Japan, and the UK. The neutral impact was also supported by Keshavarzian and Tabatabaianasab (2021), who examined the link between renewable and non-renewable energy consumption and economic growth in a sample of 10 oil-exporting countries between 1980 and 2018. The findings confirmed that renewable energy had no impact on economic expansion in half of the countries. In fact, within OPEC countries, the share of sustainable energy sources remains lower than that of fossil fuels. In the same line of analysis, Zafar et al. (2022) examined the impact of renewable energy consumption on economic growth in a sample of 15 emerging countries over the period 1990–2015. The results of the panel bootstrap test support the neutrality of the impact in all countries.

Other research has also looked at the idea of non-linearity, such as that of Ferhi and Kamel (2024), who demonstrated that the impact of renewable energy consumption was positive only beyond a specific threshold, analyzing data from 24 OECD nations between 1990 and 2015 using panel econometric analysis. In an identical framework, Chen et al. (2020) analyzed 103 countries from 1995 to 2015 based on a threshold model, revealing that renewable energy exerted a beneficial effect just

when its proportion surpassed a specific threshold, especially in non-OECD nations. Analogously, Guliyev and Tatoglu (2023) noted a favorable effect for European countries from 1970 to 1996, followed by a negative effect from 1996 onward. In the same context, Shahbaz et al. (2020), using non-linear autoregressive distributed lag (NARDL) from 1995 to 2015, found that several G7 countries showed non-linear results, such as France, Italy, Japan, and the United Kingdom, while Germany, Canada, and the United States showed neutral results. Non-linearity is also confirmed by other studies, such as that of Dabboussi and Abid (2022), who analyzed the non-linear relationship between economic growth and sectoral consumption of renewable energy in the United States between 1981 and 2021. The results reveal that the impact is positive only if each sector (electricity, industry, residential, commercial, transport) exceeds a specific consumption threshold; below this threshold, the effect becomes negative. This kind of result is also confirmed by Témé et al. (2024), who examined the impact of renewable and primary energy consumption on economic growth in four countries (Benin, Senegal, Togo, and Côte d'Ivoire) between 1980 and 2020. Using fixed and random effects econometric models, the results show that these energy sources significantly support growth. However, renewable energy consumption has a threshold effect, indicating that a certain level must be reached for the impact to be positive. The findings recommend greater integration of renewables into the region's economic development policies.

Empirical literature shows that the impact of renewable energy consumption on economic growth varies across contexts. In some cases, it is a factor supporting productivity and development, reflecting a positive relationship between renewable energy and growth. Conversely, other studies highlight negative effects, linked in particular to adaptation costs, technological constraints, and structural inefficiencies. Several studies also suggest that there is no significant relationship, indicating that the share of renewable energy in the economy may be too marginal to influence growth. Finally, a body of research highlights more complex dynamics, marked by non-linear effects or thresholds, where renewable energy changes its impact after a certain level of consumption.

Based on these empirical findings, the objective of this study is to examine the nature of the relationship between renewable energy consumption and economic growth in Morocco, formulating the following hypotheses:

- H1: Renewable energy consumption has a linear impact on economic growth.*
- H2: The effect of renewable energy consumption on economic growth is neutral.*
- H3: The relationship between renewable energy consumption and economic growth is non-linear in nature.*

2. METHODOLOGY

We focus on the long-term analysis of the nature of the relationship between renewable energy consumption and economic growth in Morocco. According to the literature, there are four possible impact cases (positive linear, negative linear, neutral, and non-linear). That leads us to opt for the Coob Douglas function in quadratic form linearized by the application of logarithm by adding the variable (renewable energy consumption) squared, to detect the linear and non-linear effects.

The relationship that can interpret all cases in the long term is as follows:

$$\ln GDP = \alpha_0 + \alpha_1 \ln RE + \alpha_2 (\ln RE)^2 + \ln K + \ln L + \varepsilon \quad (1)$$

For our research analyzing the period 1990–2023, the Gross Domestic Product (GDP) and the capital fixe (K) are expressed as billions USD constants; RE is the annual energy consumed from renewable sources (%); labor force (L) expressed in millions of people, ε is the error term. All data are based on the World Bank data.

Table 1 shows descriptive data for the variables considered in the investigation. GDP has a mean of 71 and a median of 62 which indicate a right skewed distribution, meaning some values are much higher than the mean. The difference between its minimum (42) and maximum (130)

values is quite large and indicates considerable heterogeneity among values observed. This large dispersion around the mean is demonstrated by the high standard deviation of 30. Looking at the capital variable (*K*), the mean is equal to 26 and the median is 25, which are very close, indicating a symmetrical distribution of the data. With a standard deviation of 5, indicating less variation between these values, ranging between 18 and 34. Consequently, capital is relatively homogenous across observations.

The labor variable has a maximum of 14, a median of 13, and a range of 9 to 18.5. The standard deviation (*SD*) of 3 indicates moderate variability. In general, labor is also well balanced between the observations. It implies that labor available or utilized is quite similar in terms of quantity.

The average consumption of renewable energy is 4.05, with a median of 3.99, indicating a symmetrical distribution of data. The values range from 1.38 to 7.64, showing considerable diversity between the values. The standard deviation of 1.9, which is close to half the mean, indicates moderate to wide dispersion.

Table 1. Statistics that describe the factors from 1990 to 2023

Variables	Mean	Median	Min	Max	St deviation
GDP	71	62	42	130	30
K	26	25	18	34	5
L	14	13	9	18.5	3
RE	4.05	3.99	1.38	7.64	1.9

For the purposes of this study, which aims to analyze a long-term relationship between variables, the autoregressive distributed lag (ARDL) model is selected, initially proposed by Pesaran and Shin (1999) and later extended by Pesaran et al. (2001). This choice is justified by several advantages associated with the ARDL approach. First, it is particularly well-suited for small sample sizes, which is often a limitation in time series analysis. Second, the method can be applied to variables with different integration orders, as long as none is integrated of order two (I(2)). Finally, the ARDL model effectively addresses potential endogeneity issues, making it a robust tool for estimating long-run relationships (Harris & Sollis, 2003).

The ARDL model, which is expressed as follows:

$$\begin{aligned} \Delta \ln GDP_t = & \beta_0 + \sum_{j=1}^p \beta_{1j} \Delta \ln GDP_{t-j} \\ & + \sum_{j=1}^q \beta_{2j} \Delta \ln RE_{t-j} + \sum_{j=1}^r \beta_{3j} \Delta (\ln RE)_{t-j}^2 \\ & + \sum_{j=1}^s \beta_{4j} \Delta \ln K_{t-j} + \sum_{j=1}^t \beta_{5j} \Delta \ln L_{t-j} \\ & + \rho_1 \ln GDP_{t-1} + \rho_2 \ln RE_{t-1} + \rho_3 (\ln RE)_{t-1}^2 \\ & + \rho_4 \ln K_{t-1} + \rho_5 \ln L_{t-1} + \varepsilon_t, \end{aligned} \tag{2}$$

where Δ indicates the first difference of the variable; $\ln(GDP)$ is the dependent variable; $\ln(RE)$, $\ln(FE)$, $(\ln(RE))^2$ and $\ln K$ are the independent variables; β_0 is the constant, ρ_1 , ρ_2 , ρ_3 , ρ_4 , and ρ_5 , refer to the long-run elasticities, while β_{1j} , β_{2j} , β_{3j} , β_{4j} and β_{5j} represent the short-run elasticities, ε_t is the error term.

The “Bounds st” is used to check the cointegration relationship. To do this test, it is essential to run an *F*-test on the null hypothesis $\rho_1 = \rho_2 = \rho_3 = \rho_4 = \rho_5 = 0$ compared to the alternative hypothesis $\rho_1 \neq \rho_2 \neq \rho_3 \neq \rho_4 \neq \rho_5 \neq 0$.

The computed *F*-statistic is evaluated against the lower and upper critical bounds provided by Pesaran et al. (2001). If the *F*-statistic falls below the lower bound, the null hypothesis of no cointegration cannot be rejected. Conversely, if the *F*-statistic exceeds the upper bound, the null hypothesis is rejected at the chosen level of significance, indicating the presence of a cointegration relationship among the variables. However, if the *F*-statistic lies between the two bounds, the results of the bounds test are considered inconclusive.

After confirming cointegration, the comprehension of immediate dynamics is facilitated by an Error Correction Model (ECM), as below:

$$\begin{aligned} \Delta GDP_t = & \beta_0 + \sum_{j=1}^p \beta_{1j} \Delta GDP_{t-j} \\ & + \sum_{j=1}^q \beta_{2j} \Delta RE_{t-j} + \sum_{j=1}^r \beta_{3j} \Delta RE_{t-j}^2 \\ & + \sum_{j=1}^s \Delta \ln k_{t-j} + \sum_{j=1}^t \Delta \ln L_{t-j} + \rho ECM_{t-1} + \varphi_t, \end{aligned} \tag{3}$$

where ECM_{t-1} shows how quickly the system can return back to long-run equilibrium after a short-run shock.

By employing the ARDL approach, this study captures both the short and long-term effects of renewable energy consumption and other key variables on Morocco's economic growth. The findings provide valuable insights for policymakers, offering a framework to guide the energy transition in a manner that supports, rather than compromises, sustainable economic development.

3. RESULTS AND DISCUSSION

Before applying the ARDL model for cointegration analysis, it is necessary to follow several preliminary steps to ensure the validity and robustness of the results.

3.1. Unit root test

The study utilizes the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests to determine the integration order of the time series variables. Since the ARDL bounds testing approach developed by Pesaran et al. (2001) is valid only when the variables are integrated at level 0 or 1, it is essential to verify that none of the series is integrated of order 2. The results of the stationarity tests, summarized in Table 2, indicate that all variables are non-stationary at the level but become stationary after first differencing. This confirms that the series is integrated of order one (I(1)). Consequently, the ARDL model is deemed appropriate for the empirical analysis in this study.

Table 2. Augmented Dickey-Fuller and Phillips-Perron root test

Variables	ADF (5%)		Philips-Perron (5%)		Integration order
	Level (Intercept)	First difference (intercept)	Level (Intercept)	First difference (intercept)	
Ln(RE)	-1.4493 (-2.9604)	-6.3928 (-2.9639)*	-1.4493 (-2.9604)	-6.4001 (-2.9639)*	I(1)
(ln(RE)) ²	-0.0042 (-2.9639)	-8.5449 (-2.9639)*	-0.0048 (-2.9604)	-8.0533 (-2.9639)*	I(1)
Ln(GDP)	-1.5715 (-2.9604)	-4.7410 (-2.9639)*	0.3868 (-2.9604)	-7.5038 (-2.9639)*	I(1)
Ln(k)	0.8394 (-2.9604)	-5.9169 (-2.9639)*	1.0962 (-2.9604)	-5.9138 (-2.9639)*	I(1)
Ln(L)	0.3382 (-2.9639)	-9.0679 (-2.9639)*	0.6193 (-2.9604)	-9.0286 (-2.9639)*	I(1)

Note: * denotes statistical significance at 5% level.

3.2. Optimal lag length

After testing for stationarity, finding the correct lag values for the variables being tested is important for the time series analysis. For the Lag Selection criteria, it gives us an optimal number of prior observations that need to be sucked into the model that will augment the overall power and sharpness of the predictive and interpretive functionalities of the model. Various methods and criteria exist to address this issue, each presenting advantages and disadvantages. Several standard criteria for selecting the lag include the Akaike information criterion (AIC), Schwarz information criterion (SC), sequential modified test statistic (LR), final prediction error (FPE), and Hannan-Quinn information criterion (HQ). Such criteria facilitate a balance between model fit and complexity by determining the appropriate lag length (Cavaliere et al., 2015).

According to Table 3, in addition to the AIC, which is the most frequently used, it suggests, with the LR, FPE, and HQ criteria, an optimal lag of 6 (represented by the * symbol), which is selected for this study.

Table 3. Optimal lag

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-254.52	NA	80509.9	19.809	19.954	19.851
1	-229.98	41.535	24532.2	18.613	19.194*	18.781
2	-221.63	12.195	26677.8	18.664	19.680	18.957
3	-214.75	8.470	34158.5	18.827	20.278	19.245
4	-206.85	7.898	44101.9	18.912	20.799	19.455
5	-201.41	4.189	79598.7	19.185	21.508	19.854
6	-165.19	19.498*	17610.9*	17.092*	19.850	17.886*

Note: * indicates lag order selected by the criterion.

3.3. Bounds test

After determining the integration order of the variables and selecting the appropriate lag length for the model, the autoregressive distributed lag (ARDL) approach is employed to assess the existence of a long-run relationship among the variables. The analysis makes use of the bounds testing procedure, which involves computing an *F*-statistic to test the null hypothesis that all coefficients of the lagged level variables in Equation (2) are jointly equal to zero.

The computed *F*-statistic is 20.002, which exceeds the upper critical value at the 1% significance level (5.3), as reported in Table 4. This leads to the rejection of the null hypothesis of no cointegration. Therefore, it can be concluded that a long-run equilibrium relationship exists among the model's variables.

Table 4. ARDL bound test results

F-Bounds Test				
Test	Value	Null Hypothesis: No levels relationship		
F-statistic	20,002	Signif.	I(0)	I(1)
		0.1	2.17	3.19
		0.05	2.72	3.83
		0.025	3.22	4.5
		0.01	3.88	5.3

3.4. Assumption violations, diagnostics, and stability tests

To ensure the robustness and credibility of the ARDL model results, several diagnostic tests must

be performed. The residual diagnostic outcomes, as shown in Table 5, indicate that the model variables are resilient to issues such as non-normality, serial correlation, and heteroscedasticity, given that the null hypotheses were not rejected. Consequently, the findings from the bounds testing procedure within the ARDL framework can be considered consistent, valid, and free from spurious distortions. However, to further strengthen the reliability of these results, stability tests are also essential. Table 6 and Figures 1 and 2 present, respectively, the outcomes of the Ramsey RESET test, the CUSUM test, and the CUSUM square test.

In Table 6, the *p*-values associated with both the *t*-statistic (0.736) and the *F*-statistic (0.736) exceed the conventional 5% significance threshold. This suggests that the ARDL model is appropriately specified, and its functional form does not suffer from specification errors. Also, the results in Figures 1 and 2 indicate that both the CUSUM and CUSUMQ test statistics remain within the critical bounds at the 5% significance level. This suggests that the residuals of the model are stable over time. Consequently, the model can be considered statistically reliable and suitable for further analysis.

The previous validation steps confirm the robustness of the model and justify the estimation of the long-term specification.

Table 7 illustrates the relationship between the explanatory variables and GDP. According to the findings, the long-run elasticity of GDP with respect to renewable energy (RE) consumption is estimated at 0.934017, and this coefficient is sta-

Table 5. Residual diagnostic test results

Residual diagnostic tests	Decision rule	Probability value	Decision Accept
Breusch-Godfrey Serial Correlation LM Test	H_0 = No serial correlation = $p > 0.05$ H_1 = Serial correlation = $p < 0.05$	0.361*	Accept null hypothesis of no serial correlation
Breusch-Godfrey Heteroscedasticity Test	H_0 = Homoscedasticity = $p > 0.05$ H_1 = Heteroscedasticity = $p < 0.05$	0.140*	Accept null hypothesis of homoscedasticity
Normality Test	H_0 = Residual terms are normally distributed = $p > 0.05$ H_1 = Residual terms are not normally distributed = $p < 0.05$	0.427*	Accept null hypothesis of normal distribution

Note: (*) Acceptance of null hypothesis at 1%, 5%, or 10% significance level.

Table 6. Ramsey regression equation specification error test (RESET) results

t-statistic	0.340	Prob	0.736
F-statistic	0.116	Prob	0.736

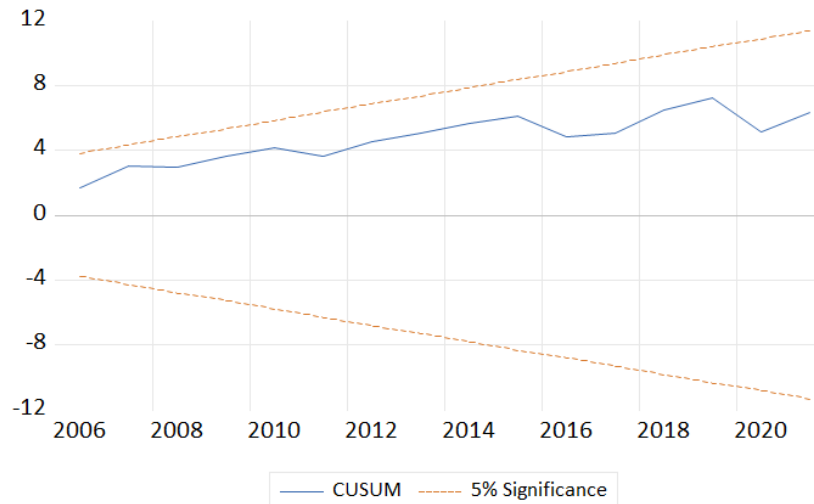


Figure 1. Stability test, CUSUM

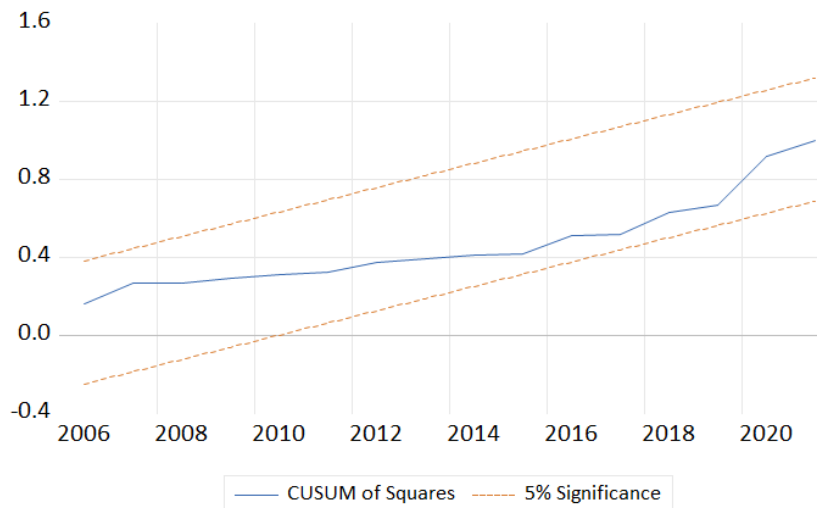


Figure 2. Stability test, CUSUMQ

tistically significant. This indicates that a 1% increase in renewable energy consumption is associated with a 0.93% increase in GDP. However, the squared term of renewable energy consumption (RE^2) carries a negative and statistically significant coefficient (-0.212636 , $p = 0.00$), suggesting that beyond a certain level, increased renewable energy consumption negatively affects GDP. This supports the presence of a non-linear, inverted

U-shaped relationship between renewable energy consumption and economic growth.

In light of the empirical long-term results, it appears that hypotheses $H1$ and $H2$, which assume a linear and neutral relationship between renewable energy consumption and economic growth, respectively, are not confirmed by the estimates. On the other hand, the results clearly validate hy-

Table 7. Long-run estimation

Variables	Coefficient	St error	T ration	Prob
Ln(RE)	0.934017	0.080857	11.55146	0.0016
(Ln(RE)) ²	-0.212636	0.06243	-3.40599	0.000
Ln(k)	0.320543	0.075883	4.22417	0.0124
Ln(L)	0.385529	0.08331	4.627643	0.0020

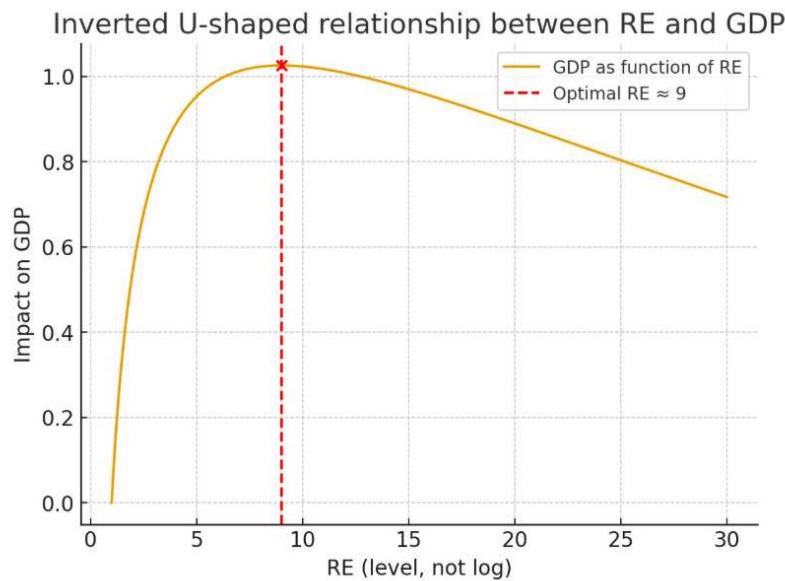


Figure 3. Inverted U-shaped relationship between renewable energy and GDP

pothesis *H3*, which is consistent with several studies, including Guliyev and Tatoglu (2023), Ferhi and Kamel (2024), Chen et al. (2020), Shahbaz et al. (2020), Dabboussi and Abid (2022), and Témé et al. (2024).

More specifically, our analysis has revealed non-linearity in the form of a U-inverted shape, leading us to determine a threshold for renewable energy consumption that must not be exceeded. To determine the threshold, the long-run results are differentiated to $\ln(RE)$ and equated to zero as follows:

$$\begin{aligned} \ln(GDP) = & 0.734017 \ln(RE) \\ & -0.212636 (\ln(RE))^2 \\ & +0.320543 \cdot \ln(k) + 0.385529 \cdot \ln(L), \end{aligned} \quad (4)$$

$$\begin{aligned} \frac{\partial \ln GDP}{\partial \ln RE} = & 0.934017 \\ & -2 \cdot 0.212636 \ln(RE) = 0. \end{aligned} \quad (5)$$

Hence, the threshold is

$$\ln(RE)^* = \frac{0.934017}{2 \cdot 0.212636} = 2.19634341. \quad (6)$$

We return to the value not transformed by exponentiation:

$$RE^* = e^{2.19634341} \approx 9\%. \quad (7)$$

Although renewable energy consumption has a positive effect on economic growth in the long run, this effect reverses and becomes negative once a certain threshold is exceeded, estimated at around 9%, as illustrated in Figure 3. It follows naturally in a country like Morocco, where energy mix includes more than 90% of fossil fuel imports, and that is at the same time firmly committed to an ambitious energy transition. Up to 9% of renewable energy consumption growth gets the benefit from partial import substitution of RE, the cheaper costs of energy, and the industrial effects of renewable energy projects and investments. But after this point, growth is limited by the structural constraints of integration: ill-suited electricity grids, lack of flexibility, intermittent sources, inadequate storage, and high adjustment costs, which weaken the effectiveness of these clean sources.

This point of return indicates that the energy transition is not simply a quantitative growth in the consumption of green renewable energies, but an overall qualitative strategy that aims to enhance the quality of renewable energies in order to make them sustainable and competitive with fossil fuels.

CONCLUSION

The objective of this study is to assess the potential long-term impact of continued and increasing consumption of renewable energy on Morocco's economic growth.

The findings of this study confirm the existence of a non-linear relationship between renewable energy consumption and economic growth, in which the effect is beneficial in the long run but reverses beyond a threshold of about 9%, which has important economic policy implications. It is therefore necessary to carefully calibrate the path to greening and avoid premature excessive dependence until competitiveness, grid integration, and flexibility/storage conditions guarantee a contribution to GDP comparable to that of fossil fuels.

Two areas of action are required. First, it is necessary to secure the flexibility of the electricity system through storage, demand management, and interconnections needed to compensate for the intermittency that characterizes renewables and maximize their efficiency on a structural basis. Second, it is vital to stimulate innovation, research and development, and the training of a highly skilled workforce, to internalize productivity gains and avert the negative growth effects of a rapid, unaccompanied expansion.

The research perspective consists of analyzing, using a disaggregated approach, the effect of renewable energy consumption on long-term GDP growth, identifying the specific contributions of each sector (solar, wind, and hydroelectric) in order to optimize the prioritization of consumption in Morocco.

AUTHOR CONTRIBUTIONS

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