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New evidence from NARDL model on CO2 emissions: Case of Morocco

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Abstract. The main objective of this study is to examine the effect of sickle energy consumption, renewable energy, and forest area on the emission of carbon dioxide (CO2) in Morocco. Many studies have abord this subject using a different approachs, most of which have used econometric models such as Vector Autoregressive (VAR) Error Correction Model (ECM) and Autoregressive Distributed Lag (ARDL). In this study, we opted for the Non-linear Autoregressive Distributed Lag (NARDL) model. The data used covers the period from 1990 to 2018 (annual data). The results of our model are significant and prove the asymmetric effects of the explanatory variables on CO2 emissions.

1 Introduction

Climate change is one of the most complicated problems the world is trying to solve. The excessive emission of gases from production and manufacturing activities poses a great threat to the environment. The data collected from OECD shows that the forest surface is in a permanent decrease.

The effect of this pollution has a direct impact on climate change. CO2 emissions doubled in the late 1980s "*Since 1751, more than 400 billion tons of carbon have been released into the atmosphere through the consumption of fossil fuels and the production of cement. Half of this CO2 has appeared since the end of the 1980s*" [1]

Currently, renewable energy is the most efficient solution to this environmental crisis, the consumption of this type of energy has no negative effect on the environment, unlike fuels, renewable energies offer environmental, energy, and economic benefits [2].

The Kyoto Protocol signed in 1997 and the Paris Agreement in 2015 aim, to face climate change and improve the capacity of governments to cope with its effects and to encourage countries to use renewable energy [3, 4]. Researchers focusing on climate change should consider the relationship between CO2, energy consumption, and forest area.

The literature on energy and environment economics presents several research topics that use econometric methods such as cointegration, causality, and regression models. Different researchers are studying this emerging problem with different variables to capture the impact on the environment.

For example, [5] analyzes the effect of trade, energy, financial development, and urbanization on environmental degradation. Applying the ARDL model, the results show that energy consumption and urbanization increase the deterioration and degradation of the environment, while trade improves the environment in the United States.

Meanwhile, [6] and [7] have empirically demonstrated similar results for Malaysia and China. By applying F-Bound and VECM, [6] offer further evidence of an inverted U-shaped relationship between CO2 emissions and long-term urbanization.

Recently, [8] reveals that coal consumption, oil consumption, economic growth, and natural gas consumption have a positive impact on environmental degradation in Pakistan in the short and long term. They further recommend that environmental degradation can be reduced by promoting renewable energy resources in Pakistan.

In addition, [8] has included globalization in this interaction. [9] applying the dynamic ARDL simulations model, their results indicate that energy consumption, financial development, trade, FDI, and globalization have a positive impact on carbon emissions in Pakistan.

2 Data and methods of analysis

2.1 Data

The data used in this research come from the World Bank's development indicators (WDI). Annual data were used, covering a 28-year period from 1990 to 2018, depending on the availability of data. The multivariate framework included total CO2 emission (CE) as the dependent variable, while the explanatory model variables are, used energy (UE), renewable energy consumption (RE), and forest area (FA). All variables

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were converted to logarithms before analysis. Summary statistics are provided in Table 1.

Table 1. descriptive statistics of the variables

	CE	RE	FA	UE
Mean	1.608331	1.077312	1.074196	2.263837
Median	1.620656	1.187750	1.076236	2.585713
Maximum	1.834474	1.371168	1.104109	2.749331
Minimum	1.350054	0.000000	1.045329	0.000000
Std. Dev.	0.148636	0.380361	0.024643	0.925132
Skewness	-0.105110	-2.405448	-0.023804	-2.066535
Kurtosis	1.742571	7.181892	1.208712	5.334517
Jarque-Bera	1.963928	49.09815	3.879933	27.22645
Probability	0.374575	0.000000	0.143709	0.000001
Obs	29	29	29	29

2.2 Methodology

This study examines the relationship between CE, RE, FA, and UE using a non-linear (asymmetric) approach to determine short- and long-term asymmetric relationships.

$$log\ CE_t = \alpha + \alpha_1 \log RE_t + \alpha_2 \log \mathrm{FA}_t + \alpha_3 \log \mathrm{UE}_t + \mu_t \quad (1)$$

Where i represents the years, log represents the logarithm. CE represents carbon emissions, RE represents renewable energy consumption, FA represents forest area and UE represents used energy.

We have adopted the ARDL nonlinear test approach developed by [10], which considers nonlinear and asymmetric cointegrations between the variables. In addition, it differentiates between the long-term effects and the short-term effects of the independent variables on the dependent variables.

It applies regardless of whether the variable is stationary at level or the first difference I (0) or I (1) provided that none of these variables is I (2) [11]. This article uses this NARDL cointegration to study the relationship between the variables.

$$\Delta EC_t = \alpha_0 + pEC_{t-1} + \theta_1^+ ER_{t-1}^+ + \theta_2^- ER_{t-1}^- + \theta_3^+ SF_{t-1}^+ + \theta_4^- SF_{t-1}^- + \theta_5^+ UE_{t-1}^+ + \theta_6^- UE_{t-1}^- + \sum_{i=0}^{q} \alpha_1 \Delta EC_t + \sum_{i=0}^{q} \alpha_2\, ER_{t-1}^+ + \sum_{i=0}^{q} \alpha_3\, ER_{t-1}^- + \sum_{i=0}^{q} \alpha_4\, SF_{t-1}^+ + \sum_{i=0}^{q} \alpha_5\, SF_{t-1}^- + \sum_{i=0}^{q} \alpha_6\, UE_{t-1}^+ + \sum_{i=0}^{q} \alpha_7\, UE_{t-1}^- + D_t + \mu_t$$

From the first equation, θ_i represents the long-term coefficients, α_i represents the short-term coefficients. The long-term coefficients give the reaction time and the speed time of the adjustment towards the equilibrium level.

At the same time, the immediate effect of the independent variables on the dependent variables was determined using the short term. We used the Wald test to determine the short-term asymmetry ($\alpha = \alpha^+ = \alpha^-$) and the long-term asymmetry ($\theta = \theta^+ = \theta^-$) for the CE variables, RE, FA, and UE.

D_t Designates a dummy variable used to know the impact of the date of rupture (t). The Akaike information criterion (AIC) helps to determine p and q, which are the optimal lags for the independent and dependent variables.

By breaking down the independent variables into positive and negative sums, we have:

$$x_t^+ = \sum_{j=1}^{t} \Delta x_j^+ = \sum_{j=1}^{t} \max(\Delta x_j, 0)$$
And (2)
$$x_t^- = \sum_{j=1}^{t} \Delta x_j^- = \sum_{j=1}^{t} \min(\Delta x_j, 0)$$

To carry out a combined test for all the levels of delayed repressors, we carried out a linked test proposed by [10] to check if there exists an asymmetric cointegration in the long term.

We applied the F-statistics test. The null hypothesis θ = 0 against the alternative hypothesis θ <0 by [12] and the T-statistics by [15] the hypothesis tests the null hypothesis at θ = 0 compared to the alternative hypothesis θ <0. To estimate the long-term asymmetric coefficients, we used $Lmi^+ = \frac{\theta^+}{\rho}$ and $Lmi^- = \frac{\theta^-}{\rho}$, where these long-term coefficients reveal the positive and negative charges of the variables exogenous and show the long-term relationship between the variables.

To estimate the asymmetric dynamic multiplier effects, the equation below is used. The equation below is used to estimate the asymmetric dynamic multiplier effects.

$$m_h^+ = \sum_{j=0}^{h} \frac{\partial EC_{t+j}}{\partial ER_t^+}, m_h^- = \sum_{j=0}^{h} \frac{\partial EC_{t+j}}{\partial ER_t^-}, m_h^+ = \sum_{j=0}^{h} \frac{\partial EC_{t+j}}{\partial SF_t^+}, m_h^- = \sum_{j=0}^{h} \frac{\partial EC_{t+j}}{\partial SF_t^-}, m_h^+ = \sum_{j=0}^{h} \frac{\partial EC_{t+j}}{\partial UE_t^+}, m_h^- = \sum_{j=0}^{h} \frac{\partial EC_{t+j}}{\partial UE_t^-} \quad (3)$$

$h \to \infty, m_h^+ \to Lm^+\ et\ m_h^- \to Lm^-$, show asymmetric responses of the dependent variable to the positive and negative variation of the independent variables.

We notice a constant change in the adjustments of the initial equilibrium to the new equilibrium between the variables of the system according to the multipliers estimated following the variation which affects the system.

3 Empirical results

3.1 Stationarity test

In this research, we used both the augmented Dickey-Fuller test (ADF) proposed by [13] and the Phillips and Perron test (PP) proposed by [14].

The null hypothesis of stationarity in the two tests is the existence of the unit root. By testing the stationarity of all the selected variables (CE, RE, FA, and UE) with an interception. Table 2 shows the unit root test for stationarity to determine if the variables are first-order integrated.

Table 2. series stationarity tests

	ADF		PP	
Variables	**level**	**1 diff**	**level**	**1 diff**
CE	-1.0792	-6.2072***	-2.1252	-7.5969***
RE	0.0768	-5.1923**	0.3534	-5.1923***
EF	-1.5854	-4.4639***	-1.5074	-4.7630***
UE	-0.4519	-5.1586***	-0.4760	-5.1586***

Notes: *, **, *** indicate statistically significant at 10%, 5%, and 1%, respectively.

The results of the stationarity tests show that all the variables of our model are of order I (1), this result allow us to apply the NARDL model

3.2. Diagnostic tests

Table 3 shows the results of the diagnostic check in terms of heteroskedasticity, functional form, and Jarque-Bera generated by the estimation of the cointegration relationship.

All the variables satisfy the statistical requirements, namely the absence of heteroskedasticity, and the Ramsey test shows that the model does not suffer from any specification error at a statistical significance level of 5%.

Table 3. Diagnostic result

Model diagnostics	stat.	p-value
Breusch/Pagan heteroskedasticity test	1.872	0.1713
Ramsey RESET test (F)	4.842	0.1139
Jarque-Bera test on normality	.1593	0.9234

3.3. Estimated result NARDL

We have analyzed the existence of cointegration using critical statistical values to determine whether the variables are affected by each other in the long term at different significant levels.

A long-term non-linear relationship between renewable energy, forest area, used energy, and carbon emissions was tested using the t_{BDM} statistics developed by [15] and the F test proposed by [12]. The results are displayed in table 4.

Table 4. cointegration test

Cointegration test statistics:	t_{BDM}	F_{PSS}
	-7.7114	17.4875

*, **, *** indicate statistically significant at 10%, 5% and 1%, respectively. The t_{BDM} statistics for 10% are (2.57 / 3.21), for 5% are (2.86 / 3.53) and for 1% (3.43 / 4.10) [12]. In addition, the values of the F_{PSS} statistics for 10% are (3.17 / 4.14), for 5% (3.79 / 4.85) and 1% (5.15 / 6.36) [12]

Our results report that the null hypothesis of non-cointegration is rejected in the case of Morocco. This implies that it is important to study the long-term asymmetric relationship between the variables of our model.

3.4. Wald Statistics

The short- and long-term asymmetric effects are presented in Table 5. This table shows the restrictions of symmetry and asymmetry in the long- and short-term relationships between Renewable Energy, Forest Space, Used Energy, and Carbon Emissions.

Table 5. Result of asymmetry in long- and short-term relationships

	Long-run effect [+]			Long-run effect [-]		
Exog. var.	**Coef.**	**F-stat**	**P>F**	**Coef.**	**F-stat**	**P>F**
UE	1.959	641.3	0.000	0.087	21.86	0.003
FA	2.085	32.87	0.001	36.641	43.16	0.001
RE	-0.692	113.6	0.000	-0.265	19.15	0.005

	Long-run asymmetry		Short-run asymmetry	
Exog. var.	**F-stat**	**P>F**	**F-stat**	**P>F**
UE	460.1	0.000	20.75	0.004
FA	42.8	0.001	26.46	0.002
RE	59.92	0.000	6.422	0.044

Note: Long-run effect [-] refers to a permanent change in exog. var. by -1

The dynamic asymmetric relationship between the given variables has been further enriched by plotting the multiplier effects (Figure 1).

The asymmetric dynamic relationship between the given variables has been further enriched by plotting the multiplier effects. These dynamic multipliers show the adjustments of renewable energy, forest space and energy use to the unit of carbon emission shocks, and its new long-term equilibrium following a positive or negative unit shock over the 28 years.

The positive (negative dotted green line) and negative (red dotted line) variation curves describe the adjustment of renewable energy; forest space and energy use have a positive and negative effect of shock multipliers. carbon emissions over 28 years.

The asymmetry line (solid blue line) reflects the difference between the positive and negative impact multipliers over 28 years.

3.5. NARDL model estimation

The estimation of the long and short-run NARDL models are presented in table 6, the coefficients of the two models are significant except for the short term model where the variable RE has non-significant coefficients, the model results show that the used energy and the decrease in forest area have a positive impact on the emission of CO2 gas, while renewable energy negatively impacts the emission of CO2 gas, the coefficients are presented in table 6.

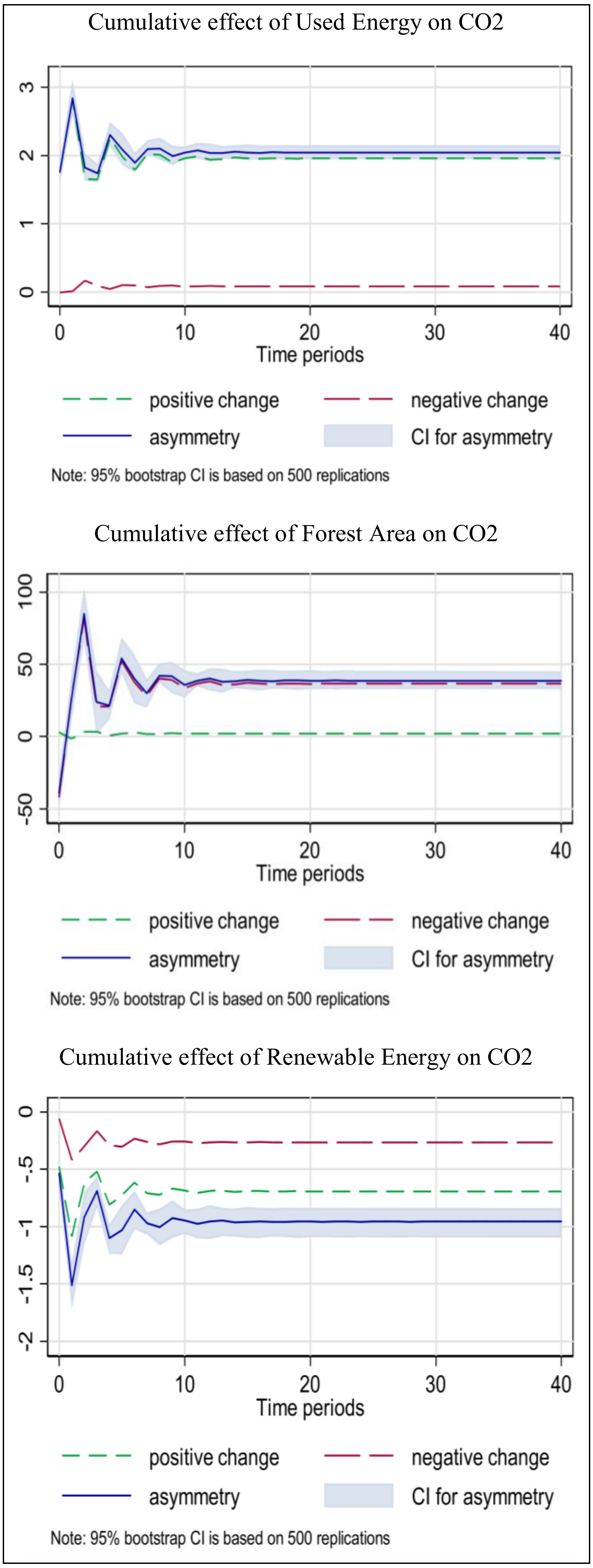

Fig. 1. The asymmetric dynamic relationships between the variables.

Table 6: Estimation of long and short run NARDL model

Variables	Coef,	Std, Err,	t	P>|t|	[95% Conf, Interval]	
			Long run model			
CE (-1)	-1,982	0,257	-7,710	0,000	-2,611	-1,353
UE (-1)$^+$	3,883	0,458	8,490	0,000	2,764	5,003
UE (-1)$^-$	-0,173	0,034	-5,110	0,002	-0,255	-0,090
FA (-1)$^+$	4,133	0,637	6,490	0,001	2,574	5,691
FA (-1)$^-$	-72,622	9,136	-7,950	0,000	-94,978	-50,266
RE (-1)$^+$	-1,371	0,158	-8,690	0,000	-1,758	-0,985
RE (-1)$^-$	0,525	0,107	4,930	0,003	0,264	0,786
			Short run model			
D (CE(-1))	0,517	0,137	3,780	0,009	0,182	0,851
D(UE)$^+$	1,768	0,164	10,770	0,000	1,367	2,170
D (UE(-1))$^+$	-0,233	0,252	-0,930	0,390	-0,851	0,384
D (UE)$^-$	0,008	0,003	2,970	0,025	0,001	0,014
D (UE(-1))$^-$	0,163	0,029	5,530	0,001	0,091	0,234
D (FA)$^+$	3,070	0,472	6,510	0,001	1,916	4,225
D (FA(-1))$^+$	-4,301	1,254	-3,430	0,014	-7,369	-1,232
D (FA)$^-$	42,004	11,439	3,670	0,010	14,013	69,995
D (FA(-1))$^-$	65,210	11,655	5,600	0,001	36,693	93,728
D (RE)$^+$	-0,479	93,728	-6,490	0,740	-0,659	-0,298
D (RE(-1))$^+$	0,059	0,080	0,740	0,489	-0,137	0,256
D (RE)$^-$	0,057	0,067	0,860	0,425	-0,106	0,221
D (RE(-1))$^-$	-0,079	0,022	-3,660	0,011	-0,132	-0,026
const	2,658	0,347	7,660	0,000	1,810	3,507

4 Discussion

The results presented in the previous section can be used for the analysis of energy use policies, renewable energy, and the protection of forest space in Morocco.

In addition, comparing the results of the previous literature with existing studies could help researchers understand whether asymmetry is important in modeling the link between used energy, renewable energy, and forest space.

The results show a non-linear cointegration between the variables (UE, FA, RE) and carbon emissions (CE). With regard to the asymmetric and symmetrical relationships between the variables, the results are quite diverse.

The results in Table 5 show evidence of an asymmetric long and short-term link between used energy, forest area, renewable energy, and carbon emissions.

Finally, the implementation of an energy conservation policy, substitution the energy sources by the renewable energy ones and protection of forest areas, will have a very significant impact on carbon emissions in Morocco.

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5 Conclusions

This article has analyzed the relationship used between energy, forest area, renewable energy, and carbon emissions in Morocco. To examine the short- and long-term relationships between variables, the nonlinear ARDL model (NARDL) procedure proposed by [13] was used.

To this end. The results of the NARDL estimation confirm the cointegration between the variables. This study was limited to Morocco. Future studies may explore the possible asymmetric relationship between energy consumption, economic growth, forest space, renewable energy, and carbon emissions from other global carbon dioxide emitters such as China, Russia, Germany, and the United States using a panel data approach.

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