Unlocking Morocco's Economic Potential: Insights into the Complex Relationship Between Electricity, Renewable Energy, and GDP

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Abstract: The objective of this paper is to shed light on the long-run and short-run causal relationships between electricity consumption, renewable electricity generation, renewable energy consumption, fossil energy consumption, energy use, carbon dioxide emissions and gross domestic product per capita for Morocco over the period 1990-2020 using the autoregressive distributed lag cointegration boundary test approach. The augmented Dickey-Fuller unit root test and the Phillips-Perron unit root test were used to verify the stationarity of the variables, while the Johansen cointegration test was applied to examine the robustness of the long-run relationships. The results showed that the long-run effects of the variables were found to have a greater effect on the gross domestic product per capita compared to the short-run dynamics, thereby demonstrating that the results are heterogeneous. The results suggest that the government of Morocco should take well-defined measures to increase the use of renewable energy resources to solve the country's energy crisis and introduce incentive mechanisms to mitigate carbon dioxide emissions.

Keywords: Renewable Energy, Economics Performance, ARDL, Energy transition, Energy Fossil, Econometrics.

INTRODUCTION

In the context of global warming, persistent oil price volatility and increasing global energy demand across the world, Morocco has ratified the main international treaties and conventions and has even elaborated its national strategy of sustainable development in 2015. All of these factors, coupled with the country's continuous commitment to meet its pledges to cut greenhouse gases, have largely favoured the emergence of renewable energy sources (i.e., solar, wind, hydro, biomass, etc.) as an alternative to exhaustible traditional energies (i.e., oil, natural gas, etc.)Ensuring environmental sustainability for a country involves prioritizing key elements such as energy security, economic growth, social responsibility, and environmental protection. Morocco has made notable strides in this regard by implementing various measures to improve its energy efficiency and effectively manage its energy security.(Kousksou et al., 2015) .

Ensuring the existence of a balance between a robust economic growth and an effective sustainable development strategy has recently become a major policy issue, and Morocco is no exception. Indeed, the country is placing renewable energies at the heart of its energy strategy to secure its environmental sustainability. Furthermore, it is showing enormous commitments to the principles of sustainable development, namely by the successive reforms endorsed to secure a solid foundation for the economic development of the country while also accelerating its environmental achievements and measures. After launching the 2009 energy strategy, the Kingdom has made immense progress and important advances in the energy sector owing to its energy policy aimed at diversifying energy sources while closely relying on renewable ones. Additionally, numerous initiatives and programs have succeeded in reducing greenhouse gas emissions (Gharnit, Bouzahzah, & Bounahr, 2021).

The Moroccan energy mix and electricity mix are both very dependent on the use of conventional energy technologies, thereby making it indispensable to invest in renewable energies in which the country has a rather strong and diverse potentiality. Additionally, the Kingdom has also set up development policies for renewable energies and a new energy strategy dedicated to reducing its energy dependencies and enhancing its energy savings (Soufiyane, Abdelmoumen, & Maha, 2020). Indeed, according to 2030(IEA, 2019), it is estimated that Morocco's new energy strategy will result in 15% to 20% of energy savings by 2030. Notwithstanding, satisfying the increasing energy demand in a sustainable manner remains a great challenge, especially given the high-

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er rates of population growth and economic growth that the country is currently undergoing.

There is certainly an enormous potential for great growth in the renewable energy sector in Morocco owing to the national strategy that is currently underway to pursue low-carbon opportunities, thus leading to optimistic expectations regarding a sustainable low-carbon economy in the country (Kousksou et al., 2015) . Nonetheless, renewable energies, although growing quickly, remain insufficient to satisfy the global strong demand and eliminate the risk of pushing CO2 emissions from the electricity sector to hit a record high(IEA, 2021).

On a separate yet important note, Morocco faces pressing obstacles in relation to energy, especially due to its high energy dependency on foreign suppliers that exceeds 90% and an energy bill that weighs heavily on the economic and financial balance of the country. Notwithstanding, it has not hesitated to invest massively in renewable energies in the hopes of becoming one of the leaders at the regional and global level. In doing so, it set ambitious goals including the increase of the share of renewable energies in its electricity mix that is set to exceed 52% by 2030. In spite of these major efforts made in the recent years, Morocco’s electricity mix is still dominated by traditional energies, hereby enduring the drawbacks of unexpected price fluctuations at the global level (Bahetta & Hasnaoui, 2021). In this regard, using renewable energies has proven itself as a potential remedy to face these drawbacks and combat global warming while offering great opportunities to address environmental issues(Dincer, 2000).

Given that the current fossil-based energy system is incongruous with the sustainable development objectives, it should be substituted for a clean energy transition(Midilli, Dincer, & Ay, 2006). Moreover, investments in green energies should be government-backed to replace fossil fuels and insure a sustainable future. Morocco’s recent orientation to increase the share of renewable energy in its total energy consumption is intricately linked to the economic growth of the country. In fact, it has been proven that there is an unidirectional relationship going from economic growth to renewable energy consumption (Gharnit et al., 2021).

It is also worth noting that the law n°13-09 has been passed in Morocco to contribute to the realization of the national strategy as well as to the development of the renewable energy sector. In fact, its 44 articles put forward a framework for the public and private actions and initiatives in Morocco to ensure the liberalization of marketing and production of electricity from renewable energies (Gharnit et al., 2021).

Numerous studies have been conducted to shed light on the relationship between renewable energies, carbon dioxide emissions and economic growth. Indeed, in the light of the growing demands for fossil fuel-based energy sources, the deployment of renewable energies should be encouraged by governments worldwide in order to boost the economic performance of countries while also advancing the Sustainable Development Goals (Ocal & Aslan, 2013).

In this paper, our aim is to shed light on the nexus between carbon dioxide emissions and the consumption of electrical energy, fossil fuel energy, and renewable energy, on economic performance for the case of Morocco. Indeed, we demonstrated the existence of a linkage between the gross domestic product per capita as an indicator of Morocco’s economic performance, and the consumption of electric power, renewable energy consumption, CO2 emissions and fossil fuel energy consumption in the country.

The remainder of this research paper is structured as follows. The section of the literature review yields a summary of existing studies in relation to our theme whereas the following section presents the empirical methodology with a focus on the data sources and a thorough description of the methods and the model employed. We then proceed to present the results of the study to finally conclude and present a list of policy implications in the last section of the paper.

Literature Review

Bridging the gap between carbon dioxide emissions and economic growth has presented itself as one of the solutions to achieve the sustainable development goals (SDGs) after their adoption by the United Nations in 2015. The role that renewable energy can play in restoring environmental and economic conditions has become a significant subject in current debates and in a series of recent studies. In fact, previous studies have emphasized that energy affects the development and economic performance of countries, thus imposing key energy sector reforms to boost the level of economic growth and enhance energy efficiency(Saidi & Omri, 2020).

Indeed, there have been numerous studies to investigate the causality relationships in the long run and short run between electric power consumption, renewable electricity output, renewable energy consumption, fossil fuel energy consumption, energy use, carbon dioxide emissions, and gross domestic product per capita, particularly for Pakistan(Rehman, Rauf, Ahmad, Chandio, & Deyuan, 2019). In the light of the results reported by this study, it is conceivable that the government of Pakistan should take many initiatives to sort out its energy crisis specifically through the use of renewable energy resources and the introduction of new policies that aim to lower carbon dioxide emissions Furthermore, the interaction between greenhouse gas emissions, nuclear energy, coal energy, urban agglomeration, and economic growth was also examined in the case of Pakistan, namely through the use of time series data between 1972 and 2019(Rehman et al., 2021), The findings of this study suggested that nuclear energy has a constructive association with economic growth, thereby implying that the government should consider adopting new policies aimed at contributing to environmental sustainability without jeopardizing the economic development of the country.

Moreover, the effect of the consumption of non-renewable and renewable energy on economic growth has been found to be significantly positive. Although energy consumption has a key role in enhancing growth, focusing on the use of non-renewable energy can lead to significant environmental issues. This suggests that promoting renewable energy is key in establishing an efficient use of energy and avoiding energy waste (Asif, Bashir, & Khan, 2021). Another attempt to investigate the association among energy, environment and economic growth was conducted in Latin-American countries from 1990 to 2014 to demonstrate a long run relationship among environment, and energy (Razzaq, Muhammad, Karim, Tariq, & Muhammad, 2021) . Indeed, using renewable sources of energy can cause CO2 emissions to shrink whereas non-renewable energy consumption increases them.

Shedding light on 15 emerging countries from 1990 to 2015, the nexus between renewable energy consumption and economic growth was analysed to prove that a negative shock in economic growth hampers renewable energy consumption (Eyuboglu & Uzar, 2022). Moreover, the existence of the Environmental Kuznets Curve (EKC) was scientifically investigated to comprehend the dynamics of the nexus among GDP, foreign investments and GHGs in order to deduct adequate policy measures to reduce emissions without jeopardizing economic growth(Hasan, Nahiduzzaman, Aldosary, Hewage, & Sadiq, 2022). This was done specifically in Bangladesh to shed light on the impact of FDI on energy consumption and GHGs Indeed, Bangladesh's economy is energy-dependent and energy supply could largely improve foreign investments in the country, thus calling for strong policy to draw transformative change in governance(Hasan et al., 2022).

Furthermore, the relationship between renewable energy, non-renewable energy, carbon emissions, economic growth, gross fixed capital formation, and urban population was investigated in China from 1960 to 2019(Zhang & Zhang, 2021). This study concluded that renewable energy has a positive impact on GDP in the short run and long run whereas non-renewable energy only presents a positive impact on GDP in the short term. Notwithstanding, emission reduction and energy efficiency policies should be supported with a focus on the adoption of renewable energies to achieve a sustainable economic growth. Additionally, some authors have driven the further development of these findings and decomposed low-precision energy consumption data from China into 149 sectors according to the high-precision input–output (I–O) table (He et al., 2021). Indeed, the promotion of the decarbonization of the power industry and enhancement of energy and raw material utilization efficiencies of other production sectors can serve as the primary emission reduction measures.

It is also worth noting that previous studies explored the nexus between electricity production from renewable resources, economic growth, and other explicative variables such as trade openness and CO2 emissions in Morocco, namely between 1990 and 2017. This has provided evidence for a strong cointegration between the variables, thereby validating the essential role of economic growth and trade openness in the deployment of renewable energy(Chama, Yahya, & Hindou, 2021). Furthermore, the link between renewable and non-renewable energy consumption, CO2 emissions, and economic growth was analysed for the case of Morocco from 1990 to 2014. It was reported that renewable energies in Morocco have begun yielding a favourable impact on the economic dimension of sustainable development(Soufiyane et al., 2020). Indeed, this work established a causal relationship from renewable energy consumption to economic growth and from economic growth to CO2 emissions. This suggests that the government as well as private companies should consider investing in innovative solutions to finance renewable energy projects to potentially replace fossil fuels in Morocco.

Finally, in an attempt to close the gap in literature regarding the relationship between institutional quality and the ecological footprint, Uzar (2021) demonstrated that institutional quality plays a crucial role in reducing ecological footprint, and that economic growth and energy consumption contribute to ecological pressure, using the AMG and CCEMG estimator in E-7 countries. Therefore, it is imperative to prioritize the improvement of institutional quality and the adoption of renewable energies to enhance environmental quality in these nations. (Uzar, 2021)

In light of the growing demand for fossil fuel-based energy sources and their potential depletion in the future, it is essential for governments worldwide to support the deployment of renewable energies through policy to improve economic performance. In summary, prioritizing renewable energy is crucial to meet energy demands sustainably.(Ocal & Aslan, 2013).

Methodology of the study

Our model specification is presented in the table below (Table 1) prior to identifying the data source, which is the World Bank database. The dataset utilized for our econometric estimates is comprised of annual time series data spanning from 1990 to 2020, resulting in a sample size of 31 observations.

Table 1. Study Variables and their Exploration.

GDPCC	**Gross Domestic Product Per Capita (in current USD)**	**WDI**
CO2	Carbon Dioxideemission in Kt	WDI
EPC	Electric Power Consumption (in KWh per capita)	WDI
EU	Energy Use (Kg of oil equivalent per capita)	WDI
FFEC	Fossil Fuel Energy Consumption (in % total)	WDI
REC	Renewable energy Consumption (in % total)	WDI
REO	Renewable electricity Output (in % total electricity output)	WDI

The trend of the surveyed variables is shown in Figure 1 below.

Econometric Methodology and Unit Root Test

The following model was employedin order to explore the associations between our variables:

$$GDPPC_t \;= f\left(CO_{2t}, EPC_t, EU_t, FFEC_t, REC_t, REO_t\right) \quad (1)$$

where $GDPPC_t$ indicates the gross domestic product per capita, CO_{2t} represents the carbon dioxide emission, EPC_t is the electric power consumption, EU_t indicates the energy use, $FFEC_t$ is the fossil fuel energy consumption, REC_t denotes the renewable energy consumption, and REO_t represents the renewable electricity output. We can also write Eq. 1 as:

$$GDPPC_t \;= \psi_0 + \psi_1 CO_{2t} + \psi_2 EPC_t + \psi_3 EU_t + \psi_4 FFEC_t + \psi_5 REC_t + \psi_6 REO_t + \mu_t$$

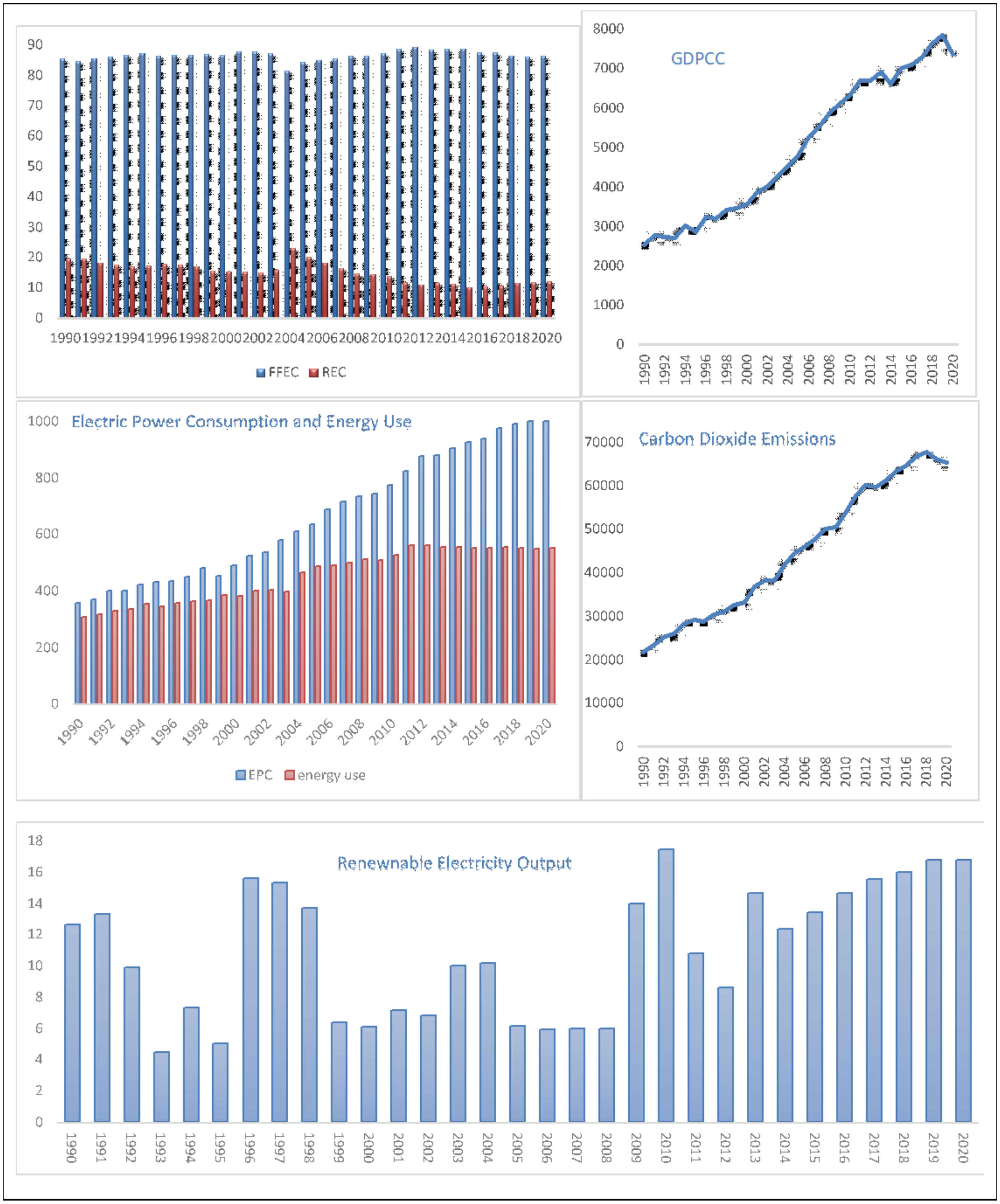

Fig. (1). Trend of variables.

Applying the natural logarithm to Eq. 2 to lower the instability and multicollinearity of the time span data produced the following log-linear model:

$$lnGDPPC_t = \psi_0 + \psi_1 lnCO_{2t} + \psi_2 lnEPC_t + \psi_3 lnEU_t + \psi_4 lnFFEC_t + \psi_5 lnREC_t + \psi_6 lnREO_t + \mu_t \qquad (2)$$

where $lnGDPPC_t$ represents the log of the gross domestic product per capita; $lnCO_{2t}$ is the log of the carbon dioxide issue; $lnEPC_t$ is the log of the electricity power consumption; $lnEU_t$ is the log of energy use; $lnFFEC_t$ represents the log of the fossil fuel energy consumption; $lnREC_t$ yields the log of the renewable energy consumption; $lnREO_t$ is the log of the renewable electricity output; t is the time dimension; μt is the error term; ψ0 is the constant intercept; and ψ1 to ψ6 are the model coefficients that demonstrate the elasticity over the long run.

Furthermore, the Augmented Dickey–Fuller (ADF) unit root test (Dickey and Fuller1979) and the Phillips–Perron unit root test(Phillips & Perron, 1988)were employed to determine whether any study variables had an integration of order 2. It is worth noting that the ARDL model involved no pretesting of the stationarity of the variables through the unit root test. The ARDL bounds testing approach was null in the I (2) case for the used variables. Using Eq. 3, we performed the unit root test as indicated below:

$$\Delta S_t = \lambda_{\circ} + \delta_{\circ} T + \delta_1 S_{t-1} + \sum_{i=1}^{m} \alpha_1 \, \Delta S_{t-1} + \mu_t \qquad (2)$$

where S denotes to be used for unit root test, T demonstrates the linear trend, Δ illustrates the first difference, t measures time, μt indicates the error term, and m demonstrates the white noise that the residuals are set toachieve.

Autoregressive Distributive Lag (ARDL)

Autoregressive distributive lag (ARDL) is a type of econometric model used to analyse the long-run and short-run relationships between variables in a time series dataset. It is a generalization of the autoregressive (AR) and distributed lag (DL) models and allows for both dynamic and static relationships between variables. ARDL models can be used to estimate the effects of exogenous variables on the outcome variable, as well as the effects of lagged values of the outcome variable on the current value. ARDL models are particularly useful for analysing the long-run and short-run effects of policy interventions, such as tax changes or changes in government spending.

The ARDL bounds testing approach was first introduced by (Pesaran & Shin, 1998). It was later ameliorated by (Pesaran, Shin, & Smith, 2001)and used by (Narayan, 2004)in a study on the tourism demand model. Analyses of the long-run and short-run relationships between gross domestic product per capita in Morocco and carbon dioxide emissions,electric power consumption, energy use, fossil fuel energy consumption, renewable energy consumption, and renewable electricity output were performed. The interactions of the long-run and short-run relationships were examined using the ARDL approach with the unrestricted error correction model (UECM). In this paper, we attempt to approximate the model separately for the long-run and short-run relationships. The long-run relationship between the study variables was specified using Eq. 3 in the following manner:

$$\begin{aligned}\Delta\, lnGDPPC_t \;&= \lambda_{\circ} + \sum_{i=1}^{A} \delta_{1_j} \Delta\, lnGDPPC_{t-k} + \sum_{i=1}^{B} \delta_{2_j} \Delta\, lnCO_{2t-k} + \sum_{i=1}^{C} \delta_{3_j} \Delta\, lnEPC_{t-k} \\ &+ \sum_{i=1}^{D} \delta_{4_j} \Delta\, lnEU_{t-k} + \sum_{i=1}^{E} \delta_{5_j} \Delta\, lnFFEC_{t-k} + \sum_{i=1}^{F} \delta_{6_j} \Delta\, lnREC_{t-k} + \sum_{i=1}^{G} \delta_{7_j} \Delta\, lnREO_{t-k} \\ &+\psi_1 lnGDPPC_{t-1} + \psi_2 lnCO_{2t-1} + \psi_3 lnEPC_{t-1} + \psi_4 lnEU_{t-1} + \psi_5 lnFFEC_{t-1} \\ &+\psi_6 lnREC_{t-1} + \psi_7 lnREO_{t-1} + \varepsilon_t \end{aligned} \qquad (6)$$

$$\begin{aligned}\Delta\, lnGDPPC_t \;&= \lambda_{\circ} + \sum_{i=1}^{H} \delta_{1_j} \Delta\, lnGDPPC_{t-k} + \sum_{i=1}^{I} \delta_{2_j} \Delta\, lnCO_{2t-k} + \sum_{i=1}^{J} \delta_{3_j} \Delta\, lnEPC_{t-k} + \sum_{i=1}^{K} \delta_{4_j} \Delta\; lnEU_{t-k} \\ &+ \sum_{i=1}^{L} \delta_{5_j} \Delta\; lnFFEC_{t-k} \\ &+ \sum_{i=1}^{M} \delta_{6_j} \Delta\; lnREC_{t-k} + \sum_{i=1}^{N} \delta_{7_j} \Delta\; lnREO_{t-k} + \alpha ECM_{t-1} + \varepsilon_t \end{aligned} \qquad (6)$$

where λ_0 is the constant intercept, A, B, C, D, E, F, and G illustrate the order of lags, Δ is the operator for first difference, and εt is the error term. In our analysis, the comovements of the variables were estimated using the F-statistic. The null hypothesis and the long-run relationship would be rejected if the estimation of the F-statistic has proven to be greater than the upper bound critical value.

Correspondingly, the short-run relationship between the study variables was determined using the ARDL approach with the error correction model (ECM) and specified in the equation:

Granger Causality test

The long-run and short-run relationshipslinking the variables were approximated using the ARDL boundtest approach for cointegration; notwithstanding, the results were unable to identify the propensity for cointegration between the variables. Therefore, to verify the existence of the proximity of cointegration, the next phase was used to investigate the causal connectivity among the variables. Indeed, the Granger causality test in the Vector Error Correction Model (VECM) framework was used to illustrate the causal effect between the variables by considering their predictability based on their historical values as well as current ones. In an attempt to classify the directions of the causality test, the short-term causal relationship was determined using the vector error correction model (Robert F & C.W.J, 1987).In this case, if the variables are cointegrated under ARDL or VECM in the long-run analysis, the short-run investigation should have an error correction term (ECT) in the specific model where the speed of adjustment is growing from its nonconformity and

Table 2. Descriptive Statistics and Correlation Matrix.

	LNGDPPC	**LnCO2**	**LnEPC**	**LnEU**	**LnFFEC**	**LnREC**	**LnREO**
Minimum	7,0895092	9,98644907	5,88378506	5,7271867	2,3918131	2,39181318	1,497440329
Maximum	8,0620227	11,0212486	6,80731802	6,3305682	3,1355246	3,1355246	2,85842802
Mean	7,5169285	10,5454193	6,33657731	6,04670604	2,7653589	2,7653589	2,20857833
Std. Dev.	0,3562179	0,31926039	0,29680822	0,20191302	0,1890986	0,1890986	0,40755367
Variance	0,127	0,102	0,088	0,041	0,036	0,036	0,166
Skewness	0,405	-0,03	0,154	0,071	-1,08	-0,443	-0,033
Kurtosis	-1,572	-1,228	-1,378	-1,51	2,624	-0,086	-1,394
Observations	31	31	31	31	31	31	31
LNGDPPC	1						
LnCO2	,942**	1					
LnEPC	,961**	,994**	1				
LnEU	,956**	,991**	,988**	1			
LnFFEC	0,286	0,349	0,337	0,27	1		
LnREC	-,648**	-,690**	-,690**	-,634**	-,879**	1	
LnREO	0,223	0,084	0,125	0,083	0,096	-0,158	1

the direction of its long-run equilibrium (i.e., conformity). That is to say, a modified model in which an error correction term is mentioned enhances the vector error correction model for short-term relationships. Nonetheless, if the cointegration between the variables cannot be established, the short-run analysis will consequently be run on a standard vector autoregression (VAR) model. Indeed, the VECM model involved in establishing Granger causality between the variables was determined in the following equation:

$$
\begin{bmatrix} \Delta\, GDPPC_t \\ \Delta\, CO_{2t} \\ \Delta\, EPC_t \\ \Delta\, EU_t \\ \Delta\, FFEC_t \\ \Delta\, REC_t \\ \Delta REO_t \end{bmatrix}
=
\begin{bmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \\ \pi_4 \\ \pi_5 \\ \pi_6 \\ \pi_7 \end{bmatrix}
+
\begin{bmatrix}
\phi_{11,1} & \phi_{12,1} & \phi_{13,1} & \phi_{14,1} & \phi_{15,1} & \phi_{16,1} & \phi_{17,1} \\
\phi_{21,1} & \phi_{22,1} & \phi_{23,1} & \phi_{24,1} & \phi_{25,1} & \phi_{26,1} & \phi_{27,1} \\
\phi_{31,1} & \phi_{32,1} & \phi_{33,1} & \phi_{34,1} & \phi_{35,1} & \phi_{36,1} & \phi_{37,1} \\
\phi_{41,1} & \phi_{42,1} & \phi_{43,1} & \phi_{44,1} & \phi_{45,1} & \phi_{46,1} & \phi_{47,1} \\
\phi_{51,1} & \phi_{52,1} & \phi_{53,1} & \phi_{54,1} & \phi_{55,1} & \phi_{56,1} & \phi_{57,1} \\
\phi_{61,1} & \phi_{62,1} & \phi_{63,1} & \phi_{64,1} & \phi_{65,1} & \phi_{66,1} & \phi_{67,1} \\
\phi_{71,1} & \phi_{72,1} & \phi_{73,1} & \phi_{74,1} & \phi_{75,1} & \phi_{76,1} & \phi_{77,1}
\end{bmatrix}
$$

$$
\begin{bmatrix} \Delta\, GDPPC_{t-1} \\ \Delta\, CO_{2t-1} \\ \Delta\, EPC_{t-1} \\ \Delta\, EU_{t-1} \\ \Delta\, FFEC_{t-1} \\ \Delta\, REC_{t-1} \\ \Delta REO_{t-1} \end{bmatrix}
+\cdots+
\begin{bmatrix}
\phi_{11,k} & \phi_{12,k} & \phi_{13,k} & \phi_{14,k} & \phi_{15,k} & \phi_{16,k} & \phi_{17,k} \\
\phi_{21,k} & \phi_{22,k} & \phi_{23,k} & \phi_{24,k} & \phi_{25,k} & \phi_{26,k} & \phi_{27,k} \\
\phi_{31,k} & \phi_{32,k} & \phi_{33,k} & \phi_{34,k} & \phi_{35,k} & \phi_{36,k} & \phi_{37,k} \\
\phi_{41,k} & \phi_{42,k} & \phi_{43,k} & \phi_{44,k} & \phi_{45,k} & \phi_{46,1} & \phi_{47,k} \\
\phi_{51,k} & \phi_{52,1} & \phi_{53,k} & \phi_{54,k} & \phi_{55,k} & \phi_{56,k} & \phi_{57,k} \\
\phi_{61,k} & \phi_{62,k} & \phi_{63,k} & \phi_{64,k} & \phi_{65,k} & \phi_{66,k} & \phi_{67,k} \\
\phi_{71,k} & \phi_{72,k} & \phi_{73,k} & \phi_{74,k} & \phi_{75,k} & \phi_{76,k} & \phi_{77,k}
\end{bmatrix}
$$

$$
\begin{bmatrix} \Delta\, GDPPC_{t-k} \\ \Delta\, CO_{2t-k} \\ \Delta\, EPC_{t-k} \\ \Delta\, EU_{t-k} \\ \Delta\, FFEC_{t-k} \\ \Delta\, REC_{t-k} \\ \Delta\, REO_{t-k} \end{bmatrix}
+
\begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \\ \theta_5 \\ \theta_6 \\ \theta_7 \end{bmatrix} ECT_{t-1}
+
\begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \\ \lambda_5 \\ \lambda_6 \\ \lambda_7 \end{bmatrix}
\qquad (7)
$$

Equation 7 shows the Granger causality for the gross domestic product per capita under the VECM, where Δ indicates a difference operator, λ is the error term, and θ is the coefficient of the error term ($ECT_{t\text{-}1}$). If θ presents a significant probability for its coefficient coupled with a negative sign, it implies, using the t statistic, that the variables have a long-run relationship. It should be noted that ECTis used to determine the value of the long-run relationship instead of λ. To investigate the short-run Granger causality relationships, the F-statistic in the Wald statistical test was utilized. For instance, 휙12, k ≠ 0∀k indicated that carbon dioxide emissions are related to gross domestic product per capita according to the Granger causality test. Likewise, 휙21, k ≠ 0∀k also indicated a causal connectedness between carbon dioxide emissions and gross domestic product per capita.

Empirical Result

The summary statistics and correlation matrix results are illustrated in Table **2**. The Jarque–Bera statistics and the probability values indicated that the variables are distributed normally. Moreover, the correlation analysis indicated that there is a positive corelation between the study variables.

Results of Unit Root Test

To prove the integration order among the study variables, we appliedthe Augmented Dickey Fuller and Philippe Person test which are among the most popular tests in the existing literatureconcerning the study of the stationarity of time series. The results are presented in the table below:

The application of the ADF and PP tests on the studied series shows that some variables are not stationary at level. This leads to the rejection of the stationarity hypothesis for all the

Table 3. Results of Stationarity Test.

Variables	ADF at Level		ADF 1st Difference		P-P at Level		P-P 1st Difference	
	t stat	P value	t stat	P value	t stat	P value	t stat	P value
LnGDPPC	-1.682911	0.7273	-3.971188	0.0251	-1.773588	0.6856	-3.971188	0.0251
LnCO2	-3.211907	0.1057	-5.423384	0.0012	-3.201210	0.1078	-6.351363	0.0002
LnCEPC	-2.353862	0.3920	-5.982178	0.0003	-2.245288	0.4454	-6.181003	0.0002
LnEU	-2.43290	0.3280	-5.322709	0.0014	-2.545614	0.3056	-5.658121	0.0007
LnFFEC	-2.257871	0.1927	-5.613693	0.0001	-2.257871	0.1927	-5.814401	0.0001
LnREC	-1.709721	0.7153	-4.309523	0.0125	-1.709721	0.7153	-4.291557	0.0130
LnREO	-3.133131	0.0374	-5.314207	0.0003	-3.184828	0.0336	-5.355382	0.0003

Table 4. Bounds Test Results.

Test Statistics	Value	Signif.	I(0)	I(1)
F-statstic	5.741800	10%	2.334	3.515
k	6	5%	2.794	4.148
		1%	3.976	5.691

Table 5. Johansen cointegration Test Results.

Nullhypothesis	Traceteststatistic	*p*value	Nullhypothesis	Maximumeigenvalue	*p*value
$r\leq0$	270.5082*	0.0000	$r\leq0$	108.9977*	0.0000
$r\leq1$	159.5335*	0.0000	$r\leq1$	61.99756*	0.0002
$r\leq2$	99.5468*	0.0002	$r\leq2$	42.84820*	0.0050
$r\leq3$	57.66558*	0.0038	$r\leq3$	32.37983*	0.0124
$r\leq4$	25.26664	0.1573	$r\leq4$	11.07775	0.5478
$r\leq5$	13.27780	0.1135	$r\leq5$	6.640000	0.5056
$r\leq6$	5.549800*	0.0197	$r\leq6$	6.537800*	0.0197

R shows the cointegrating equation numbers *Rejection of the hypothesis at the 0.05 level.

series at level. Since the variables are non-stationary at level, we proceed to running tests on the variables transformed into first difference. The results show that after differentiating the variables once, all variables were confirmed as stationary. The tests applied to the first difference of the data set reject the hypothesis of non-stationarity for all the variables used in this study. It is therefore useful to conclude that all variables are integrated of order (1). Therefore, no series is integrated of order (2) or higher, which is crucial for the application of ARDL.

Results of the ARDL Bounds Test with Cointegration

Table **4** shows the results of the ARDL bounds test. The computed F-statistics were 5,741800, which exceeded the upper critical bound. The results of the cointegration showed the relationships between gross domestic product per capita, carbon dioxide emissions, electric power consumption, energy use, renewable energy consumption, fossil fuel energy consumption, and renewable electricity output.

Table **5** shows the results of the Johansen cointegration test (Johansen and Juselius 1990) to confirm long term relationship. The trace test statistics reject the null hypothesis cointegration in the model. The trace statistics and the largest eigenvalue is better than the critical value values.

Results of Long-run and Short-run Analyses

The results of the long-run and short-run analyses and the residual diagnostic test are given in Table **6**. Indeed, these results indicated the relationships linking the variables.

Part A of table **6** shows the elasticity of the variables in the long run. The coefficient of carbon dioxide emissions obtained is 1.493812 with a p-value of 0.0102, which is positive and statistically significant at the 1% level. The results also showed that the electricity consumption and electricity generation from renewables had a positive effect on gross domestic product per capita: the coefficients were 1.459968 and 0.485965 with p values of 0.0038 and 0.0022, respec-

Table 6: Results of the Long-Run and Short-Run Analysis and Residual Diagnostic Test.

Dependent variable is LNGDPPC: ARDL selected bass on AIC

Panel A:Variable	**long-run analysisCoefficient**	**Std.error *T*ratio**	***p* value**	**PanelB:short-runanalysisVariable Coefficient**		**Std.error**	***T*ratio *p* value**	**Panel C: residualdiagnostictest**
LnCO$_2$	1.493812***	0.391186 2.581304	0.0102	ΔLnCO$_2$0.733647**		0.329280	2.258870 0.0434	*R*-squared0.967731
LnFFEC	−1.345273***	0.526175 −3.322318	0.0043	ΔLnFFEC−2.401106***		0.752957	−2.7368050.0134	Adjusted *R*-squared 0.964818
LnREC	−4.722095**	1.382418 −2.153264	0.0465	ΔLnREC	−0.138157	1.036895	−0.1342020.7753	Durbin–Watson stat.2.266325
LnEPC	1.459968***	0.493541 3.264912	0.0038	ΔLnEPC	1.381272***	0.273564	3.472302 0.0021	*F*-statistic55.0172***
LnEU	−3.229247***	1.124694 −3.529574	0.0012	ΔLnEU	−2.746542***	0.826351	−3.1475670.0047	χ^2*SERIAL*1.433 (01365).
LnREO	0.485965***	0.133617 3.897686	0.0022	ΔLnREO	−0.453443***	0.132909	−3.3166260.0032	χ^2*NORMAL*1.811 (0.2712)
C	6.816435**	12.618747 2.054786	0.0444	ECM(−1)	−0.559238***	0.015653	−6.2255300.0000	χ^2*ARCH*2.114 (0.1476)
								χ^2 *RESET* 0.162 (0.7531)

*** and ** are significant at 1% and 5%, respectively.

tively. Indeed, a 1% increase in carbon dioxide emissions, electricity consumption, and electricity generation from renewable energy leads to an increase in gross domestic product per capita of 1.07%, 1.93%, and 0.57%, respectively. Therefore, fossil energy consumption, renewable energy consumption, and energy use have a negative and statistically significant effect on gross domestic product per capita; the coefficients are -1.345273, 4.722095, and -3.229247 respectively.

The results obtained suggest increasing the amount of renewable energy used in the energy mix to ensure energy supply(Soufiyane et al., 2020).Indeed, the government should put in place measures to enhance the promotion of renewable energies, not to mention the full liberalization of the national electricity market(Bahetta, Dahhou, & Hasnaoui, 2021). In order to achieve a low-carbon economy, those who are in chargeof the conduct of national energy policy should be urged to strengthen the incentive system for renewable energy deployment, namely through providing a more appropriate legal and institutional framework. The integration of renewable energy into the energy mix can help reduce the country's carbon dioxide emissions and give a new boost to the Moroccan economy. That being said, potential actions may also be needed to increase energy efficiency and the use of renewable energy to reduce fossil fuel consumption and improve environmental performance(Kharbouch, Dahhou, & Bahetta, 2022). For conventional energy and sustainable development, major constraints will have to be optimized in the power sector to escalate the consumption of renewable energy shares. Additionally, the sustainability of economic growth is crucial for the modernization of the renewable energy sector even though it still mainly depends on fossil energy consumption in most countries (Chimbo, 2020).

Part B of Table 6 shows the results concerning the short-run dynamics. The ECM requires cointegration between variables; the occurrence of cointegration separates the short-term dynamics and uses the relationship with the coefficients to measure the speed of adjustment. The results showed that the coefficients of carbon dioxide emissions and electric energy consumption had a positive and statistically significant relationship with gross domestic product per capita with p-values of 0.0434 and 0.0021, respectively. This means that a 1% increase in the variables was linked to increases in gross domestic product per capita of 0.733647% and 1.381272%, respectively.

A summary of the long-run and short-run effects is presented in figure 2. Based on the magnitudes of the coefficients, the long-run effects outweigh the short-run dynamics in terms of the impact of the variables on gross domestic product per capita. Furthermore, the long-run and short-run relationships for all variables were consistent, except for renewable electricity generation, which had a negative effect on gross domestic product per capita in the long run and a positive effect in the short run. The overall results revealed heterogeneity in the short and long run, which provided crucial information for policy recommendations.

Part C of Table **6** shows the results of the residual diagnostic test. The R-squared value is 0.967731, which shows a 97% variation in the gross domestic product per capita described in the model, and the adjusted R-squared value is 0.964818. The F-statistic showed a confirmed joint significance at 1% regarding the independent variables. Additionally, the value of the Durbin-Watson statistic was 2.266, indicating that there is no autocorrelation in the model.

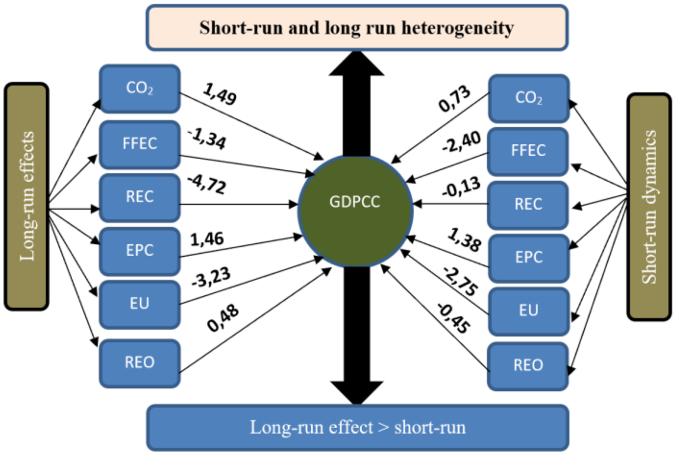

Fig. (2). Summary of the long-run effects and short-run dynamics.

Table 7. Results of the Granger Causality Test Under Vector Error Correction Model.

	ΔGDPPC	**ΔCO₂**	**ΔEPC**	**ΔEU**	**ΔFFEC**	**ΔREC**	**ΔREO**
ΔGDPPC	–	1.270663 (0.235)	0.122124(0.977)	1.022159 (0.334)	0.668285	0.554381	1.761832
ΔCO_2	0.27082 (0.532)	–	0.125621 (0.688)	0.011435 (0.455)	0.505215	0.446294	0.772899
ΔEPC	0.213331 (0.437)	1.628022 (0.618)	–	1.265438 (0.568)	0.203748	1.000026	0.129334
ΔEU	1.153667 (0.264)	6.04628** (0.035)	0.524372 (0.540)	–	1.367133	1.482864	0.260231
ΔFFEC	1.675468 (0.438)	7.746332*** (0.072)	0.382212 (0.116)	1.752841 (0.435)	–	3.151121* (0.002)	0.121671
ΔREC	1.855432 (0.227)	12.18154*** (0.064)	0.000482 (0.248)	3.165245* (0.003)	4.543455** (0.041)	–	0.533361
ΔREO	6.715113*** (0.057)	0.415322 (0.117)	0.273123 (0.656)	3.167462* (0.001)	2.083871	2.468827	–

Dependent variables Independent variables

*, **, and *** are significant at the 1%, 5%, and 10%, respectively

Results of the Short-run Granger Causality Test under Vector Error Correction Model

Table **7** shows the results of the short-run Granger causality test at VECM. The presence of cointegration allowed us to quantify the direction of the causal relationships between the variables. The ARDL boundary testing approach showed that there is long-term cointegration between the variables. Notwithstanding, short-term causality in the sense of Granger suggested that the results should be used to express the ultimate conclusions of a sound future strategy. Consequently, Granger causality tests under VECM show that there is a strong association between the variables. That being the case, the Moroccan government needs to tap into the financial instruments of the energy market and design effective plans to increase renewable energy production such as solar, hydro, wind, and biomass, rather than focusing on fossil fuel production.

The CUSUM and CUSUM-squared structural stability tests showed that the analyses of the long-run and short-run constraints were stable. The CUSUM and CUSUM-squared test graphs are shown in figure 3 and 4 with a 5% level of significance.

Model Robustness Test

A robustness test for a model is a type of test that measures the model's ability to handle unexpected inputs, scenarios,

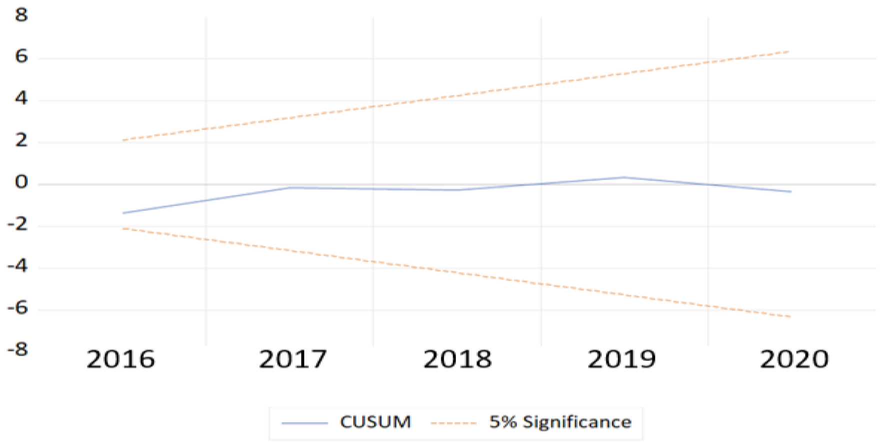

Fig. (3). Plot of CUSUM.

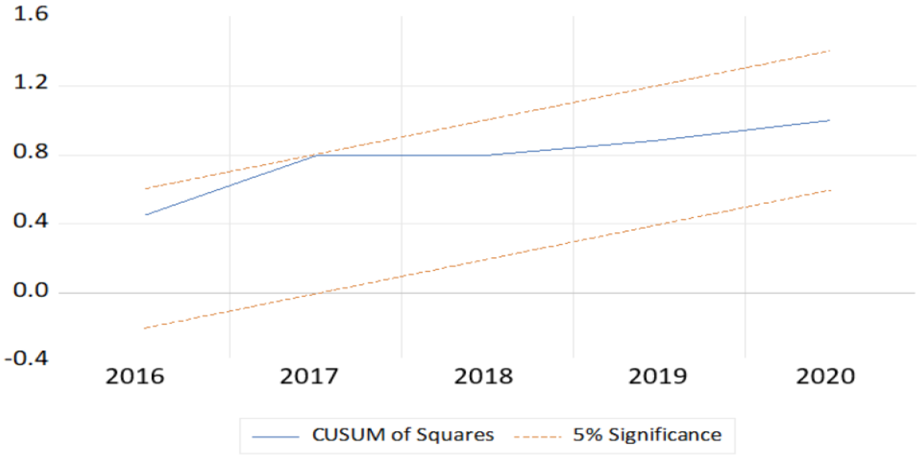

Fig. (4). Plot of CUSUM Squared.

and data points. The goal of the test is to identify any potential flaws or weaknesses in the model that could lead to incorrect or inaccurate predictions. The test should evaluate the model's performance with a variety of inputs, scenarios, and data points. It should also assess the model's ability to handle unexpected or unexpected data points, such as outliers or rare events. The test should also consider the impact of varying parameters on the model's performance.

Table 8. Model Robustness Test.

Verified hypothesis	Applied test	Statistic	Probability
Autocorrelation of errors	Breush-Godrey	1,823891	0.1032
Heteroscedasticity	Arch	0.602189	0.4468
Normality	Jarque-Bera	2.008219	0.366371
Specification	Ramsey	1.121025	0.3250

The validity of our estimated model and the validity of the results obtained from the short-term and long-term relationships need to beconfirmed using a set of assumptions. We test the assumptions on error correlation, heteroskedasticity, normality, specification, and stability of the coefficients. In the table below, the probability of the statistic for the 4 tests is greater than 5%. This means that the hypothesis H0 is accepted in all these tests. It is also worth noting that the errors are neither correlated nor homoscedastic and that their distribution follows a normal distribution. This leads to affirm that our model is well specified. Furthermore, the stability of the coefficients of our model over time is validated by the CUSM and CUSUMQ tests because the curve does not go out of the corridor in these two tests (Figure 3 and Figure 4 above).

CONCLUSION AND POLICY IMPLICATIONS

Energy plays a critical role in the economic development and well-being of human beings. This study investigated the causal relationship between various energy-related variables in Morocco. The study found that carbon dioxide emissions, electricity consumption, and renewable electricity production have a positive and significant impact on GDP per capita in the long run. These findings indicate that increasing renewable energy production and reducing carbon emissions could boost economic growth in Morocco. However, renewable energy consumption, fossil energy consumption, and energy use were negatively linked with GDP per capita, suggesting that Morocco needs to adopt more efficient energy policies to increase economic growth sustainably.

The study also used the Dickey-Fuller and Phillips-Perron unit root tests to verify the stationarity of the variables and the autoregressive distributed lag approach to examine the causal relationships between long-term and short-term variables. The results showed that the long-term effects were more significant than the short-term dynamics, indicating that Morocco's energy policies need to focus on sustainable, long-term solutions. Additionally, the VECM Granger causality test showed a one-way and a two-way relationship between all variables except for GDP per capita and carbon emissions, which suggests that there is a feedback hypothesis at play.

Overall, the study highlights the importance of sustainable energy policies that prioritize renewable energy production and reducing carbon emissions to foster economic growth in Morocco. The findings suggest that policymakers should focus on long-term solutions and adopt more efficient energy policies to increase economic growth sustainably. The feedback hypothesis also underscores the need for a comprehensive approach to energy policy that considers all relevant variables and their interactions.

The findings of this study revealed a robust connection between the analysed variables. As a result, it is recommended that the Moroccan government implements initiatives to stimulate the energy sector and introduces new measures to decrease carbon emissions. These strategic actions should prioritize the adoption of renewable energy sources and the reduction of energy-intensive fossil fuel production and consumption. Furthermore, the outcomes of this research can provide valuable insights to the Moroccan government and policymakers in evaluating the state of the energy sector and its environmental implications, ultimately enabling them to pursue opportunities for a low-carbon future.Our energy policy recommendations primarily focus on fiscal measures related to renewable energy.

Specifically, we suggest that the Moroccan government incentivizes the adoption of renewable energy sources to reduce the country's reliance on imported fossil fuels. This can be achieved through tax incentives that encourage investment and consumption of renewable energy sources, as well as facilitating the transition from conventional technologies to cleaner alternatives.Another critical aspect to consider is creating an investment-friendly environment that can attract both domestic and foreign investors. Additionally, investing in the development of a skilled workforce and human capital is essential for facilitating the widespread adoption of renewable energy sources and driving growth in the energy sector of Morocco. Above all, this study underscores the urgency of implementing significant energy reforms to foster sustainable economic growth and enhance long-term sustainability.

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