Science of Law, 2026, No. 1, pp. 7-14
DOI: 10.55284/n03hr372

Exploring the Nonlinear Relationship between Renewable Energy Consumption and Green Economic Growth Across Income Groups: Evidence from PSTAR Model

Nouha Hadj Mansour

University of Sousse Faculty of Economic Sciences and Management of Sousse, Tunisia.

Keywords:
CO_2 emissions,
Green economic growth,
Renewable energy,
PSTAR model,
SDGs.

Abstract. The transition to a sustainable energy system is imperative given the escalating concerns over fossil fuel dependency, energy security, and the pursuit of sustainable economic growth. This study investigates the nonlinear relationship between renewable energy consumption and economic growth across 61 countries, categorized into high-, middle-, and low-income economies, over the period 1990-2020. Using the Panel Smooth Transition Auto-Regressive (PSTAR) model, the results indicate that the impact of renewable energy consumption on green economic growth is conditional on a threshold value of 3.883. Below this threshold, renewable energy consumption negatively affects economic growth, whereas above it, it becomes a significant driver of economic expansion. Furthermore, the transition from a low to a high renewable energy consumption regime is abrupt, as indicated by the gamma transition parameter of 2.592. These findings hold significant policy implications, suggesting the need for tailored energy policies that facilitate the transition to higher renewable energy consumption levels to achieve sustainable economic growth. The study provides concrete policy recommendations based on empirical insights.

1. INTRODUCTION

Energy consumption plays a pivotal role in economic development, yet its environmental ramifications necessitate a transition toward sustainable alternatives. Traditional energy sources, primarily fossil fuels, have been the dominant driver of industrialization and economic growth. However, their extensive use has led to environmental degradation, exacerbated by greenhouse gas emissions (Inglesi-Lotz, 2016). Technological advancements and policy shifts have paved the way for the integration of renewable energy, which offers a cleaner, sustainable alternative (Souhail et al., 2021).

The global energy landscape has witnessed substantial transformations. The World and China Energy Outlook 2050 (2019) predicts that clean energy will gradually replace coal, reaching a 56% share by 2050 (He et al., 2021; Rahman et al., 2021). Despite these efforts, the question remains: does renewable energy consumption contribute to economic growth, and if so, is the relationship linear or nonlinear? Previous studies have presented mixed findings. While some researchers argue that renewable energy consumption fosters economic growth through technological innovations, job creation, and energy security (Apergis & Salim, 2015; Khan et al., 2020; Topcu & Tugcu, 2020), others suggest that high initial investment costs and inefficiencies in renewable energy technologies may hinder economic expansion, particularly in developing countries (Shahbaz et al., 2020; Maji et al., 2019).

This study seeks to examine the nonlinear dynamics between renewable energy consumption and economic growth across different income-level countries. By applying the PSTAR model, we investigate whether renewable energy consumption has heterogeneous effects on economic growth at different consumption thresholds. Specifically, the study aims to answer the following research question: How does the nonlinear relationship between renewable energy consumption and economic growth vary across countries with different income levels?

Despite the growing body of research on renewable energy and economic growth, the literature remains inconclusive regarding the nature of this relationship. Most studies have relied on linear models, which may fail to capture the complex and dynamic interaction between renewable energy consumption and economic performance. This study aims to fill this gap by employing a nonlinear framework, specifically the PSTAR model, to analyze whether the impact of renewable energy consumption on economic growth varies across different income levels and thresholds.

Our contributions to the literature are as follows: Firstly, unlike previous studies that assume a linear relationship, we employ a nonlinear approach to examine the threshold effects of renewable energy consumption on economic growth. Secondly, we differentiate between High, Middle, and Low-Income countries, recognizing that the impact of renewable energy consumption may vary depending on economic development levels. Finally, our findings offer valuable policy implications by identifying the threshold beyond which renewable energy consumption becomes a significant driver of economic growth.

By addressing these gaps, this study provides a more comprehensive understanding of the renewable energy-economic growth nexus and offers practical recommendations for policymakers seeking to balance economic and environmental priorities.

The paper is structured as follows: Section 2 presents a review of the existing literature. Section 3 outlines the data and methodology. Section 4 discusses the empirical findings. Section 5 concludes the study and provides policy recommendations.

2. LITERATURE REVIEW

The relationship between renewable energy consumption and economic growth has been widely debated in academic literature. Some studies suggest a positive impact, while others highlight adverse effects or nonlinear associations, often contingent on external factors such as technological progress, investment capacity, and policy frameworks.

2.1. Positive Impact of Renewable Energy on Economic Growth

Several scholars argue that renewable energy consumption fosters economic growth. Khan et al. (2020) assert that integrating renewable energy enhances economic performance by reducing dependency on fossil fuels and stimulating technological advancements. Similarly, Topcu and Tugcu (2020) highlight the role of renewable energy in job creation and economic diversification, emphasizing its potential to reduce unemployment. Apergis and Salim (2015) further suggest that renewable energy investments contribute to industrial expansion and technological innovation, positively affecting long-term economic growth.

Empirical studies have corroborated these claims. Zafar et al. (2020) demonstrate that reducing fossil fuel reliance enhances GDP growth, while Odhiambo (2009) and Naseri et al. (2016) confirm the energy-growth nexus in various economies. Zrelli (2017), analyzing Mediterranean countries, finds a bidirectional causal relationship between renewable energy consumption and economic growth, underscoring its role as a fundamental driver of development.

2.2. Negative or Nonlinear Effects of Renewable Energy on Economic Growth

Conversely, some studies argue that renewable energy consumption may impede economic growth, particularly in the short run. The high investment costs and technological limitations associated with renewable energy transition often pose economic constraints (Shahbaz et al., 2020). Maji et al. (2019) contend that the shift toward renewable energy reduces total factor productivity, thereby slowing economic expansion. Similarly, Han et al. (2020) argue that renewable energy adoption lowers corporate profitability, making it less attractive for businesses.

Bhattacharya et al. (2016) provide empirical evidence from the U.S., Ukraine, and India, indicating that renewable energy consumption negatively affects economic development due to high transition costs. Ocal and Aslan (2013) also find inconsistencies in the energy-growth relationship, suggesting that economic structures and technological capacities influence the impact of renewable energy adoption. Qi and Li (2017) highlight China's challenges in renewable energy expansion, citing high operational costs and limited technological advantages as barriers to sustained economic growth.

2.3. Nonlinear Perspectives and the PSTAR Model

Given the mixed findings, recent research has emphasized the importance of nonlinear modeling in examining the energy-growth relationship. Studies employing threshold models indicate that the impact of renewable energy varies depending on consumption levels. Our study builds on this approach by employing the PSTAR model to assess whether renewable energy consumption exhibits distinct effects on economic growth at different thresholds.

The findings of this research contribute to the ongoing debate by demonstrating that renewable energy consumption initially exerts a negative impact on economic growth but becomes a positive driver once a critical threshold is surpassed. This aligns with previous studies emphasizing the importance of policy interventions to facilitate a smooth transition toward higher renewable energy consumption (Bayar et al., 2019; Carley et al., 2020).

Thus, the following hypothesis is put in this study:

Hypothesis (1): the RE at lower and higher levels impacts EAMFP differently

The majority of the findings, which draw on earlier research examining the linear causal relationship between renewable energy and economic growth, indicate a range of inconsistent and non-stable impacts over the course of the study. This study contributes by employing the nonlinear techniques, namely PSTAR model, to conduct a series of empirical assessments of the nonlinear effects of renewable energy use on economic growth. It is crucial to use the PSTAR approach to determine if the transition from one weak regime to another strong regime is abrupt or smooth if the authors demonstrate that such a connection is nonlinear.

3. DATA AND METHODOLOGY

The purpose of this study is to examine the impact of RE on EAMFP using threshold panel data models. According to Fehri et al. (2024) and Ashfaq et al.(2024) , our model is presented as follows:

$$LnEAMFP_{it} = \beta_0 + \beta_1 LnGFCF_{it} + \beta_2 LnPOP_{it} + \beta_3 LnRE_{it} + \beta_4 LnCO2_{it} + \beta_5 LnTRADE_{it} + \beta_6 LnFDI_{it} + \varepsilon_t \quad (1)$$

The definition of attributes and the sources are presented in Table 1.

Table 1. Definition of variables.

Variable	Designation	Source
EAMFP	Environmental Adjusted Multifactor Productivity	OECD
GFCF	Gross fixed capital formation (% of GDP)	WDI
POP	Labor force, total	WDI
RE	Renewable energy consumption (% of total final energy consumption)	WDI
CO2	CO2 emissions (kt)	WDI
TRADE	Terms of Trade	WDI
FDI	Foreign direct investment, net inflow (% of GDP)	WDI

This study highlights the importance of considering the determinants of the non-linear relationship between renewable energy and green economic growth. By assessing macroeconomic

factors.

We will also seek to determine whether thresholds are characterizing the relationship between RE and EAMFP in 61 countries for different incomes between 1990 and 2020. The Panel Threshold Auto-Regressive (PTAR) model was established by Hansen

(1999). The Figure 1 summarize the empirical framework in this research.

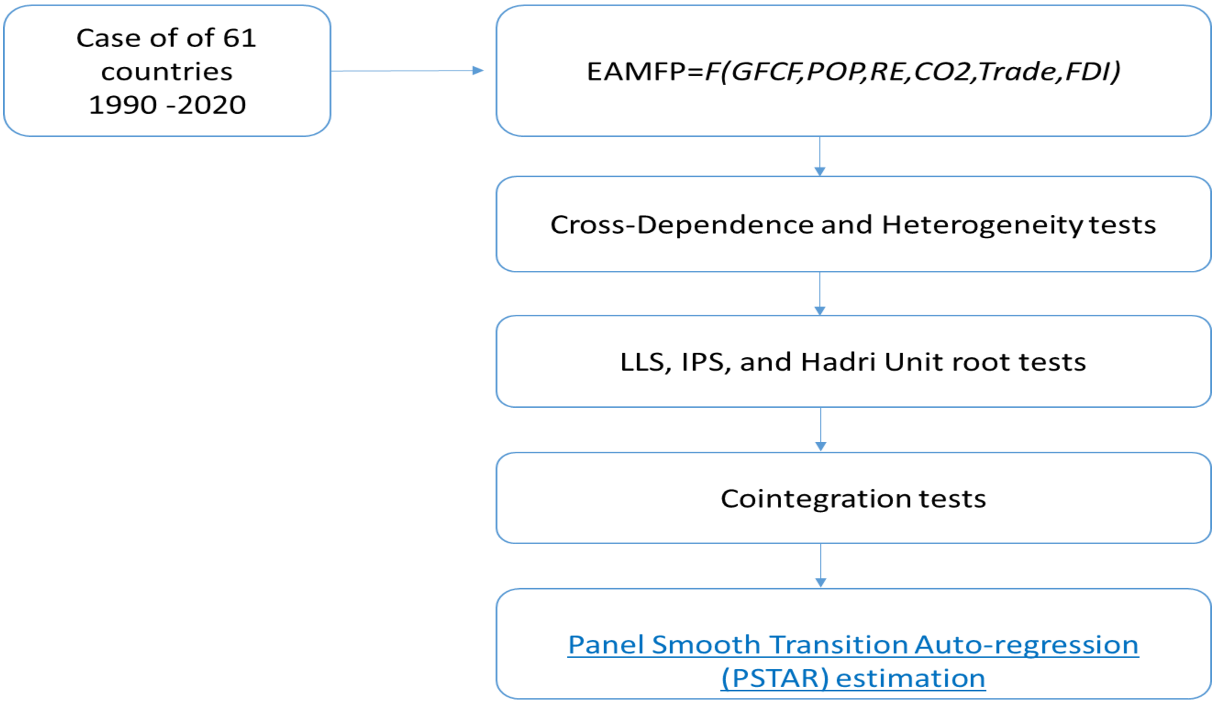

Figure 1. Empirical framework.

Using this model, the endogenous variable y_{it} depends on several different non-dynamic relationships. Consequently, the process $y_{it}, t \in Z, i \in Z$ (Equation 1) satisfies a two-regime PTAR model only if:

$$y_{it} = \mu_i + \sum_{j=1}^{p} \rho_j \, y_{\mathrm{it-j}} + \beta_1' X_{it} + \beta_2' X_{it} I(q_{it} > c) + \varepsilon_{it} \tag{2}$$

where μ_i is the vector of individual fixed coefficients, ρ_j is the autoregressive coefficients of the process y_{it} , $I(q_{it} > c)$ denotes the indicator function concerning the transition variable q_{it} and the threshold parameter c, $X_{it} = (X_{it}^1, \dots, X_{it}^k)$ is the matrix of k exogenous variables that do not contain lagged explanatory variables, $\beta = (\beta_1, \dots, \beta_k)$ and $\varepsilon_{it} \sim N(0, \sigma^2)$.

For their part, González et al. (2005) proposed to reinforce the PTAR model by creating a model called PSTAR. The purpose of this model is to move from a fast transition approach to a smooth transition approach in the case of time series. Thus, the process $y_{it}, t \in Z, i \in Z$, conforms to a two-regime PSTAR model (Equation 3) if and only if:

$$y_{it} = \mu_i + \sum_{j=1}^{p} \rho_j \, y_{\mathrm{it-j}} + \beta_1' X_{it} + \beta_2' X_{it} G(q_{it}; \gamma, c) + \varepsilon_{it} \tag{3}$$

where $G(q_{it}; \gamma, c)$ signifies the transition function for the transition variable q_{it}, the threshold parameter c, and the smoothing coefficient γ.

As a preliminary step, it is crucial to estimate the PSTAR model and check for linearity, specifically the existence of a statistically significant regime-switching effect. González et al. (2017) outlined a procedure to test the null hypothesis of linearity ($H_0: \beta_2{}' = 0$, equivalent to $H_0: \gamma = 0$) in the context of a PSTAR model. It is possible to apply the Wald, Fisher, and LR tests, where the corresponding statistics for each (specified in Equation 4) are as follows:

$$LM_w = \frac{TN(RSS_0 - RSS_1)}{RSS_0}; \; LM_F = \frac{TN(RSS_0 - RSS_1)/K}{RSS_0/(TN-N-K)}; \; LR = -2[log(RSS_0) - log(RSS_1)] \tag{4}$$

where RSS_0 and RSS_1 are the panel residual sum of squares. Under the null hypothesis, the Wald LM_w, LR statistics are calculated according to a chi-squared distribution with K degrees of freedom, representing the number of variables; and the LM_F statistics follow a chi-squared distribution.

4. EMPIRICAL RESULTS

In what follows, we show the relative descriptive statistics of the different variables changed into a logarithm (see Table 2). By using the Jarque & Bera (1987) normality test and the Born & Breitung (2016) serial autocorrelation test, the null hypothesis of these two tests is rejected.

Table 2. Retrieval of the various descriptive statistics of the series.

Designation	ln_EAMFP	ln_POP	ln_GFCF	ln_TRADE	ln_RE	ln_CO2	ln_FDI
Mean	7.343	15.331	3.434	4.053	3.492	-0.288	0.342
SD	1.092	1.893	0.534	0.534	1.136	1.363	1.469
Min	4.732	10.337	-1.229	-0.243	-2.813	-3.894	-8.948
Max	9.590	20.500	4.538	5.395	4.588	2.149	3.835
Skewness	-0.118	0.021	-1.730	-1.357	-1.903	-0.428	-1.738
Kurtosis	2.132	3.434	13.028	11.697	7.678	2.327	8.364
JarqueBera (JB)	63.66	15.01	8866	6540	2866	93.26	3219
Probabilité JB	1.5e-14	5.5e-04	0.000	0.000	0.000	5.6e-21	0.000
Born-Breitung (BB)	106.79	186.30	28.28	14.82	27.21	39.94	46.58
Probabilité BB	0.000	0.000	0.000	0.001	0.000	0.000	0.000
CV	0.149	0.124	0.136	0.136	0.325	-4.729	4.295
Observations	1891	1891	1891	1891	1891	1891	1891

Note: JB refers to the Jarque & Bera (1987) normality test. BB refers to Born & Breitung (2016). SD represents the standard deviation. All variables are in natural logs.

Following globalization, cross-sectional dependence may be within and among nations (De Hoyos & Sarafidis, 2006; Bilgili et al., 2017; Dong et al., 2018; Shahbaz et al., 2018). In addition, the unit root and panel cointegration tests are greatly skewed if the cross-sectional dependence is not taken into account (O'Connell, 1998; Atasoy, 2017; Pesaran, 2021).

Table 3. Cross-dependence and heterogeneity tests.

Tests	Valeur	Probabilité
Pesaran	63.955	0.000
Frees	12.728	0.000
Friedman	539.902	0.000

Therefore, the tests suggested by Friedman (1937), Breusch & Pagan (1980), Frees (1995), Pesaran (2004), Pesaran (2006), Peseran (2015), and Pesaran et al. (2008) are used to test cross-sectional dependence. These tests were crucial in identifying how frequently shocks occurred in the cross-sectional portion of the data set. Regarding Table 3, the result indicates a breakdown to reject the cross-sectional independent null hypothesis. In addition, the second panel in Table 3 tests the hypothesis of homogeneity proposed by Pesaran & Yamagata (2008). The results of the homogeneity test reveal that the two statistics indicate statistically significant probability values at the 1% level, leading us to accept the alternative hypothesis of heterogeneous coefficients.

Due to the presence of cross-sectional dependency and heterogeneity, we employ Pesaran (2003) and Pesaran (2007) second-generation unit root tests. Table 4 shows that all series show the presence of unit roots in level (rejection H0). As a result, we can assume that all of the series are integrated into order 1. As a result, we must investigate the cointegration relationship between variables using the first-generation tests of Kao (1999) and Pedroni (2004), as well as a second-generation test of Persyn & Westerlund (2008). See Table 5.

Table 4. Results of the second generation of unit root test.

Variables	In level			In first difference		
	LLC	IPS	Hadri	LLC	IPS	Hadri
ln_EAMFP	-2.933*** (0.001)	4.517 (1.000)	130.885 (0.000)	-14.514*** (0.000)	-19.795*** (0.000)	-0.269 (0.606)
ln_EMPLOY	-9.382*** (0.000)	-2.630 (0.004)	146.109* (0.000)	0.1313** (0.552)	-4.8739*** (0.000)	17.173 (0.000)
ln_GFCF	-5.298*** (0.000)	-3.738 (0.000)	52.520 (0.0000)	-19.360*** (0.000)	-23.0376*** (0.000)	-4.2088*** (1.000)
ln_TRADE	-2.050** (0.020)	-1.787* (0.037)	62.400 (0.000)	-18.040*** (0.000)	-22.750*** (0.000)	1.495 (0.067)
ln_RE	0.519 (0.698)	4.7627 (1.000)	113.465 (0.000)	-18.080*** (0.000)	-22.488*** (0.000)	3.378 (0.000)
ln_CO2	-3.130*** (0.000)	2.189 (0.985)	117.937 (0.000)	-17.764*** (0.000)	-23.398*** (0.000)	-1.763 (0.961)
ln_FDI	-18.583*** (0.000)	-12.727*** (0.000)	42.235 (0.000)	-25.301*** (0.000)	-27.045*** (0.000)	-5.603*** (1.000)

Note: ***, **, * represent the significance at 1%, 5%, and 10%; C: Constant; T: Trend; NS: Non-Stationary; S: Stationary; All variables are in natural logs.

Table 5. Results of cointegration tests.

	Tests	p-value			Decision
First generation	Kao (1999)	0.03			Cointegration
	Pedroni (2004)	0.02			Cointegration
Second generation	Persyn & Westerlund (2008)	Value	p-value	Robust p-value	Decision
	G_t	-1.413	1.00	0.00	Cointegration
	G_a	-0.426	1.00	0.00	Cointegration
	P_t	-5.528	1.00	0.00	Cointegration
	P_a	-0.353	1.00	0.00	Cointegration

We begin by checking for the presence of a non-linear effect of renewable energy on economic growth for this selected panel of countries. For the linearity test, we check whether the order "m" is equal to one or not. The results of the specification test are presented in Table (6). Indeed, the table shows that the p-value of the Lagrange Multiplier (LM) test and the likelihood test (LR) for the null hypothesis of linearity compared to the alternative of the logistic PSTAR specification (m = 1). We find that the null hypothesis of linearity is rejected at the 1% significance level. Moreover, the rejection of linearity is stronger by the logistic specification (m = 1). The results imply that there is a non-linear relationship between renewable energy consumption and growth in this global panel. We therefore estimate the non-linear growth model using the PSTAR estimation.

Table 6. PSTAR(1) linearity tests.

Tests	**m = 1** **Statistique**	**P-value**
Multiplicateur de Lagrange (LM)	72.236	0.000
Fisher (LMF)	10.344	0.000
Rapport de vraisemblance (LR)	73.652	0.000

The linearity tests are only a first step before proceeding to the final estimation of the PSTR model. Determining the optimal number of transition functions is an equally important second step, which allows us to determine the number of regimes describing the dynamics of the relationship between renewable energy and economic growth. However, in order to be consistent with the theoretical models described above, the maximum number of regimes is fixed at two.

In the next step, we begin a grid search to obtain threshold values "c" for the one-lag PSTAR model (as shown in the Appendix). The optimal threshold value is the one that minimises the residual sum of squares (RSS) sequence. Table (7) shows the results of the tests for the existence of the threshold value and provides information on the transition parameter.

Table 7. Test for the existence of RE threshold effects.

Order	**Threshold ($\hat{c}$)**	**Parameter of transition ($\hat{\gamma}$)**	**RSS**	**AIC**	**BIC**
m = 1	3.883	2.592	84.074	-3.087	-3.040

Table (7) presents the results of the tests for the existence of the threshold value and provides information on the transition parameter. The value minimising SCR, AIC and BIC is reached at the value of LnRE equal to 3.883 for m = 1, which is exponentiated at 48.570.

We arrive, therefore, at the estimation by the PSTAR model, applying the linear and non-linear ordinary least squares method on our data in order to move the threshold value to its equilibrium point to reduce the level of political stability. Indeed, Table (8) presents the estimate of a regime below the threshold value. We conclude that the effect of renewable energy consumption on economic growth is non-linear.

Table 8. PSTAR(1) regression.

LnEAMFP	**Regime 1 : LnRE ≤ 3.883**		**Regime 2 : LnRE > 3.883**	
Variable	Coefficient	t-statistic	Coefficient	t-statistic
$LnEAMFP_{it-1}$	0.656	30.296	-0.069	-2.551
$LnPOP_{it}$	0.321	5.714	-0.284	-3.784
$LnGFCF_{it}$	-0.083	-1.575	0.103	2.166
$LnTRADE_{it}$	0.304	7.165	-0.068	-2.790
$LnCO2_{it}$	0.365	5.951	-0.139	-1.554
$LnRE_{it}$	-0.137	-3.726	0.373	2.888
$LnFDI_{it}$	-0.020	-1.730	0.037	2.120

For a low RE regime relative to EAMFP (LnRE < 3.883; i.e. BR = 48.570), the RE elasticity is estimated at -0.137. For a high ER regime (3.883 < LnRE), the RE elasticity coefficient is estimated at 0.373. For which renewable energy consumption has become positive and significant for economic growth. And so the "growth hypothesis" is validated when RE > 48%. In other words, we find a sample of 1,538 observations that are able to boost their economic growth by 0.373 from a 1% increase in renewable energy consumption. In fact, these results are in line with those of Rahman and Velayutham (2020).

Figure 2 shows that the smooth transition function with respect to the transition variable (LnRE), suggests that the transition from a low RE regime to a high one is relatively abrupt because the value of is high, i.e. 2.592.

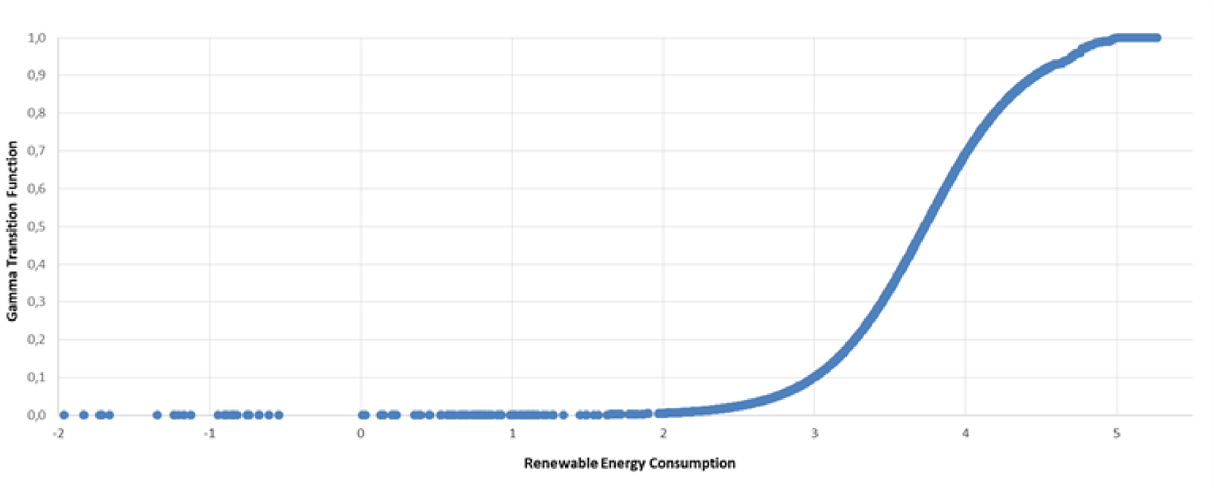

Figure 2. Log (EAMFP) estimated transition function of Log (RE).

5. CONCLUSION

The aim of this research is therefore to study the relationship between renewable energy consumption and green economic growth in a multidimensional framework by introducing different explanatory variables, namely capital, labor, trade openness, foreign direct investment and CO2 emissions over the period 1990-2020. for the case of countries with different incomes, namely low-income countries (12 countries), middle-income countries (25 countries) and high-income countries (24 countries).

In the light of our results, the non-linear PSTAR approach verifies that the relationship between renewable energy consumption and economic growth has only one threshold (break-even point) equal to 3.883, and that renewable energy consumption will only be favorable to green economic growth above this threshold (Regime 2: LnRE > 3.883).

The results of our work are also revealing from the point of view of the relationship between energy and economic growth. The expansion of solar and wind energy technologies, for example, is a solution that can help to reduce regional inequalities, and also to tackle the problem of social exclusion in African countries. This is especially true since these forms of energy favors decentralized applications, particularly in the context of rural electrification and isolated areas. This enables households living in remote areas not connected to the national grid to benefit from the services offered by electricity from renewable sources.

Energy is a central element in the basket of goods and services to which every household must have access if it is not to be considered poor. The lack of energy infrastructure and the quality of housing are among the characteristics of poverty. To combat poverty, action must therefore focus, among other things, on the development and expansion of renewable energy technologies. Consequently, it will be essential for governments to include general actions that stimulate the deployment of renewable energies, such as the development of human institutional capacities, the establishment of research and development infrastructures and the creation of a favorable investment environment.

Financing renewable energy in African countries is another challenge to integrating renewable energy into the current energy mix. In these economies, the banking sector is the main source of external financing. As a result, renewable energy projects are at a particular disadvantage. In fact, the financing of these projects is closely linked to the development of financial institutions. Consequently, local governments should increase their capacity to finance these projects. An important step in this respect is to improve the quality of national financial markets in order to increase national financing capacity.

From a political point of view, it is a question of ensuring a political framework to stimulate the use and development of renewable energies and to create a favorable environment to attract more investments in this sector. In addition, it is important to stimulate private investors and encourage them to become more actively involved in the vast field of renewable energy activity. To achieve this, we need to encourage more public-private partnership initiatives and identify the obstacles to increasing investment in renewable energies. Finally, it can be said that achieving the Sustainable Development Goals (SDGs) requires, among other things, continued substitution in favor of renewable energies, which should result in increased investment in this sector of activity.

REFERENCES

Apergis, N., & Payne, J. E. (2014). A time-varying coefficient approach to the renewable and non-renewable electricity consumption–growth nexus: Evidence from a panel of emerging market economies. *Energy Sources, Part B: Economics, Planning, and Policy, 9*(1), 101–107. https://doi.org/10.1080/15567249.2013.792400

Apergis, N., & Payne, J. E. (2011). The renewable energy consumption–growth nexus in Central America. *Applied Energy, 88*(1), 343–347. https://doi.org/10.1016/j.apenergy.2010.07.013

Apergis, N., & Salim, R. (2015). Renewable energy consumption and unemployment: Evidence from a sample of 80 countries and nonlinear estimates. *Applied Economics, 47*(52), 5614–5633. https://doi.org/10.1080/00036846.2015.1054071

Ashfaq, S., Sun, L., Waqas, F., Gulzar, S., Mujtaba, G., & Nasir, R. M. (2024). Renewable energy and green economic growth nexus: Insights from simulated dynamic ARDL. *Gondwana Research, 127*, 288–300.

Bao, C., & Xu, M. (2019). Cause and effect of renewable energy consumption on urbanization and economic growth in China's provinces and regions. *Journal of Cleaner Production, 231*, 483–493. https://doi.org/10.1016/j.jclepro.2019.05.191

Bayar, Y., & Gavriletea, M. D. (2019). Energy efficiency, renewable energy, and economic growth: Evidence from emerging market economies. *Quality & Quantity, 53*, 2221–2234. https://doi.org/10.1007/s11135-019-00867-9

Bhattacharya, M., Paramati, S. R., Ozturk, I., & Bhattacharya, S. (2016). The effect of renewable energy consumption on economic growth: Evidence from top 38 countries. *Applied Energy, 162*, 733–741. https://doi.org/10.1016/j.apenergy.2015.10.104

Bilen, K., Ozyurt, O., Bakırcı, K., Karslı, S., Erdogan, S., Yılmaz, M., & Comaklı, O. (2008). Energy production, consumption, and environmental pollution for sustainable development: A case study in Turkey. *Renewable and Sustainable Energy Reviews, 12*(6), 1529–1561. https://doi.org/10.1016/j.rser.2007.03.003

Bose, B. K. (2010). Global warming: Energy, environmental pollution, and the impact of power electronics. *IEEE Industrial Electronics Magazine, 4*(1), 6–17. https://doi.org/10.1109/MIE.2010.935860

Bulut, U., & Muratoglu, G. (2018). Renewable energy in Turkey: Great potential, low but increasing utilization, and an empirical analysis on renewable energy–growth nexus. *Energy Policy, 123*, 240–250. https://doi.org/10.1016/j.enpol.2018.08.057

Carley, S., & Konisky, D. M. (2020). The justice and equity implications of the clean energy transition. *Nature Energy, 5*, 569–577. https://doi.org/10.1038/s41560-020-0641-6

Chang, T., Gupta, R., Inglesi-Lotz, R., Simo-Kengne, B., Smithers, D., & Trembling, A. (2015). Renewable energy and growth: Evidence from heterogeneous panel of G7 countries using Granger causality. *Renewable and Sustainable Energy Reviews, 52*, 1405–1412. https://doi.org/10.1016/j.rser.2015.08.022

Charfeddine, L., & Kahia, M. (2019). Impact of renewable energy consumption and financial development on CO_2 emissions and economic growth in the MENA region: A panel vector autoregressive analysis. *Renewable Energy, 139*, 198–213. https://doi.org/10.1016/j.renene.2019.01.010

Diez-Martínez, C. V. (2021). Clean energy transition in Mexico: Policy recommendations for the deployment of energy storage technologies. *Renewable and Sustainable Energy Reviews, 135*, Article 110407. https://doi.org/10.1016/j.rser.2020.110407

Dominković, D. F., Bačeković, I., Pedersen, A. S., & Krajačić, G. (2018). The future of transportation in sustainable energy systems: Opportunities and barriers in a clean energy transition. *Renewable and Sustainable Energy Reviews, 82*, 1823–1838. https://doi.org/10.1016/j.rser.2017.06.117

Ferhi, A., & Kamel, H. (2024). The nonlinear nexus between renewable energy consumption and economic growth in OECD countries: Evidence from PTR and PSTR estimates. *Journal of Economic Studies, 51*(1), 185–201. https://doi.org/10.1108/JES-12-2022-0660

Frees, E. W. (1995). Assessing cross-sectional correlation in panel data. *Journal of Econometrics, 69*(2), 393–414. https://doi.org/10.1016/0304-4076(94)01658-M

Frees, E. W. (2004). *Longitudinal and panel data: Analysis and applications in the social sciences*. Cambridge University Press.

Friedman, M. (1937). The use of ranks to avoid the assumption of normality implicit in the analysis of variance. *Journal of the American Statistical Association, 32*(200), 675–701. https://doi.org/10.1080/01621459.1937.10503522

Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N., & Gorini, R. (2019). The role of renewable energy in the global energy transformation. *Energy Strategy Reviews, 24*, 38–50. https://doi.org/10.1016/j.esr.2019.01.006

González, A., Teräsvirta, T., van Dijk, D., & Yang, Y. (2017). *Panel smooth transition regression models* (Working Paper No. 2017-36). Department of Economics and Business Economics.

Han, D., Li, T., Feng, S., & Shi, Z. (2020). Does renewable energy consumption successfully promote the green transformation of China's industry? *Energies, 13*(1), Article 229. https://doi.org/10.3390/en13010229

Hansen, B. E. (1999). Threshold effects in non-dynamic panels: Estimation, testing, and inference. *Journal of Econometrics, 93*(2), 345–368. https://doi.org/10.1016/S0304-4076(99)00025-1

Inglesi-Lotz, R. (2016). The impact of renewable energy consumption on economic growth: A panel data application. *Energy Economics, 53*, 58–63. https://doi.org/10.1016/j.eneco.2015.01.003

Kao, C. (1999). Spurious regression and residual-based tests for cointegration in panel data. *Journal of Econometrics, 90*(1), 1–44. https://doi.org/10.1016/S0304-4076(98)00023-2

Khan, H., Khan, I., & Binh, T. T. (2020). The heterogeneity of renewable energy consumption, carbon emission, and financial development in the globe: A panel quantile regression approach. *Energy Reports, 6*, 859–867. https://doi.org/10.1016/j.egyr.2020.04.002

Koçak, E., & Şarkgüneşi, A. (2017). The renewable energy and economic growth nexus in Black Sea and Balkan countries. *Energy Policy, 100*, 51–57. https://doi.org/10.1016/j.enpol.2016.10.007

Kotzebue, J. R., & Weissenbacher, M. (2020). The EU's clean energy strategy for islands: A policy perspective on Malta's spatial governance in energy transition. *Energy Policy, 139*, Article 111361. https://doi.org/10.1016/j.enpol.2020.111361

Kraft, J., & Kraft, A. (1978). On the relationship between energy and GNP. *Journal of Energy and Development, 3*, 401–403.

Long, A. (1985). On the relationship between energy and GNP: A reexamination. *Journal of Energy and Development, 5*, 326–331.

Maji, I. K., Sulaiman, C., & Abdul-Rahim, A. S. (2019). Renewable energy consumption and economic growth nexus: Fresh evidence from West Africa. *Energy Reports, 5*, 384–392. https://doi.org/10.1016/j.egyr.2019.03.005

Markandya, A., Arto, I., González-Eguino, M., & Román, M. V. (2016). Towards a green energy economy? Tracking the employment effects of low-carbon technologies in the European Union. *Applied Energy, 179*, 1342–1350. https://doi.org/10.1016/j.apenergy.2016.02.122

Marks-Bielska, R., Bielski, S., Pik, K., & Kurowska, K. (2020). The importance of renewable energy sources in Poland's energy mix. *Energies, 13*(18), Article 4624. https://doi.org/10.3390/en13184624

Menegaki, A. N. (2011). Growth and renewable energy in Europe: A random effects model with evidence for the neutrality hypothesis. *Energy Economics, 33*(2), 257–263. https://doi.org/10.1016/j.eneco.2010.10.004

Naseri, S. F., Motamedi, S., & Ahmadian, M. (2016). Study of mediated consumption effect of renewable energy on economic growth of OECD countries. *Procedia Economics and Finance, 36*, 502–509. https://doi.org/10.1016/S2212-5671(16)30068-5

Ocal, O., & Aslan, A. (2013). Renewable energy consumption–economic growth nexus in Turkey. *Renewable and Sustainable Energy Reviews, 28*, 494–499. https://doi.org/10.1016/j.rser.2013.08.036

Odhiambo, N. M. (2009). Energy consumption and economic growth nexus in Tanzania: An ARDL bounds testing approach. *Energy Policy, 37*(2), 617–622. https://doi.org/10.1016/j.enpol.2008.09.077

Payne, J. E. (2009). On the dynamics of energy consumption and output in the US. *Applied Energy, 86*(4), 575–577. https://doi.org/10.1016/j.apenergy.2008.07.003

Pedroni, P. (2004). Panel cointegration: Asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. *Econometric Theory, 20*(3), 597–625. https://doi.org/10.1017/S0266466604203073

Pesaran, M. H. (2003). *Estimation and inference in large heterogeneous panels with cross-section dependence* (CESifo Working Paper No. 869). CESifo.

Pesaran, M. H. (2004). *General diagnostic tests for cross-section dependence in panels* (Cambridge Working Papers in Economics No. 0435). University of Cambridge.

Pesaran, M. H. (2006). Estimation and inference in large heterogeneous panels with a multifactor error structure. *Econometrica, 74*(4), 967–1012. https://doi.org/10.1111/j.1468-0262.2006.00692.x

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics, 22*(2), 265–312. https://doi.org/10.1002/jae.951

Pesaran, M. H. (2015). Testing weak cross-sectional dependence in large panels. *Econometric Reviews, 34*(6–10), 1089–1117. https://doi.org/10.1080/07474938.2014.956623

Pesaran, M. H. (2021). General diagnostic tests for cross-sectional dependence in panels. *Empirical Economics, 60*(1), 13–50. https://doi.org/10.1007/s00181-020-01875-7

Pesaran, M. H., & Yamagata, T. (2008). Testing slope homogeneity in large panels. *Journal of Econometrics, 142*(1), 50–93. https://doi.org/10.1016/j.jeconom.2007.05.010

Pesaran, M. H., Ullah, A., & Yamagata, T. (2008). A bias-adjusted LM test of error cross-section independence. *The Econometrics Journal, 11*(1), 105–127. https://doi.org/10.1111/j.1368-423X.2007.00227.x

Qi, S. Z., & Li, Y. (2017). Does renewable energy consumption affect economic growth? An empirical study based on the European Union. *World Economy Research, 4*, 106–119.

Rahman, M. M., & Alam, K. (2021). Clean energy, population density, urbanization and environmental pollution nexus: Evidence from Bangladesh. *Renewable Energy, 172*, 1063–1072. https://doi.org/10.1016/j.renene.2021.03.103

Shahbaz, M., Raghutla, C., & Chittedi, K. R. (2020). The effect of renewable energy consumption on economic growth: Evidence from the renewable energy country attractiveness index. *Energy, 207*, Article 118162. https://doi.org/10.1016/j.energy.2020.118162

Sohail, M. T., Ullah, S., Majeed, M. T., Usman, A., & Andlib, Z. (2021). The shadow economy in South Asia: Dynamic effects on clean energy consumption and environmental pollution. *Environmental Science and Pollution Research, 28*, 29265–29275. https://doi.org/10.1007/s11356-021-12690-7

Topcu, M., & Tugcu, C. T. (2020). The impact of renewable energy consumption on income inequality: Evidence from developed countries. *Renewable Energy, 151*, 1134–1140. https://doi.org/10.1016/j.renene.2019.11.103

Westerlund, J. (2007). Testing for error correction in panel data. *Oxford Bulletin of Economics and Statistics, 69*(6), 709–748. https://doi.org/10.1111/j.1468-0084.2007.00477.x

Yu, E. S. H., & Hwang, B. W. (1984). The relationship between energy and GNP: Further results. *Energy Economics, 6*(3), 186–190. https://doi.org/10.1016/0140-9883(84)90015-X

Yu, J. (1992). Cointegration tests of energy consumption, income and employment. *Resources and Energy, 14*(3), 259–266. https://doi.org/10.1016/0165-0572(92)90010-E

Zafar, M. W., Shahbaz, M., Sinha, A., Sengupta, T., & Qin, Q. (2020). How renewable energy consumption contributes to environmental quality? The role of education in OECD countries. *Journal of Cleaner Production, 268*, Article 122149. https://doi.org/10.1016/j.jclepro.2020.122149

Zrelli, M. H. (2017). Renewable energy, non-renewable energy, carbon dioxide emissions and economic growth in selected Mediterranean countries. *Environmental Economics and Policy Studies, 19*(4), 691–709. https://doi.org/10.1007/s10018-016-0170-7