INVESTIGATING THE NONLINEAR RELATIONSHIP BETWEEN SOCIAL DEVELOPMENT AND RENEWABLE ENERGY CONSUMPTION: A NONLINEAR AUTOREGRESSIVE DISTRIBUTED LAG (ARDL) BASED METHOD

Documents de travail GREDEG
GREDEG Working Papers Series

Rami Kacem
Abir Khribich
Damien Bazin

GREDEG WP No. 2024-07
https://ideas.repec.org/s/gre/wpaper.html

Investigating the Nonlinear Relationship between Social Development and Renewable Energy Consumption: A Nonlinear Autoregressive Distributed Lag (ARDL) Based Method

KACEM Rami B H.
Université de Carthage, Tunisia, LEGI, Tunisia Polytechnic School, Tunisie
ORCID ID: 0000-0002-2745-7014
rami.benhajkacem@ept.ucar.tn
&
KHRIBICH Abir
Université Côte d'Azur, CNRS, GREDEG, France
ORCID ID: 0000-0002-1651-6218
akhribich@gredeg.cnrs.fr
&
BAZIN Damien
Université Côte d'Azur, CNRS, GREDEG, France
ORCID ID: https://orcid.org/0000-0002-0020-5044
damien.bazin@gredeg.cnrs.fr

GREDEG Working Paper No. 2024-07

Abstract

The purpose of this paper is to explore how social development affects renewable energy consumption. The proposed methodology derives from the Social Development Index (SDI) which is calculated by aggregating several indicators associated with social well-being. In addition, the added value of this paper, compared to the literature, is to consider a possible non-linear relationship between social development and renewable energy consumption, based on the nonlinear Autoregressive Distributed Lag (ARDL) approach. Using Tunisian data for empirical validation, the proposed procedure provides original results. Indeed, it provides more details about the impact of increasing versus decreasing portions of social development on renewable energy consumption in the short and long run. Thus, it is found that renewable energy consumption is particularly sensitive to the decrease in social development. Indeed, according to our estimation and for the Tunisian case, a 1% decrease in social development leads to a decrease in renewable energy consumption by 3.235%. The proposed procedure merit to be validated for different cases and contexts.

Keywords: ARDL; Capabilities; Causality; Renewable energy; Social development; Tunisia.
JEL Classification: C20, Q20, Q28.

Investigating the Nonlinear Relationship between Social Development and Renewable Energy Consumption: A Nonlinear Autoregressive Distributed Lag (ARDL) Based Method

1. Introduction

Social development is a concept that encompasses education, health, interpersonal relationships, as well as a sense of belonging to a community. It is essential for individuals to feel capable and motivated to act [44, 45]. In this regard, it is therefore a valuable lever for combating climate change. Societies that promote social development thus create a fertile ground for citizen engagement and involvement in the fight against climate change, thereby contributing to a greener and more resilient future for all. Countries with a high level of social development create an environment conducive to citizen engagement in the fight against climate change.

The development of health, education, or access to the internet, for example, promotes the development of renewable energies. Indeed, citizens in good health are more likely to actively participate in ecological initiatives, while those with a strong social network and a good level of education tend to be better informed and engage more in sustainable practices [1, 23].

The disparity in access to renewable energy can be viewed through the lens of Sen's rich and poor man scenario [43]. Just as the rich man has the freedom to choose whether to eat, in developed countries, all communities would have the freedom to choose renewable energy sources over conventional ones. However, similar to the poor man who has no choice but to go hungry, many communities in developing countries lack the capability to access renewable energy due to economic, infrastructural, and educational barriers. The relationship between social development and renewable energy consumption may not be proportional or linear in developing countries. It is important to recognize that this relationship may be impacted by socio-economic barriers.
However, the relationship between social development and renewable energy utilization and its policy implications got negligible attention, especially in developing countries. A couple of studies were found discussing the causal relationship between renewable energy consumption and social development in Henan province of China, the OECD countries and European union member countries [1, 15, 23]. Besides, we hardly find any study discussing this relationship in

developing countries. Also, the direction of causality between social development and renewable energy use remained yet to be determined.

In many developing countries, the constraints on freedom of choice are not merely economic but are also shaped by the availability of infrastructure, knowledge, and supportive policies. Investigating how social development impacts renewable energy consumption in such contexts is crucial. It allows for a deeper understanding of where people generally might not have the freedom to opt for renewable energy due to various barriers.

Adding to this, the case of Tunisia presents an illustrative example where the dynamics between social development and renewable energy consumption could offer insights into broader trends across developing countries. This examination can reveal how advancements in social development might enable or hinder the adoption of renewable energy, reflecting on the necessity to build capabilities that allow for a genuine choice between renewable and conventional energy sources. Understanding these relationships is essential for crafting policies and initiatives that not only promote renewable energy adoption but also enhance the freedoms and capabilities of individuals and communities to make sustainable energy choices.

The remainder of the paper is organized as follows: Section 2 provides a literature review of the previous studies on the determinants of renewable energy consumption. In section 3, a description of the proposed methodology will be presented concerning the calculation method of the Social Development Index (SDI) and the used econometric methods. In section 4, empirical validation for the Tunisian case is provided along with exhaustive interpretation, while section 5 concludes with policy recommendations.

2. Literature review

Renewable energy sources have acquired great importance in many studies due to their cleanness and less negative environmental impact. The lion's share of the literature on energy consumption has focused on analyzing the impact of economic factors such as economic growth, financial development, trade openness, and CO_2 emissions, in order to understand the phenomenon and to contribute to its development [2, 4, 5, 8, 11, 13, 39, 62].

Environmental variables were subsequently studied to investigate the relationship between economic development and renewable energy consumption [27, 29, 32, 41]. Lin and Omoju

[27] studied fossil fuels, the regulatory framework, and renewable energy potential as the possible determinants of REC. Nyiwul [33] inserted the population to the determinants of REC. Recently, Yao *et al.* [60], Mehara*et al.,* [31] and Lee and Lee, [25] investigated human capital as a determinant of renewable energy consumption.

Later on, Li *et al.,* [26] supplied the existing literature by including energy productivity and eco-innovation among the major important factors in enhancing renewable energy consumption. Moreover, Alvarez-Herranz*et al.* [3] endorsed the idea of the nexus between renewable energy consumption and the investment in research and development.

In the last few years, the effects of political and institutional factors, such as democracy and corruption, on renewable energy have also received considerable attention. For instance, Cadoret and Padovano [10] considered corruption and lobbying by the manufacturing industry among the most important factors mitigating renewable energy deployment while Sequeira and Santos [46] investigated how democracy helps the economy's transition to renewable energy sources. In keeping with Uzar [56], who considered institutional quality as one of the determinants of renewable energy consumption.

Nevertheless, despite its importance, little attention has been paid in the literature to include social aspect in the study of renewable energy consumption. In addition, most of these studies are focused on the causality nexus running from renewable energy consumption to social development and not the opposite direction. In this context, the International Renewable Energy Agency (IRENA) [19] has analyzed the relationship between socio-economic benefits of renewable energy, covering aspects such as wider measures of welfare, ameliorated livelihoods, gender, and other benefits. Uzoma *et al.* [57] have investigated the social impacts of renewable energy in the South-East Zone of Nigeria.

For Steg *et al.* [49], a wide range of changes in household energy behavior are needed to achieve a sustainable energy transition. However, according to Rifkin [40], for this change to occur, humanity must first reflect on its consumption patterns and develop an awareness of its actions and their consequences.

To this end, the problems that can hinder the development of renewable energies are linked to a lack of information about their benefits. Thus, the social acceptability of renewable energies is among the barriers that have prevented their spread in the world. Several associative movements have formed to dissuade the development of certain projects, particularly wind energy, such as *Vent de Raison* (Belgium), *Vent de colère* (France), *Opzione 0* (Italy), *Stilhed* (Denmark), *etc.*[7, 28, 59].

The social hostility towards the development of renewable energies is sometimes explained by the phenomenon «*NIMBY*» («*Not In My Back Yard*») but for other authors, it has been strongly linked to an insufficient level of social development. For example, knowledge of the causes and consequences of climate change, as well as the impact of human behaviour on climate change, is not always accurate and there is still confusion about the processes that cause global warming [9, 58], so only about half of people know that if today's GHG level in the atmosphere were stabilized, the climate would still be warm for at least another 100 years [51]. For example, knowledge about climate change is higher among those with higher levels of education [51]. Similarly, people have a limited understanding of the severity of their behavior that contributes to climate change. For example, only a limited number of people know that heating and cooling homes contribute to global warming [9]. In general, people identify the causes of global warming more with other activities such as industry than with their own actions [58].

However, people who are well-informed about climate change and the causes of climate change are generally more worried about climate change [18, 50, 51]. In the same context, resistance to change, cultural reasons, unknown technologies or technologies considered unfamiliar and unnecessary, insufficient information, lack of local participation and preference for traditional energy are thus seen as social barriers to renewable energy consumption [34, 42]. Similarly, insufficient research and development institutions are an obstacle to the spread of renewable energy in a country because it can make it difficult to adapt the new technology [34].

To the best of the author's knowledge, empirical studies that investigate the impact of social development on renewable energy consumption are rare. Only Khribich *et al.* [23] have examined the bidirectional relationship between social development and renewable energy consumption for 27 high-income countries, based on Vector Error Correction Model (*VECM*). They found that social development significantly affects the renewable energy consumption only in the long run. Note that their procedure only considers the linear relationship and a possible non-liner relationship is totally neglected, which may give additional information and different interpretations and economic implications of results.

3. Data and methodology

3.1. Data and selected variables

The main purpose of this study is to investigate the causal relationship between renewable energy consumption and social development and to find the best modelling method considering linear and non-linear specifications. For empirical validation, we use Tunisian annual data gathered from the World Development Indicators (*WDI*) of the World Bank between 1990 to 2016. Details on the used data and their sources are provided in Table 1.

Table 1. Description of the raw variables.

Variable	**Definition**	**Source**
RE	Renewable energy consumption (% of total final energy consumption)	World Bank
GDP	Gross Domestic Product per capita	World Bank
SDI	Social development index	Authors

Thus, as a dependent variable, Renewable Energy consumption (*RE*) is measured as the share of renewable energy in total final energy consumption. The main explanatory variable is the Social Development Index (*SDI*), calculated following Khribich *et al*., (2021) [23], (see sub-section 4.2) and the Gross Domestic product *per capita* (*GDP*) as proxy of economic development.

3.2. *The Social Development Index*

Social development is seen as a concept that is not sufficiently conceptualized to make common sense for all. Perhaps, because it is a much broader concept which affects all facets related to the quality of life of citizens and aims to carry out development policies today that will positively influence the well-being of future generations [12].

Social development must therefore be seen as a multidimensional process that involves the reorganization and reorientation of the entire economic and social system, involving major changes in institutional, social and administrative structures, common attitudes, and even customs and beliefs [52]. Moreover, "Social development" means all approaches and ways of doing things that enable citizens to participate actively in society by improving their living conditions and by supporting the development of individual potentials and collective. In addition, social development aims to ensure that each individual can derive his or her fair share from collective enrichment. It is a development based on values of equity, integrity, openness, and solidarity" [12].

Social development may also be defined as: "a process that aims at the integration and participation of all individuals in development policies, for the World Bank this has two implications; the first is an improvement in the welfare of quality of life of all citizens and can be assimilated at the same time to human development (a good level of education and good health), the second involves social changes in norms and institutions to make development more equitable and inclusive for the whole of society, especially for the marginalized and the poorest" [14].

Thus, in order to measure social development, we have considered appropriate components, constrained by the availability of consistent time series data, which widens the scope of human wellness. The idea is thus to aggregate several indicators, related to demographics, education, health, consumption, IT and research, to calculate a social development index.

Note that the proposed procedure to calculate the SDI is based on the calculation principle of the "Human Development Index" (Union Nations [54]) and following previous works that have calculated a similar index in different contexts [20, 21, 22, 23, 24, 30, 48, 61]. Thus, seventeen proxies of social development are aggregated (*see* Table 2), using Eq. (1), in order to obtain the Social Development Index.

Table 2. The used social development proxies compared to the literature

Category	Indicator	Source
Demographic	-Population density (people per sq. km of land area)	[22] [23]
	-Urban population (% of total population)	[21] [22] [23] [24]
	-Life expectancy at birth total (years)	[22] [24] [30]
	-Adolescent fertility rate (births/1,000 women ages 15-19)	[23]
Education	-School enrolment secondary (% gross)	[20] [23] [24]
	-School enrolment tertiary (% gross)	[20] [22] [23] [24]
	-School enrolment secondary (gender parity index (GPI))	[20] [23] [24]
	-School enrolment tertiary (gender parity index (GPI))	[20] [22] [23] [24]
Health	-Infant survival rate per 1,000 live births	[21] [22] [23]
	-Physicians (per 1,000 people)	[23] [24]
	-Immunization. DPT (% of children ages 12-23 months)	[23] [30]
	-Immunization. Measles (% of children ages 12-23 months	[23]
Consumption	-Electric power consumption (kWh per capita)	[20] [22] [23]
	-Energy use (kg of oil equivalent per capita)	[22] [23]
	-Mobile cellular (telephone) subscriptions	[20] [23] [24]

IT and research	-Individuals using the internet (% of population)	[23]
	-Researchers in research & development (per million people)	[23]

The choice of each variable needs discussion. Indeed, the urban population (proportion compared to the total population) indicates the percentage of the total population with urban facilities and public services, including better sanitation, medical care and educational access, transport and communications, access to water supply *etc.*[20, 22, 23, 24].

Population density enhances the development of infrastructure and the implementation of living standards and stimulates both competition and the development of cooperative behaviour in a society, encouraging participation and entrepreneurship [23, 24, 61].

The infant survival rate per 1,000 live births is incorporated with the view that this indicates the quality of health and nutrition in the country and also reflects the degree of existence of contagious diseases in a country, as infants are more susceptible to these problems. Physician per thousand of population provides a general idea of the availability of health care in a country. [20, 22, 23, 24, 30].

Life expectancy at birth reveals the quality of health, nutrition, and income, and thus, this indicator is also well interconnected with many other indices of quality of life, such as salary and housing. A low figure usually shows there is a sizeable percentage of the population facing poor living conditions and there is a lack of proper health facilities in the country [22, 23, 30].

The electric power consumption (kWh/capita) and energy use (kg of oil equivalent/capita) indicate the access to acceptable living conditions and thus the level of modernization of society regarding the use of new technologies [20, 22, 23]. All variables related to education are also fundamentally classical indicators of social development [20, 22, 23, 24].

Also, we include in our index not used indicators by the previous sited works such as the proportion of individuals using the internet (% of the population)and the number of researchers in research and development (per million people), which are nowadays considered good indicators of a modernized society [21, 48].

Immunization against DPT and Measles are also incorporated that they give an indication of the health situation in the country.

The last variable selected is the adolescent fertility rate (births/1000 women ages 15-19). It is included to enrich the Social Development Index. Indeed, the adolescent fertility rate was considered as a progress indicator for the Millennium Development Goal target for achieving universal access to reproductive health. It is obvious that a high adolescent fertility rate means that many young women face an elevated risk of maternal death and disability (UN [53]; UNFPA [55]).

Thus let X_{kt} (*k=1,…,17*) be a key indicator of social development for Tunisia at year *t* (*t*=1990 to 2016), the Social Development Index for Tunisia at year *t* is calculated based on the following formula:

$$SDI_t = \frac{1}{17}\sum_{k=1}^{17}\frac{X_{kt}-Xmin_{kt}}{Xmax_{kt}-Xmin_{kt}} \qquad (1)$$

Where $Xmin_{kt}$ and $Xmax_{kt}$ are the minimum and the maximum values of the variable k for Tunisia at year *t*.

Thus, each variable that enters the index is normalized to be between *0* and *1* whatever the measurement unit.

Note that this aggregation method assumes that all introduced variables have the same direction of importance level, *i.e.*, the bigger the variable value, the better the situation is ($Xmax$ indicates a better situation than $Xmin$). This imposes some difficulties with the adolescent fertility rate variable, which declines within modernized society. For that, we have inversed its direction of importance level by considering the $Xmax$ as $Xmin$ and vis versa, to keep the information provided by the variable under the principle of the HDI aggregation methodology.

3.3. The econometric methodologies

In order to analyse the causality relationships between social development and renewable energy consumption, we propose to investigate tow possible specifications. The first is classical, based on the estimation of an ARDL Model as defined by Pesaran et Shin (1998) [35] and developed by Pesaran, Shin and Smith (2001) [37], and the second is nonlinear by estimating a non-linear ARDL model as proposed by Shin, Yu & Greenwood-Nimmo, (2014) [47]. Both approaches are suitable when using macroeconomic variables that are not integrated of same orders (*I(0)* or *I(1)*).

The classical procedure supposes that the relationship is linear [23]. Thus a linear ARDL model takes the following form:

$$\Delta RE_t=\alpha_0+\sum_{i=1}^{m}\alpha_{1i}\Delta RE_{t-1}+\sum_{i=1}^{p}\alpha_{2i}\,\Delta SDI_{t-i}+\sum_{i=1}^{q}\alpha_{3i}\,\Delta GDP_{t-i}+\beta_1 RE_{t-1}+\beta_2 SDI_{t-1}+\beta_3 GDP_{t-1}+\varepsilon_t \qquad (2)$$

Where

RE is the renewable energy consumption variable,

SDI is the Social Development Index,

GDP is the logarithm of Gross Domestic Product *per capita*.

ε_t is pure white noise error term.

Δ is the first difference operator. *m*, *p*, *q* are the lagged values of Δ.

Note that the long-run relationship between the variables is expressed by the coefficients $\alpha_{1i}, \ldots \alpha_{3i}$ whereas the coefficients $\beta_1 \ldots\ldots \beta_3$ express the short-term relationship between the independent variables and the dependent variable taking into consideration the *i* lagged level.

In addition, in order to investigate the long and the short-run dynamic relationships, we follow Pesaran *et al.,* [37] which proposed two steps based procedure. In the first step, the long-run parameters in Eq.1 are estimated to obtain the residuals corresponding to the deviation from equilibrium. In the second step, the parameters related to the short-run adjustment are estimated. The resulting equations employed in conjunction with Granger causality [17] testing are as follows:

$$\Delta \boldsymbol{RE_t} = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i} \Delta \mathrm{RE}_{t-1} + \sum_{i=1}^{q} \alpha_{2i} \Delta \mathrm{SDI}_{t-i} + \sum_{i=1}^{q} \alpha_{3i} \Delta GDP_{t-i} + \beta_1 \mathrm{RE}_{t-1} + \beta_2 \mathrm{SDI}_{t-1} + \beta_3 GDP_{t-1} + \theta \mathrm{ECT}_{t-1} + \varepsilon_t \qquad (3)$$

Where ECT_{t-1} is the error correction term obtained by estimating the long term cointegration based on Eq. (2).

The alternative procedure that we propose in this paper is to investigate an eventual nonlinear relationship between social development and renewable energy consumption.

Let *Y* a dependant variable explained by a given explanatory variable *X*. considering that the relationship between *X* and *Y* is nonlinear consists to derive asymmetric dynamic multipliers associated with unit changes in X^+ and X^- respectively on *Y*. Thus, *X* is decomposed into X^+ and X^- around a threshold of zero, thereby distinguishing between positive and negative changes in the rate of growth of *X*. The resulting partial sum processes maintain an intuitively appealing and economically meaningful interpretation in a wide range of applications.

Considering this modelling procedure, we propose to estimate a non-linear ARDL model which takes the following form:

$$\Delta RE_{\boldsymbol{t}} = \alpha_0 + \sum_{i=1}^{p-1} \alpha_{1i} \Delta \mathrm{RE}_{t-1} + \sum_{i=1}^{q-1} (\beta_1^- \Delta SDI_{t-1}^- + \beta_1^+ \Delta SDI_{t-1}^+ + \beta_2^- \Delta GDP_{t-1}^- + \beta_2^+ \Delta \mathrm{GDP}_{t-1}^+) + \gamma_0 RE_{t-1} + \gamma_1^- SDI_{t-1}^- + \gamma_1^+ SDI_{t-1}^+ + \gamma_2^- GDP_{t-1}^- + \gamma_2^+ GDP_{t-1}^+ + \varepsilon_t \qquad (4)$$

Where

$SDI^-, SDI^+, GDP^-, GDP^+,$ are the positive and negative asymmetries of independent variables in level.

$\Delta SDI^{-}, \Delta SDI^{+}, \Delta \text{GDP}^{-}, \Delta \text{GDP}^{+}$, are the positive and negative asymmetries of independent variables in first difference.

$\beta_1^-,\ \beta_2^-, \gamma_1^-, \gamma_2^-\ \beta_1^+,\ \beta_2^+, \gamma_1^+, \gamma_2^+$ are the positive and negative parameters of asymmetries.

ε_t is an id process with zero mean and constant variance.

In practice, the positive signal ($^+$) indicates the increasing portion of the explanatory variable and the negative signal ($^-$) is the decreasing portion of the explanatory variable. Thus, it will be possible to investigate the effect of the explanatory variable when it is increasing and/or decreasing separately, giving that more appropriate results if the investigated relationship is not linear.

Note that in order to estimate the linear and nonlinear ARDL models, it is mandatory to apply at first a unit root test for analysing the stationary of the series. For that, we use the Augmented Dickey–Fuller (ADF) (1981) [16] and the Phillips–Perron (PP) (1988) [38] tests.

Next, the existence of cointegration relationship between variables is examined by testing the significance of the lagged levels of variables using the computed F-statistic (Bound test) [36].

4. Results and discussion

Table 4 presents the results of the Augmented Dickey–Fuller (ADF) [16] and the Phillips–Perron (PP) [38] unit root tests which are applied to test the stationarity of the used series. We deduce that only the GDPc has a unit root in the level forms, and becomes stationary as a result of the first difference taking, indicating that it is integrated in order 1 (I(1)). Furthermore, RE, SDI and CO_2 are stationary and integrated of order I(0). Thus, given that the series have different orders of integration (0 and 1), the common practice in the literature is to estimate an ARDL model.

Table 3. Unit root test results.

	Level		First Difference	
	ADF	PP	ADF	PP
Renewable Energy (RE)	-3.589 (0.0308)	-19.271 (0.0293)	- -	- -
Social Development (SDI)	-7.240 (0.0000)	-8.145 (0.0000)	- -	- -
Gross Domestic Product per capita (GDP)	-0.438 (0.9857)	-2.604 (0.9775)	-4.258 (0.0037)	-21.836 (0.004)

Note: Values between parentheses are the P-values

For that, we continue our analysis by applying an ARDL bound test to select the optimal lag that minimize the Final Prediction Error criterion (FPE). Lags are selected according to the Akaike Information Criteria (AIC). The result leads to choosing the optimal lags: (1, 1, 1).
Following this, we test the existence of a cointegration relationship among the variables, using the bounds F-statistic developed by Pesaran *et al.* (2001) [37]. The results of the tests are reported in Table 4.

Table 4. Bounds cointegration test – linear and nonlinear ARDL

Critical values	**I(0) Bound**	**I(1) Bound**	**Linear ARDL**	**Nonlinear ARDL**
			F-statistic	
10%	3.17	4.14	3.702	11.277
5%	3.79	4.85		
2.5%	4.41	5.52		
1%	5.15	6.36		
			T-statistic	
10%	-2.57	-3.21	-3.31	-6.87
5%	-2.86	-3.53		
2.5%	-3.13	-3.80		
1%	-3.43	-4.10		

The computed F-statistic are equal to 3.702 and 11.277 for linear and nonlinear specifications respectively. Thus, we deduce that the F-statistic is higher than the upper bound critical values (4.85) at the 5% significance level only for nonlinear specification. Considering, the T-statistics, which should be less than the critical values, only the nonlinear ARDL shows a T-statistic value that leads to accepting the hypothesis of cointegrating relationship. This result suggests that there is a cointegration relationship considering nonlinear ARDL but not a linear one, which consolidate the need for using a nonlinear ARDL model to analyse the causal relationship between social development and renewable energy consumption instead of the classical ARDL model.

To consolidate this result, Table 5 provides common information criteria to compare quality of estimations of both ARDL models. Thus, given that the AIC and BIC values are lower for nonlinear ARDL specification, we deduce that results of nonlinear ARDL model is better than those considering a classical linear procedure of an ARDL approach.

Table 5: Information criteria for linear and nonlinear ARDL model

Model	AIC	BIC
Linear ARDL	-178.6	-171.1
Nonlinear ARDL	-203.3	-180.9

After identifying the cointegration relationship, we proceed to estimate the long-run and short-run relationships between variables based on the estimation of the nonlinear ARDL model as defined in Eq.(4). Results are presented in tables (6) and (7). Note that Table (6) presents the result of the regression of Eq. (4) while Table (7) presents the asymmetry statistics.

Table 6. Regression results of nonlinear ARDL model

Dependent Variable ΔRE			
Variables	Coefficient	T	P-value
y_{t-1}	-2.52	-6.87	0.001
$x1p_{t-1}$	0.039	0.76	0.482
$x1n_{t-1}$	8.15	5.82	0.002
$x2p_{t-1}$	0.093	2.21	0.078
$x2n_{t-1}$	0.318	4.52	0.06
Δy_{t-1}	0.712	2.88	0.034
$\Delta x1p$	0.058	1.03	0.352
$\Delta x1p_{t-1}$	-0.112	-1.54	0.184
$\Delta x1p_{t-2}$	-0.053	-0.81	0.456
$\Delta x1n$	0.634	0.29	0.781
$\Delta x1n_{t-1}$	1.904	1.22	0.276
$\Delta x1n_{t-2}$	0.231	0.14	0.891
$\Delta x2p$	0.075	2.01	0.008
$\Delta x2p_{t-1}$	0.146	4.32	0.135
$\Delta x2p_{t-2}$	0.084	2.08	0.093
$\Delta x2n$	0.020	0.53	0.619
Δx2nt-1	-0.292	-3.51	0.017
Δx2nt-1	-0.212	-2.67	0.044

Constant		0.322	6.91	0.001
Fisher	6.66			0.023
R^2	0.96			
$\overline{R^2}$	0.82			
Portmanteau test up to lag 10 (chi2)			10.88	0.3671
Breusch/Pagan heteroskedasticity test (chi2)			1.059	0.3035
Ramsey RESET test (F)			5.919	0.1479
Jarque-Bera test on normality (chi2)			2.511	0.2849

Table 7. Asymmetry statistics of nonlinear ARDL estimation result

Exog. var.	Long-run effect [+]			Long-run effect [-]		
	Coef.	F-stat	P>F	Coef.	F-stat	P>F
SDI	0.016	0.554	0.490	-3.235	55.24	0.001
GDPc	0.037	6.122	0.056	-0.126	43.96	0.001
	Long-run asymmetry			Short-run asymmetry		
		F-stat	P>F		F-stat	P>F
SDI		53.8	0.001		0.505	0.509
GDPc		13.7	0.014		22.13	0.005

The analysis of causality nexus is conduced based on the asymmetry statistics. Thus, results show that there is a significant asymmetry in the relationship between renewable energy consumption and social development (*p-value=0.001*) only in the long run. In addition, based on the significance of the positive versus negative long run effects, results show that renewable energy consumption is significantly influenced by the decrease of social development. Nevertheless, an increase in social development doesn't have significant effect on renewable energy consumption in Tunisia.

The proposed procedure and its result is thus original and important given that, on the one hand, it provides more details about the causal relationships between social development and renewable energy consumption compared to the literature. On the other hand, it shows the sensitivity of renewable energy consumption to the decrease of social development. Indeed, according to Table 7, a 1% decrease in social development leads to a decrease in renewable energy consumption by 3.235%.

5. Conclusion

The objective of this study was to empirically examine the short-term and long-term causal relationship between renewable energy consumption and social development considering a possible nonlinear association between them.
Thus, it is shown that a nonlinear ARDL model is more appropriate to analyse this kind of relationship. In addition, results show that there is an asymmetry of the effect of social development on renewable energy consumption in the long run. Thus, it is deduced that renewable energy consumption is significantly affected in the long run by the decrease in social development. Thus, this result consolidates the literature about the significance of the impact of social development on renewable energy consumption in the long run, but in addition, it provides original details about the kind of this relationship.

This study suggests that social development is a necessary but not sufficient condition for the adoption and use of renewable energy technologies. In other words, while social development is important for creating an enabling environment that supports the adoption and use of renewable energy technologies. For example, investing in education can help to promote awareness of the benefits of renewable energy and increase the skills and knowledge needed to install and maintain renewable energy systems [6, 44, 45]. Nevertheless, other factors may be necessary to drive actual consumption of renewable energy.

For example, policies and regulations that incentivize the adoption and use of renewable energy technologies, such as economic growth, financial development, trade openness and institutional conditions, may be necessary to drive actual consumption of renewable energy, even in the presence of high levels of social development. Similarly, technological advancements and improvements in the cost may be necessary to make them a more attractive option for Tunisian consumers, even in the presence of high levels of social development.

Overall, this result suggests that social development is an important factor in creating an enabling environment for the adoption and use of renewable energy technologies, but other factors may also be necessary to drive actual consumption of renewable energy. Further research is needed to explore the specific factors that drive renewable energy consumption and how they interact with social development in Tunisia.

References

[1] Abbas, K.; Butt, K. M.; Xu, D.; Baz, K.; Sheraz, M.; Kharl, S. H. Dynamic Prognostic Interaction between Social Development and Energy Consumption Optimization: Evidence from European Union Member Countries. Energy 2023, 278, 127791. https://doi.org/10.1016/j.energy.2023.127791.

[2] Akar, B.G., 2016. The Determinants of Renewable Energy Consumption: An Empirical Analysis For The Balkans, European Scientific Journal 12: 594–607. https://doi.org/10.19044/esj.2016.v12n11p594.

[3] Alvarez-Herranz, A., Balsalobre-Lorente, D., Shahbaz, M., Cantos, J.M, 2017.Energy innovation and renewable energy consumption in the correction of air pollution levels, Energy Policy 105: 386–397. https://doi.org/10.1016/j.enpol.2017.03.009.

[4] Anton, S.G.,Nucu, A. E. A., 2020. The Effect of Financial Development on Renewable Energy Consumption. A Panel Data Approach, Renewable Energy 147: 330–338, https://doi.org/10.1016/j.renene.2019.09.005.

[5] Apergis, N., Payne, J. E., 2010. Renewable Energy Consumption and Economic Growth: Evidence from a Panel of OECD Countries, Energy Policy 38: 656–660, https://doi.org/10.1016/j.enpol.2009.09.002.

[6] Ballet, J., Bazin, D., Dubois, J.-L., Mahieu, F.-R. 2011. A note on sustainability economics and the capability approach Ecol. Econ., 70: 1831-1834

[7] Bauwens, T., 2015. Propriété coopérative et acceptabilité sociale de l'éolien terrestre, Reflets et perspectives de la vie économique 1(Tome LIV): 59–70. https://doi.org/10.3917/rpve.541.0059.

[8] Ben Jebli, M., Ben Youssef, S., Ozturk, I., 2016. Testing Environmental Kuznets Curve Hypothesis: The Role of Renewable and Non-Renewable Energy Consumption and Trade in OECD Countries, Ecological Indicators 60 : 824–831, https://doi.org/10.1016/j.ecolind.2015.08.031.

[9] Bord, R. J.,O'Connor, R. E., Fisher, A.,2000. In what sense does the public need to understand global climate change?, Public Underst Sci 9: 205–218. https://doi.org/10.1088/0963-6625/9/3/301.

[10] Cadoret, I., Padovano, F., 2016. The political drivers of renewable energies policies, Energy Economics 56: 261–269. https://doi.org/10.1016/j.eneco.2016.03.003.

[11] Cherni, A.,Jouini, S. E.,2017. An ARDL Approach to the CO_2 Emissions, Renewable Energy and Economic Growth Nexus: Tunisian Evidence, International Journal of Hydrogen Energy 42: 29056-29066. https://doi.org/10.1016/j.ijhydene.2017.08.072.

[12] CLD de l'Erable, (2011), Politique de développement social. https://drive.google.com/file/d/1nj9zViZNkwxWdP5y5k3SLE29aKd-. [Accessed 20 October 2023].

[13] Çoban, S., Topcu, M., 2013. The Nexus between Financial Development and Energy Consumption in the EU: A Dynamic Panel Data Analysis, Energy Economics 39: 81–88.https://doi.org/10.1016/j.eneco.2013.04.001.

[14] Davis, G. 2002.A History of the Social Development Network in the World Bank 1973–2002, 78.https://documents1.worldbank.org/curated/en/806361468779696310/pdf/316180SDP0560H1of0SD0in0WB01public1.pdf [Accessed 25 December 2023]

[15] Deng, F., Li, H., Yang, M. *et al.* On the nonlinear relationship between energy consumption and economic and social development: evidence from Henan Province, China. *Environ Sci Pollut Res* **28**, 33192–33207 (2021). https://doi.org/10.1007/s11356-021-12623-4

[16] Dickey, D. A., Fuller, W. A.1981. Likelihood Ratio Statistics for AutoRegressive Time Series with a Unit Root, Econometrica, 49: 1057–1072.https://www.jstor.org/stable/1912517

[17] Granger, C. W. J. 1969. Investigating causal relations by econometric models and cross-spectral methods, Econometrica 37: 424–438 https://doi:10.2307/1912791.JSTOR1912791

[18] Guy, S., Kashima, Y., Walker, I., O'Neill, S. 2014. Investigating the effects of knowledge and ideology on climate change beliefs: Knowledge, ideology, and climate change beliefs, Eur. J. Soc. Psychol., 44:421–429. https://doi.org/10.1002/ejsp.2039.

[19] International Renewable Energy Agency (IRENA). 2014. Renewable Energy benefits: understanding the socio-economics, Mimeo.https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Nov/IRENA_Understanding_Socio_Economics_2017.pdf?la=en&hash=C430B7EF772BA0E631190A75F7243B992211F102 [Accessed 15 May 2023]

[20] Jamal, H., Khan, A. J.2002. Social development and economic growth: a statistical exploitation, Karachi: Social Policy and Development Center.

[21] Jean-Marie, B. 2001. De la pertinence de l'usage de l'internet dans les pays en voie de développement, Les Cahiers du numérique 281–297.https://www.cairn.info/revue-les-cahiers-du-numerique-2001-3-page-281.htm

[22] Kacem, R. H. 2014.Cointegration and causality between economic growth and social development in Saudi Arabia. Journal of Knowledge Management, Economics and Information Technology4: 1–15.http://www.scientificpapers.org/wp-content/files/1439_Rami_Ben_HajKacem_Cointegration_and_causality_between_economic_growth.pdf [Accessed 14 April 2023]

[23] Khribich, A., Kacem, R. H., Dakhlaoui, A.2021. Causality nexus of renewable energy consumption and social development: evidence from high-income countries, Renewable Energy, 169: 14–22. https://doi.org/10.1016/j.renene.2021.01.005.

[24] King, A. M. 1974 Economic growth and social development: a statistical investigation, Review of Income and Wealth 20: 251–72. https://doi.org/10.1111/j.1475-4991.1974.tb00922.x

[25] Lee, J.-W., Lee, H.2016. Human capital in the long run, Journal of Development Economics 122: 147–169. https://doi.org/10.1016/j.jdeveco.2016.05.006.

[26] Li, J., Zhang, X., Ali, S., Khan, Z. 2020. Eco-innovation and energy productivity: New determinants of renewable energy consumption, Journal of EnvironmentalManagement 271:111028. https://doi.org/10.1016/j.jenvman.2020.111028.

[27] Lin, B., Omoju, O. E. 2017. Does private investment in the transport sector mitigatethe environmental impact of urbanisation? Evidence from Asia, Journal ofCleaner Production 153: 331–341. https://doi.org/10.1016/j.jclepro.2017.01.064.

[28] Maillebouis, C.2003. Nimby ou la colère des lieux. Le cas des parcs éoliens Nimby or the angst of gods. The case of French projects for windmill, Nature Sciences Sociétés, 11: 190–194. https://doi.org/10.1016/S1240-1307(03)00050-5.

[29] Marques, A. C., J. A. Fuinhas, J. A., Pires Manso, J. R. 2011.Motivations driving renewable energy in European countries: A panel data approach, Energy Policy 38(11): 6877–6885. https://doi.org/10.1016/j.enpol.2010.07.003.

[30] Mazumdar, K. 1996. An Analysis of Causal Flow Between Social Development and Economic Growth: The Social Development Index, American Journal of Economics and Sociology 55: 361–83.https://doi.org/10.1111/j.1536-7150.1996.tb02323.x.

[31] Mehrara, M., Rezaei, S., Razi, D. H. 2015.Determinants of Renewable Energy Consumption among ECO Countries; Based on Bayesian Model Averaging and Weighted-Average Least Square, ILSHS 54: 96–109.
https://doi.org/10.18052/www.scipress.com/ILSHS.54.96.

[32] Nicolini, M., Tavoni, M. 2017.Are renewable energy subsidies effective? Evidence from Europe, Renewable and Sustainable Energy Reviews 74: 412–423.
https://doi.org/10.1016/j.rser.2016.12.032.

[33] L. Nyiwul, L. 2017. Economic performance, environmental concerns, and renewable energy consumption: drivers of renewable energy development in Sub-Sahara Africa, Clean Techn Environ Policy 19(2): 437–450.
https://doi.org/10.1007/s10098-016-1229-5.

[34] Painuly, J.P. 2001. Barriers to renewable energy penetration; a framework for analysis, Renewable Energy, 24: 73–89.
https://doi.org/10.1016/S0960-1481(00)00186-5.

[35] Pesaran, M. H., Shin, Y., Smith, R. J. 1996. Testing for existence of a long-run relationship, Department of Applied Economics Working Paper 9622, University of Cambridge. https://doi.org/10.1016/S0304-4076(03)00092-7

[36] Pesaran, M. H., Shin, Y. 1998. An Autoregressive Distributed-Lag Modelling Approach to Cointegration Analysis, Econometrics and Economic Theory in the 20th Century : The Ragnar Frisch Centennial Symposium 31: 371–413 http://dx.doi.org/10.1017/CCOL0521633230.011.

[37] Pesaran, M. H., Shin, Y., Smith, R. J. Bounds Testing Approaches to the Analysis of Level Relationships, Journal of Applied Econometrics 16: 289–326.https://www.jstor.org/stable/2678547.

[38] Phillips P.C.B.,Perron, P. 1988. Testing for a Unit Root in Time Series Regression, Biometrika 75: 335–346.https://doi.org/10.1093/biomet/75.2.335

[39] Razmi, S. F., Bajgiran, B. R., Behname, M.,Salari, T. E., Razmi, S. M. J.2020. The Relationship of Renewable Energy Consumption to Stock Market Development and Economic Growth in Iran, Renewable Energy 145: 2019–2024.
https://doi.org/10.1016/j.renene.2019.06.166.

[40] Rifkin, J. 2000. L'âge de l'accès, La révolution de la nouvelle économie, Paris, Edit. La Découverte.

[41] Romano, A. A., Scandurra, G., Carfora, A., Fodor, M. 2016.Renewable investments: The impact of green policies in developing and developed countries, Renewable and Sustainable Energy Reviews 68: 738–747.
https://doi.org/10.1016/j.rser.2016.10.024.

[42] Rosso-Cerón, A.M., Kafarov, V.2015. Barriers to social acceptance of renewable energy systems in Colombia, Current Opinion in Chemical Engineering 10: 103–110. https://doi.org/10.1016/j.coche.2015.08.003.

[43] Sen, A. (1982). *Poverty and famines: an essay on entitlement and deprivation*. Oxford university press

[44] Sen, A K. 1993. Capability and Well-being in: Nussbaum and Sen (eds). 31–53.

[45] Sen, A K. 1994. Well-being, capability and public policy. Giornale degli economisti eannali di economia 7;9 : 333–348

[46] Sequeira, T. N., Santos, M. S.2018. Renewable energy and politics: A systematic review and new evidence, Journal of Cleaner Production 192: 553–568.
https://doi.org/10.1016/j.jclepro.2018.04.190.

[47] Shin, Y., Yu, B. and Greenwood-Nimmo, M., 2011. Modelling Asymmetric Cointegration and Dynamic Multiplier in a Nonlinear ARDL Framework. Mimeo, New York, NY. http://dx.doi.org/10.2139/ssrn.1807745

[48] Somekh, B. 1995. The Contribution of Action Research to Development in Social Endeavours: A Position Paper on Action Research Methodology, British Educational Research Journal 21: 339–55. https://doi.org/10.1080/0141192950210307.

[49] Steg, L., Lindenberg, P., Keizer, K. 2016.Intrinsic Motivation, Norms and Environmental Behaviour: The Dynamics of Overarching Goals, IRERE, 9: 179–207.https://doi.org/10.1561/101.00000077.

[50] Sundblad, E.-L., Biel, A., Gärling, T.2009. Knowledge and Confidence in Knowledge About Climate Change Among Experts, Journalists, Politicians, and Laypersons, Environment and Behavior, 41: 281–302. https://doi.org/10.1177/0013916508314998.

[51] Tobler, C., Visschers, V. H. M., Siegrist, M. 2012. Consumers' knowledge about climate change, Climatic Change, 114:189–209. https://doi.org/10.1007/s10584-011-0393-1.

[52] M. P.Todaro , Economic Development, London: Longman, 6th ed.,1997.

[53] United Nations. 2008. World Fertility Patterns 2007. Wallchart. New York.

[54] Union Nations Development Program (UNDP). 1990. Human Development Report, New York, UN.http://www.hdr.undp.org/en/reports/global/hdr1990.

[55] United Nations Population Fund (UNFPA). 2010. How Universal is Access to Reproductive Health? A review of the evidence.https://unfpa.org/sites/default/files/pub-pdf/universal_rh.pdf. [Accessed 12 March 2023].

[56] Uzar, U. 2020. Political economy of renewable energy: Does institutional quality make a difference in renewable energy consumption?, Renewable Energy 155: 591–603. https://doi.org/10.1016/j.renene.2020.03.172.

[57] Uzoma, C.C., Ibeto, C.N., Okpara, C.G., Nwoke, O.O., Obi, I.O., Nnaji, C.E., Oparaku, O.U., Unachukwu, G.O. Social Impacts of RenewableEnergy on the South-East Zone of Nigeria. Proceedings of the 2ndProceedings of the 2nd Int'l W/Shop on Renewable Energy for Sustainable Dev. In Africa, IWRESDA '10,27th to 29th July, 2010.

[58] Whitmarsh, L., Seyfang, G.,O'Neill, S. 2011. Public engagement with carbon and climate change: To what extent is the public "carbon capable"?, Global Environmental Change, 21: 56–65. https://doi.org/10.1016/j.gloenvcha.2010.07.011.

[59] Wüstenhagen, R., Wolsink, M., Bürer, M. J. 2007 Social acceptance of renewable energy innovation: An introduction to the concept, Energy Policy, 35: 2683–2691. https://doi.org/10.1016/j.enpol.2006.12.001.

[60] Yao, Y., Ivanovski, K., Inekwe, J., Smyth, R.2019. Human capital and energy consumption: Evidence from OECD countries, Energy Economics 84: 104534. https://doi.org/10.1016/j.eneco.2019.104534.

[61] Yegorov, Y.A. 2009. Socio-economic influences of population density, Chinese Business Review 8: 1–47. https://www.davidpublisher.com/Public/uploads/Contribute/5564250c80e80.pdf

[62] Zeren, F.,Akkuş, H. T. 2020. The Relationship between Renewable Energy Consumption and Trade Openness: New Evidence from Emerging Economies, Renewable Energy 147: 322–329. https://doi.org/10.1016/j.renene.2019.09.006.

Appendix.

Table.6 Serial correlation LM test

Breush-Gofrey serial correlation LM test	
Prob.chi2	0.2298

Note: H0: There is no serial correlation between errors

Table.7 heteroscedasticity White test

White test	
Prob.chi2	0.4076

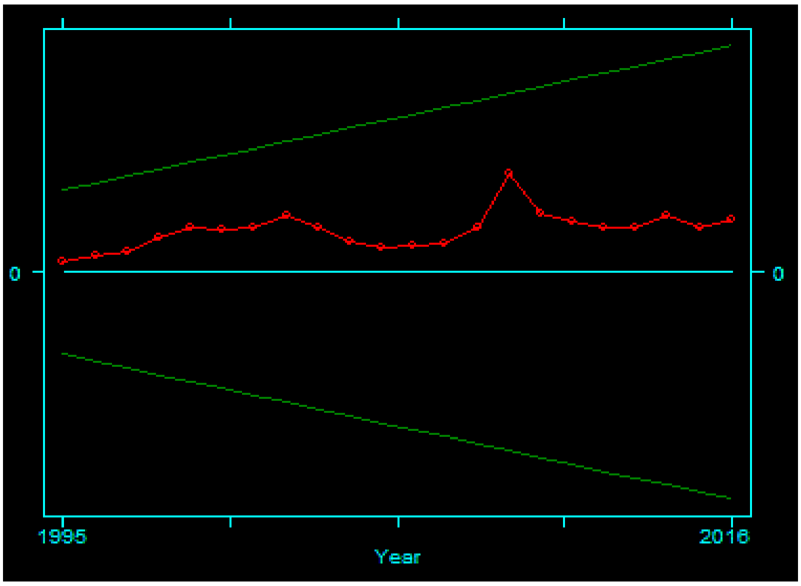
Note: H0: the variances for the errors are equal.

Table 8. Normality test

	Statistic	P
Skewness	1.86	0.9324
Kurtosis	0.69	0.4056

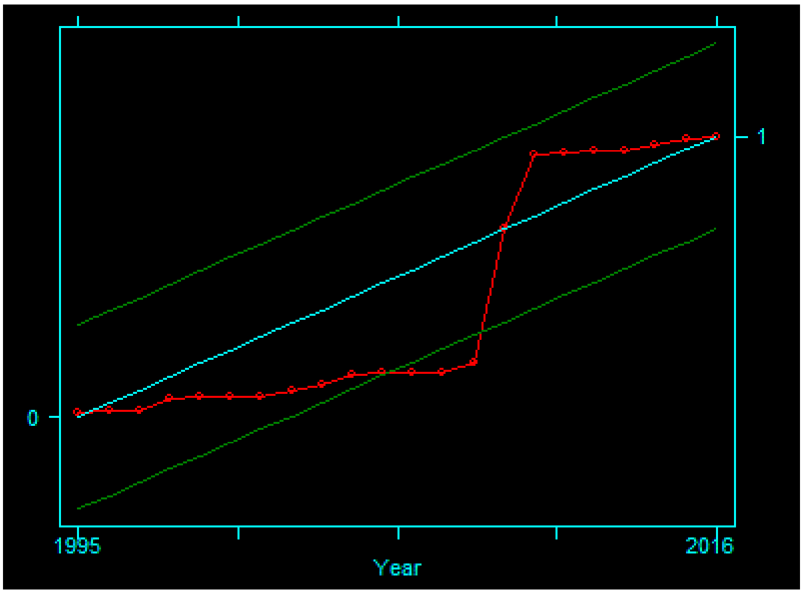
Note: H0: The data is normally distributed.

Figure1. CUSUM test



Note: The CUSUMQ curve is reported to be outside the interval for three years (fig.2). We have introduced a correction term in the model to correct this effect. However, this correction term appeared to be statistically insignificant. For this, we finally consider that the model we have estimated is stable.

Figure1. CUSUMQ test



Note: This result indicates that coefficients are stable over the study period and the model is valid.

DOCUMENTS DE TRAVAIL GREDEG PARUS EN 2024

GREDEG Working Papers Released in 2024

2024-01	Davide Antonioli, Alberto Marzucchi, Francesco Rentocchini & Simone Vannuccini *Robot Adoption and Product Innovation*
2024-02	Frédéric Marty *Valorisation des droits audiovisuels du football et équilibre économique des clubs professionnels : impacts d'une concurrence croissante inter-sports et intra-sport pour la Ligue 1 de football*
2024-03	Mathieu Chevrier, Brice Corgnet, Eric Guerci & Julie Rosaz *Algorithm Credulity: Human and Algorithmic Advice in Prediction Experiments*
2024-04	Mathieu Chevrier & Vincent Teixeira *Algorithm Control and Responsibility: Shifting Blame to the User?*
2024-05	Maxime Menuet *Natural Resources, Civil Conflicts, and Economic Growth*
2024-06	Harald Hagemann *Hayek's Austrian Theory of the Business Cycle*
2024-07	Rami Kacem, Abir Khribich & Damien Bazin *Investigating the Nonlinear Relationship between Social Development and Renewable Energy Consumption: A Nonlinear Autoregressive Distributed Lag (ARDL) Based Method*