



Exploring the Influence of Export Diversification, Technological Innovation, and Political Indices on Renewable Energy Consumption: Evidence from Oil-Exporting Nations

Mahdi Mahdiuon^a  and Kiumars Shahbazi^a 

a. Department of Economics and Management, Urmia University, Urmia, Iran.

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Abstract

The panel smooth transition regression model was employed to evaluate the role of governance indices in the impact of export diversification and technological innovation on renewable energy consumption. We estimated the relationship among the variables from 1996 to 2014 by considering the lagged form of governance indices as a transition variable. Technological innovation, international trade, governance index, CO2 emissions, OPEC (Organization of the Petroleum Exporting Countries) oil price, and income inequality were included as controlled variables. Based on the results, at high levels of governance indices and beyond the threshold point, the effect of export diversification on renewable energy consumption became negative, whereas the effect of technological innovation was positive in both regimes. The results suggest that there is a need for cutting-edge, renewable, energy-based production processes to establish non-polluting, energy-efficient, and eco-friendly procedures at both industrial and household levels. The production and consumption of renewable energy resources, in which the role of development-oriented governments is crucial, should be enhanced to simultaneously achieve environmental improvement, economic goals, and sustainable and green development.

Keywords: export diversification, political and governance indices, renewable energy consumption, technological innovation, threshold effect.

JEL Classification: E61, F18, H11, O12, P18.

Introduction

Energy is vital for the development of human civilization and socioeconomic well-being (Pradhan et al., 2021; Kumar et al., 2023). Many countries rely on fossil fuels, such as coal, natural gas, and oil, for their energy needs. However, fossil fuels are not environmentally friendly and are consumed and degraded at a higher rate than renewable energy sources. Fossil fuels are non-renewable energy sources and threaten human resilience and stability. Furthermore, the economic growth

driven by fossil fuels is considered a cause of global warming and climate change (Stern, 2006). According to a report published by the United Nations Environment Program (UNEP) in 2020, "Despite a slight reduction in carbon dioxide emissions due to the COVID-19 pandemic, the world is still on track for a temperature increase of more than three degrees Celsius in the current century." This is far beyond the goals of the Paris Agreement, which aims to restrict global warming to keep temperatures below 2 °C and to pursue 1.5 °C.

Due to its low carbon emissions and environmentally friendly nature, renewable energy can be the best option for most countries to solve environmental challenges and provide a stable energy source for economic growth. Renewable energy is generally defined as energy obtained from natural sources that renew themselves in a period shorter than a human's life without depleting the Earth's resources.

Renewable energy resources such as sunlight, wind, rain, tides, sea waves, biomass, or geothermal energy are available in the Earth's core. They have the advantage of being available almost everywhere in one form or another. They are also infinite and, most importantly, cause very little environmental damage and climate change. Therefore, more and more countries are considering renewable energy resources as an alternative to fossil fuels to address environmental challenges and energy shortages. The consumption of renewable energies is expected to surge in the upcoming years. Environmental challenges can only be addressed by the widespread use of renewable energy solutions. In order to achieve this, there is a need to encourage innovation, research, and development expenditures in both the energy and industry sectors to establish advanced, efficient, and environmentally friendly production processes. The transition from fossil fuels to cleaner energy solutions should be managed gradually to avoid significant problems for the industry sector and labor force employment due to spill-over effects between sectors (Destek and Sinha, 2020).

This study aimed to examine the impact of export diversification and technological innovation on renewable energy consumption in 10 selected oil-exporting countries, namely Argentina, Canada, Colombia, Denmark, Finland, France, Germany, Norway, Sweden, and the United States, from 1996 to 2014. Export diversification refers to the shift from "traditional" to "new" exports. The results indicate that neglecting the environmental repercussions of export promotion may increase unpleasant environmental externalities. For technological innovation, we considered research and development expenditures as an important determining factor. Additionally, we used another variable called "political and

governance indices" that indicates the governance quality in the selected countries. This variable consists of six other indicators, and we applied the rule of law to present this index. One way to explain the role of governance quality (political and governance indices) in the influence of export diversification and technological innovation on the consumption of renewable energy is using the panel smooth transition regression (PSTR) approach to model the non-linear and threshold relationships between the variables using the transition function and threshold variable observations continuously. Based on previous studies, given the important role of export diversification and technological innovation, and the need to expand the production and use of renewable and clean energy solutions, investigating the relationship between these variables can provide clear insights for policymakers and help them adopt accurate policies to reduce pollutants. The PSTR model was developed by Fok (2005), Gonzalez (2005), and Colletaz and Hurlin (2006). This study used the political and governance index with one lag as the transition variable.

Section 2 presents the possible determinants of renewable energy solutions. Section 3 outlines the econometric procedures used for the renewable energy function. Section 4 presents the results and discussions. Finally, Section 5 includes policy directions and conclusions.

Literature Review

To expand the use of renewable energies, it is essential to understand the factors that affect the production and consumption of these energy resources. In response to the increasing environmental challenges, many countries are turning to renewable energy resources (Bekun et al., 2019), such as wind, geothermal, tidal, and solar energy.

Several studies have investigated the impact of policy, innovation, and export diversification on renewable energies. Given the importance of policymakers' implementing precise policies and developing renewable energy sources, it can be said that renewable energies can significantly contribute to achieving general environmental goals and energy security (Yan et al., 2020). Therefore, some studies have focused on the relationship between environmental policy and green (clean) innovation in renewable energy technologies (Palage et al., 2019). According to them, countries with high-quality governance tend to implement more effective environmental policies that promote renewable energy consumption. This is because transparent, accountable, and efficient governments are better equipped to design, enforce, and sustain policies that support the

transition to renewable energy, ultimately leading to improved environmental outcomes and sustainable development. Since implementing the first environmental regulations in the world, there have been many concerns in environmental economics and among policymakers. In this regard, Zhao et al. (2022) stated that governments' efforts to reduce the deterioration and destruction of the environment and prevent global warming relocate production companies to places with looser environmental regulations, disrupting the spatial distribution of production networks and discouraging technological innovation. However, some studies have challenged this claim and believe strict environmental policies actually increase innovation (Downing and White, 1996; Milliman and Prince, 1999).

Porter and Van der Linde (1991) hypothesized that environmental regulations encourage companies to increase investment in research and development projects and promote innovative activities, which later became known as Porter's theory. As Li and Shao (2021) point out, regulations are the driving force behind renewable energy innovation in OECD (Organization for Economic Co-operation and Development) countries. Among the available policy instruments, both market-based tools and command-and-control-based tools are widely used and confer environmental benefits (Blackman et al., 2018). Economic instruments in environmental policies are generally used to correct negative externalities by adjusting the final prices of goods and services. This adjustment ensures that the prices fully reflect all the costs and benefits associated with the consumption of certain environmental goods and services. Such instruments include using taxes and subsidies as incentives for compliance, which affects the behavior of companies. These companies must find ways to cope with the new conditions imposed on them, such as environmental protection and related compliance costs. Innovation in renewable energy technologies is one such way that not only offers a win-win strategy for dealing with environmental challenges but also accelerates technological progress in the renewable energy sector and ensures efficient utilization of human and natural resources (Wang and Zhang, 2018; Albrizio et al., 2017). Companies tend to respond to strict and detailed environmental policies by investing more in research and development related to renewable energy, which increases the number of patents for clean technologies. The implementation of strict environmental policies creates a significant demand for clean energy sources and technologies (Popp et al., 2010), which further motivates companies to innovate in this field. As the expected returns from

investing in clean technologies become higher than the associated costs, companies become more likely to engage in innovative activities.

According to many researchers, market-based instruments are more effective in promoting clean innovation due to their flexibility in meeting environmental regulatory needs (Dechezleprêtre and Sato, 2017). However, the successful application of market-oriented environmental regulations requires sound institutional infrastructure and efficient energy markets. Another type of environmental policy is command and control (CAC). This policy defines what is legal and illegal, with the government authority presenting quality standards/targets that must be complied with (the 'command' component). Non-compliance may result in negative sanctions such as prosecution (the 'control' component). CAC encompasses a variety of methods, including laws, incentives, threats, contracts, and agreements (Baldwin et al., 2011; Abbot, 2009). This approach uses three standards: environmental, emission, and technology. CAC policies effectively save the environment and promote innovation by holding polluters responsible for the costs of pollution reduction (Bergquist et al., 2013; Tang et al., 2020).

To improve technological innovations and renewable energy consumption, we can offer suggestions to countries that aim to achieve clean and sustainable growth. First, governments should continue to implement diverse environmental policies and increase the strictness and precision of these policies. Clean innovations can help companies offset the costs of complying with environmental regulations and expand their market share in clean products. Therefore, appropriate and strict environmental policies can encourage companies to implement green (clean) innovations in renewable energy. Second, policymakers should emphasize political tools that are not solely based on the market. This is because legislation and pricing mechanisms in energy markets are often inadequate, and market-based environmental policies may only place cost pressures on firms without creating sufficient incentives for clean innovation. Third, when implementing environmental policies to promote renewable energy innovation, all energy types should be considered, and specific policies should be applied to each (Pitelis et al., 2020). Finally, governments should develop policies that encourage clean investment. To this end, efforts should be made to reduce the barriers to clean investment and motivate customers to use clean products.

The significant role of international trade in globalization motivates us to pay attention to the influence of export diversification on renewable energy consumption. In this regard, Shahzad et al. (2021) state that product diversification

policies positively affect renewable energy demand in both developing and developed economies, and the non-linear relationship between export diversification and renewable energy is confirmed for selected countries. Empirical results using the FGLS (feasible generalized least squares) and FMOLS (fully modified ordinary least squares) methods show the U-shaped effect of export diversification and extensive and intensive export margins on renewable energy consumption for these countries. These results confirm the findings of Shahbaz and Gozgor (2019) and Shahbaz et al. (2019) suggesting that export diversification can be used as a political tool to reduce non-renewable energy demand and as a key policy to increase renewable energy consumption.

Another crucial factor to consider is income inequality. Higher levels of income inequality can theoretically hinder renewable energy consumption, as unequal societies may lack the broad-based public support and financial resources needed to invest in renewable technologies. Additionally, wealth disparities can lead to unequal access to renewable energy benefits, slowing overall adoption and perpetuating reliance on fossil fuels.

Matallah et al. (2023) investigated the interaction between oil revenues, innovation, and renewable energy production in eight oil-rich MENA (Middle Eastern and North African) countries between 1996 and 2020. The main results indicate that a significant transition to renewable energies in oil-rich MENA countries cannot be achieved without innovation and good governance. Sachan (2023) investigated the factors affecting renewable energy consumption by drawing a sample from BRICS countries (Brazil, Russia, India, China, and South Africa) between 1990 and 2015. The results show that the environmental policy stringency index and human development index significantly and positively influence renewable energy consumption, while carbon dioxide emission indicators and gross fixed capital formation have a negative and significant relationship with renewable energy consumption. In China, Li (2023) observed that financial development and research and development expenses are the most important factors strengthening the energy transition, while human resources, communication, and information technology also boost the renewable energy transition. In other words, the country should focus on promoting financial development. Shahbaz (2019) ascertained that education negatively correlates with energy demand, and export diversification also lowers energy demand in the long run. While economic growth intensifies energy consumption, oil prices reduce energy demand in the long term.

Khan et al. (2021) confirmed that reducing the composite risk index, transitioning to renewable energy, and developing technological innovation related to the environment will help to reduce CO₂ emissions in the long term. However, export diversification uniformly increases CO₂ emission levels. These findings also confirm the environmental Kuznets curve (EKC) hypothesis, suggesting that the economic growth of RCEP (Regional Comprehensive Economic Partnership Agreement) countries is both the initial factor and the final impediment to CO₂ emissions. In addition to carbon emissions, increasing international trade has also intensified the demand for cleaner energy solutions. Qayyum et al. (2021) explored the relationship between financial development, renewable energy consumption, technological innovation, and CO₂ emissions from 1980 to 2019, considering the critical role of urbanization and economic growth. According to the results, financial development positively and significantly influences CO₂ emissions. On the other hand, the coefficients of renewable energy consumption and technical innovations are significantly negative in both the long and short terms, indicating that increasing these criteria will reduce CO₂ emissions. These findings support the pro-environment nature of technological advancement.

Finally, fluctuations in OPEC oil prices influence renewable energy consumption through economic theories of supply and demand, price elasticity, and substitution effect. According to the substitution effect, as OPEC oil prices rise, consumers and businesses seek alternatives to expensive oil, increasing demand for renewable energy. The price elasticity of demand theory suggests that higher oil prices make renewable energy more price-competitive, encouraging investment and adoption. Conversely, when OPEC oil prices fall, the reduced cost advantage of renewables may slow their adoption, as consumers revert to cheaper fossil fuels.

In summary, this part of the article examines the history of research on the factors affecting renewable energy consumption and highlights the need for further studies in this field. Consequently, based on the literature review, we aimed to investigate the impact of export diversification, technological innovation, income inequality, oil prices, carbon emissions, international trade, and governance on the demand for cleaner energy resources.

Methodology

Panel Smooth Transition Regression

To model the effect of export diversification and technological innovation on renewable energy consumption, we will first elucidate the PSTR as an econometric

approach. The PSTR model is distinct from the panel threshold regression (PTR) model, which divides panel observations into smaller homogeneous regimes with sharp thresholds, as it allows for a smooth transition from one regime to another. The advantage of a smooth transition model is that it can encompass a range of regimes. As mentioned earlier, the PSTR model is suitable for simultaneously solving the heterogeneity and time variability problems. To this end, according to Gonzalez et al. (2005) and Colletaz and Hurlin (2006), a panel smooth transition model with two extreme regimes and one transition function is defined as follows:

$$y_{it} = \mu_i + \beta_0 x_{it} + \beta_1 x_{it} F(q_{it}; \gamma, c) + u_{it} \quad (1)$$

where i and t are natural numbers representing countries and years, respectively, y_{it} is the dependent variable, x_{it} is a vector of explanatory variables, μ_i indicates the fixed individual effects, and u_{it} is the error term, which is independently and identically distributed ($iid \sim (0, \sigma^2)$). $F(q_{it}; \gamma, c)$ represents a continuous and bounded transition function of the observed variable q_{it} that belongs to the range of 0-1. q_{it} is the transition variable, which creates a non-linear relationship. According to Colletaz and Hurlin (2006), this variable can be chosen from among the explanatory variables, the lagged form of the dependent variable, or any other variable outside the model that is related to the studied model in terms of theoretical foundations. $\gamma > 0$ is the slope parameter expressing the speed of the transition from one regime to another. Finally, c is the location parameter.

Following Gonzalez et al. (2005), this function is specified in the following logistic form:

$$F(\gamma, c, q_{it}) = \left[1 + \exp \left(-\gamma \prod_{j=1}^m (q_{it} - c_j) \right) \right]^{-1} \quad (2)$$

where $\gamma > 0$ and $c_1 \leq c_2 \leq \dots \leq c_m$. The lagged form of the political and governance indices has been chosen as a transition variable, which is believed to be the reason for non-linearity. Gonzalez et al. (2005) stated that the transfer function usually has one or two threshold levels ($m = 1, m = 2$); thus, we discuss the continuous and bounded feature of the transfer function, which ranges between 0 and 1.

Assuming $m = 1$, there is a transfer function with two regimes. Thus, by setting the slope parameter to infinity, if $q_{it} > c$, the transfer function has a numerical value of 1 ($F = 1$). If $m = 2$ and the slope parameter tends towards infinity, there will be three regimes, with the two outside regimes being similar, while the inside regime is diverse. This means that for values greater and smaller than the transfer variable, the transfer function has a numerical value of 1 ($F = 1$); otherwise, it has a numerical value of 0 ($F = 0$).

If the transition speed between regimes or the slope parameter tends toward 0, the PSTR model will be a linear regression model with a fixed effect. In the PSTR model, the estimated coefficients related to the transfer variable and the slope parameter change continuously between the two extreme cases of $F = 1$ and $F = 0$. These two extreme cases can be specified as follows:

$$y_{it} = \begin{cases} \mu_i + \beta_0 x_{it} + u_{it} & \dots F = 0 \\ \mu_i + (\beta_0 + \beta_1) x_{it} + u_{it} & \dots F = 1 \end{cases} \quad (3)$$

The PSTR model will be estimated by removing individual-specific means and then using the nonlinear least squares method, which is equivalent to the maximum likelihood estimator. If q_{it} belongs to the set of regressors, the elasticity becomes:

$$e_{it} = \frac{\partial \ln y_{it}}{\partial \ln x_{it}} = \beta_0 + \beta_1 F(q_{it}; \gamma, c) + [\beta_1 \ln x_{it}] \frac{\partial F(q_{it}; \gamma, c)}{\partial \ln x_{it}} \quad (4)$$

Generalized to more than two distinct regimes, the PSTR model can ultimately be specified as follows:

$$y_{it} = \mu_i + \beta_0 x_{it} + \sum_{j=1}^r \beta_j x_{it} F_j(q_{it}; \gamma_j, c_j) + u_{it} \quad (5)$$

where $r+1$ is the number of regimes, r represents the number of transition functions used to specify the nonlinear behavior between the variables, and $F_j(q_{it}; \gamma_j, c_j)$, $j=1, \dots, r$ are the transition functions.

The PSTR model can be regarded as a heterogeneous, time-varying-parameter panel data model.

Estimation Steps

As stated by Fok et al. (2005), Gonzalez et al. (2005), and Colletaz and Hurlin (2006), the steps needed to estimate a PSTR model are as follows:

First, linearity against PSTR is tested; if the null hypothesis of the linear relationship between the variables is rejected, the number of transition functions needed to specify the nonlinear behavior between variables should be determined.

Although the linearity test can be done by testing the null hypothesis of $H_0: \gamma=0$ or $H_0: \beta_1=0$, the test statistics related to both hypotheses will not be standard since the PSTR model under the null hypothesis contains unidentified nuisance. To address this problem, Luukkonen et al. (1988) and Teräsvirta (1988) have suggested using the Taylor series of the transition function. Later, Gonzalez et al. (2005) and Colletaz and Hurlin (2006) suggested using the first and second-order Taylor expansions of the transition function $F(q_{it}; \gamma, c)$ around $\gamma=0$.

$$y_{it} = \mu_i + \beta_0 x_{it} + \beta_1 x_{it} q_{it} + \dots + \beta_m x_{it} q_{it}^m + u_{it} \quad (6)$$

Considering Equation (6), the null hypothesis for linearity becomes $H_0: \beta_1 = \dots = \beta_m = 0$. The rejection of this hypothesis implies a non-linear relationship. Otherwise, a linear model must be specified to test this hypothesis.

According to Colletaz and Hurlin (2006), we use the Wald Lagrange multiplier (LM_w), Fisher Lagrange multiplier (LM_f), and likelihood ratio (LR) tests, calculated as follows:

$$LM_w = \frac{TN - (SSR_0 - SSR_1)}{SSR_0} \quad (7)$$

$$LM_f = \frac{[(SSR_0 - SSR_1)/K_m]}{SSR_0/(TN - N - mK)} \quad (8)$$

$$LR = -2[\log(SSR_1) - \log(SSR_0)] \quad (9)$$

In the above equations, (SSR_0) is the sum of squared residuals of the linear panel model, and (SSR_1) is the sum of squared residuals of the non-linear panel model in the PSTR approach. Additionally, T represents the duration of the studied period, N denotes the total number of countries, K represents the number of explanatory variables, and m represents the number of thresholds.

If the results indicate that a PSTR pattern exists in the behavior of variables, the next step is to determine the number of transition functions needed to specify the existing non-linear behavior. To do so, the hypothesis of the presence of one transition function is tested against the hypothesis of more than one transition function. This process is similar to the linearity test, apart from testing the Taylor approximation of the second transition function, which can be specified as follows:

$$y_{it} = \mu_i + \beta_0 x_{it} + \beta_1 x_{it} F_1(q_{it}; \hat{y}_1, \hat{c}_1) + \beta_2 x_{it} q_{it} + \dots + \beta_m x_{it} q_{it}^m + u_{it} \quad (10)$$

A test for no remaining non-linearity can be performed using $H_0: \beta_2 = \dots = \beta_m = 0$. If the null hypothesis is not rejected, one transition function is sufficient for investigating the non-linearity between variables. However, there will be at least two transition functions if the null hypothesis is rejected. Afterwards, the hypothesis of two transition functions should be tested against the hypothesis of three transition functions. This process should be continued until the null hypothesis is accepted.

Model Specification

As mentioned earlier, this study aimed to investigate the effect of export diversification and technological innovation on renewable energy consumption

using PSTR as a non-linear econometric approach. Therefore, the model is specified as follows:

$$\begin{aligned}
 LRE_{it} = & \mu_i + \alpha_1 LTrade_{it} + \alpha_2 CO2_{it} + \alpha_3 lopec_{it} + \alpha_4 R\&D_{it} \\
 & + \alpha_5 ED_{it} + \alpha_6 GI_{it} + \alpha_7 Lgini_{it} \\
 & + \sum_{j=1}^r [\beta_1 LTrade_{it} + \beta_2 CO2_{it} + \beta_3 lopec_{it} \\
 & + \beta_4 R\&D_{it} + \beta_5 ED_{it} + \beta_6 GI_{it} \\
 & + \beta_7 Lgini_{it}] F_j(q_{it}^j; \gamma_{j.c_j}) + u_{it}
 \end{aligned} \tag{11}$$

LRE represents the logarithm of the proportion of renewable energy consumption to final energy consumption. *LTrade* represents the logarithm of the proportion of trade to gross domestic product (GDP). *CO2* represents CO2 emissions in metric tons per capita. The logarithm of OPEC oil price (*lopec*) is used as another control variable, obtained from Statista (The Statistics Portal). Furthermore, research and development play an undeniable role in energy consumption. The proportion of research and development expenditures to GDP (*R&D*) is used as an explanatory variable. *ED* expresses export diversification, which is believed to be a crucial factor in determining renewable energy consumption. *GI* is the governance index, which consists of six other factors. Here, we use the "rule of law" factor. The last explanatory variable used in the model is *Lgini*, which is the logarithm of the Gini index. The Gini index is a measure of statistical dispersion intended to represent income inequality within a nation or a social group. The data needed for this study are acquired from the World Development Indicators (WDI) and the International Monetary Fund (IMF). The transition variable is the political and governance index with one lag. Concisely, the steps taken in this part are as follows: testing linearity against the PSTR model, determining the number of transition functions, and specifying the model. Now that the methodology is explained explicitly, we can proceed to the next step.

Empirical Results and Their Discussion

Data Description

Analyzing the descriptive statistics of variables can help understand the results and the situation in 10 selected crude oil-exporting countries: Argentina, Canada, Colombia, Denmark, Finland, France, Germany, Norway, Sweden, and the USA. Table 1 describes the data.

Table 1. Descriptive Statistics

Variables	Mean	Maximum	Minimum	SD	Skewness	Kurtosis
<i>LRE</i>	1.245591	1.779452	0.352602	0.342318	-0.25512	2.136668
<i>LTrade</i>	1.743443	2.020478	1.330063	0.186692	-0.74164	2.351860
<i>CO2</i>	9.016415	20.4698	1.347285	5.199263	0.518997	2.383715
<i>lopec</i>	1.640264	2.039216	1.089198	0.305739	-0.15205	1.603973
<i>R&D</i>	2.027227	3.913820	0.106030	1.036171	-0.48159	2.249001
<i>ED</i>	2.158747	3.875174	1.376792	0.638307	1.206618	3.557147
<i>GI</i>	1.291610	2.124782	-0.92503	0.937503	-1.42389	3.292335
<i>Lgini</i>	1.534554	1.768638	1.376577	0.105125	0.715206	2.331225

Source: WDI, IMF, and Statista.

Unit Root Test

In the presence of cross-sectional dependence, it is essential to test whether the data are stationary using Im, Pesaran & Shin's panel unit root test before proceeding with the PSTR model (Pesaran, 2007). The unit root test is applied to the data, and the results are presented in Table 2. It can be observed that all the variables, except for *LTrade*, are non-stationary. To resolve this issue, we can either use Kao's co-integration test or apply the methods of Kadilli and Markov (2011) and Chang (2006) after estimating the PSTR model.

Table 2. Pesaran (2007) Unit Root Test

	Without trend	With trend
<i>LRE</i>	1.58884 (0.9440)	-1.85389 (0.0319)
<i>LTrade</i>	-1.57871 (0.0572)	-2.25029 (0.0122)
<i>CO2</i>	-1.11428 (0.8674)	-0.97931 (0.1637)
<i>Lopec</i>	2.73709 (0.9969)	-2.8319 (0.0023)
<i>R&D</i>	-0.10226 (0.4593)	-0.96933 (0.1662)
<i>ED</i>	0.92213 (0.8218)	-0.10198 (0.4594)
<i>GI</i>	-0.61310 (0.2699)	-3.82814 (0.0001)
<i>Lgini</i>	-0.03043 (0.4879)	-1.34720 (0.0890)

Source: Research findings.

Note: The values in parentheses are *p*-values.

Empirical Results

Based on Table 3, all the statistics for the LM_w coefficient, LM_f coefficient, and LR indicate a non-linear relationship between the variables. After confirming a non-linear relationship among the variables, it is necessary to test the non-linear relationship of residuals to determine the number of transition functions. Table 4 suggests that the null hypothesis regarding the presence of one transition function cannot be rejected. Consequently, using one transition function does not maintain a non-linear relationship. In other words, utilizing one transition function can specify the non-linear behavior between export diversification, technological innovation, and renewable energy consumption.

Table 3. Test for Linearity

	LM_w	LM_f	LR
$H_0: r=0$ vs $H_1: r=1$	52.819 (0.000)	10.327 (0.000)	65.108 (0.000)

Source: Research findings.

Note: r is the number of transition functions, and the values in parentheses are p -values.

Table 4. No Remaining Nonlinearity Test

H_0 :PSTR with $r=1$ vs H_1 :PSTR with at least $r=2$	LM_w	LM_f	LR
	10.589 (0.158)	1.291 (0.260)	10.982 (0.139)

Source: Research findings.

Note: r is the number of transition functions, and the values in parentheses are p -values.

After verifying a non-linear relationship among variables and determining the sufficiency of using one transition function to specify the non-linear behavior, the next step is establishing the optimal case between one or two thresholds, represented by $m=1$ and $m=2$. Based on the following criteria, if the model with one threshold ($m=1$) is better than the two-threshold model ($m=2$), then there will be two regimes. The number of thresholds represents the number of location parameters, which means that if one threshold exists, there is only one location parameter. Similarly, two thresholds imply two location parameters ($m=2$) and three regimes. Therefore, the ideal model based on the Schwarz Criterion (SC) and Akaike Information Criterion (AIC) should be selected after estimating each case. Table 5 shows that the PSTR model with one threshold is optimal according to

both AIC and SC. Thus, the PSTR model with one threshold and one location parameter ($m=1$) is selected.

Table 5. Determining the Number of Location Parameters

PSTR model	$m=1$	$m=2$
AIC criterion	-6.7165	-6.7002
Schwarz criterion	-6.4430	-6.4096

Source: Research findings.

As mentioned previously, the problem of non-stationary variables must be solved before analyzing the results. The presence of non-stationary variables leads to spurious regression, for which two procedures can be followed. The first is differencing, which annihilates important information related to the variables and any long-run relationship among them. As our intention in this research was to model the non-linear relationship between variables, it was essential to use the variables at a particular level. Therefore, differencing the variables would not be desirable. The second method to overcome this problem, as presented by Kadilli and Markov (2011) in PSTR, is to test whether the residuals of the PSTR model are stationary. If the residuals are stationary, the model's estimation is consistent, and no spurious regression exists. Therefore, following Kadilli and Markov (2011), the residuals of the PSTR model were extracted using Im et al. (2003) (Table 6).

Table 6. Residuals of the PSTR Model

Statistic	-4.16321
Prob.	0.0000

Source: Research findings.

Based on Table 6, the residuals of the PSTR model are stationary, indicating that there is no spurious regression, and the model estimation is consistent. Therefore, the model can be estimated. After selecting the PSTR model with one transition function and one threshold parameter, which means a two-regime model, the PSTR model is estimated in Table 7.

Table 7 shows the results obtained for the estimated model. According to this table, the slope parameter, expressing the adjustment speed between the two regimes, is relatively sharp and equals 88.1237. The regime-switching location (location parameter) is 1.6091. Thus, if the political and governance index exceeds 1.6091, the variables behave under the second regime; otherwise, they will be in the first regime. Since the coefficients of the variables change according to the

value of the transition variable (political and governance index) and slope parameter, they do not remain the same for different countries and at different times. Consequently, the data presented in Table 7 cannot be directly elucidated, and only the signs of regression coefficients may be interpreted. The trend of the transition function is displayed in Figure 1.

Table 7. Parameter Estimation of the PSTR

Dependent Variable: Renewable Energy Consumption		
Model		
Variable	First regime coefficients	Second regime coefficients
<i>LTrade</i>	0.0397 (0.3640)	1.0387 (10.8791)
<i>CO2</i>	-0.0328 (-6.1493)	-0.0218 (1.5894)
<i>lopec</i>	0.0188 (0.6509)	0.0834 (1.4974)
<i>R&D</i>	0.4758 (4.3547)	0.1199 (-3.4249)
<i>ED</i>	-0.0319 (-1.7077)	0.0666 (2.5187)
<i>GI</i>	0.0208 (0.6759)	0.1959 (2.5197)
<i>Lgini</i>	1.5139 (10.6954)	0.7274 (-4.2248)
Location parameter: C=1.6091		
Slope parameter: $\gamma=88.1237$		

Source: Research findings.

Note: Values in parentheses are *t*-ratios; the author's research.

The two existing extreme regimes are examined to provide a more explicit understanding of the obtained results:

The first regime corresponds to the case where the slope parameter tends toward infinity, and the transition variable's value is less than the threshold level (location parameter). In this condition, the transition function takes the value of zero, and the PSTR model is specified as follows:

$$LRE = c + 0.0397LTrade_{it} - 0.0328CO2_{it} + 0.0188lopec_{it} + 0.4758R\&D_{it} - 0.319Ed_{it} + 0.0208GI_{it} + 1.5139Lgini_{it} \quad (12)$$

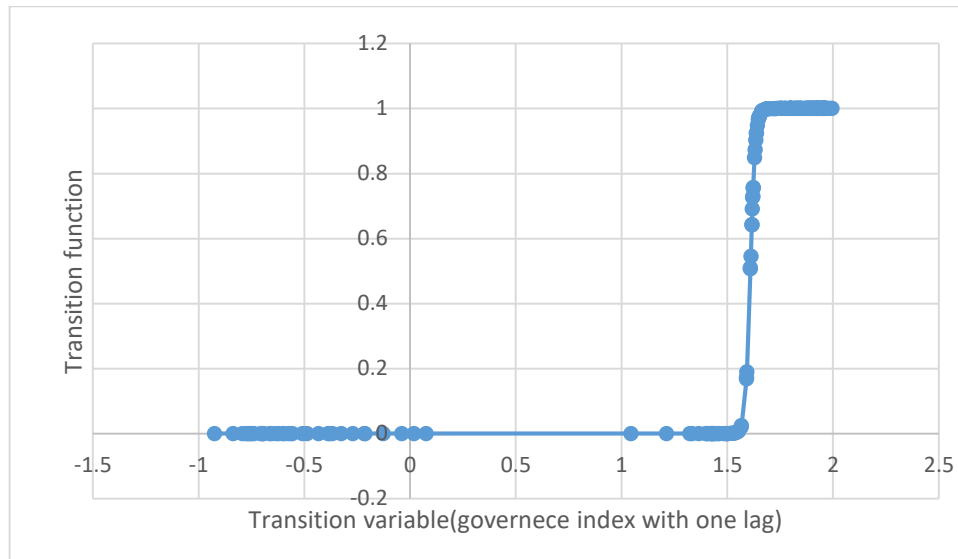


Figure 1. Trend of the Transition Function

Source: Research findings.

The second extreme regime represents the case where the slope parameter tends toward infinity; however, unlike the previous regime, the transition variable (political and governance index with one lag) is greater than the threshold parameter. As a result, the transition function takes the value of 1, and the PSTR model can be specified as follows:

(13)

$$LRE = C + 1.0387LTrade_{it} - 0.0218Co2_{it} + 0.0834lopec_{it} + 0.1199R\&D_{it} + 0.0666ED_{it} + 0.1959GI_{it} + 0.7274Lgini_{it}$$

It can be concluded from the results that the estimated coefficients of the ratio of research and development expenditures to GDP are significant and positive in both regimes. Nevertheless, in the second regime, the research and development coefficient ($\alpha_4 + \beta_4 = 0.1199$) is lower than that of the first regime ($\alpha_4 = 0.4758$). By increasing research and development expenditures, renewable energy consumption surges, and after the political and governance index exceeds the threshold value of 1.6091, the effect of an increase in research and development expenditures compared to before the threshold parameter (first regime) drops.

As demonstrated in Figure 2, the regime switch between the two regimes occurs with a relatively sharp transition speed. This phenomenon can be justified by stating that in the second regime, the effect of technological innovation decreases due to high production, although most of these countries are developed countries and produce and export in high quantities.

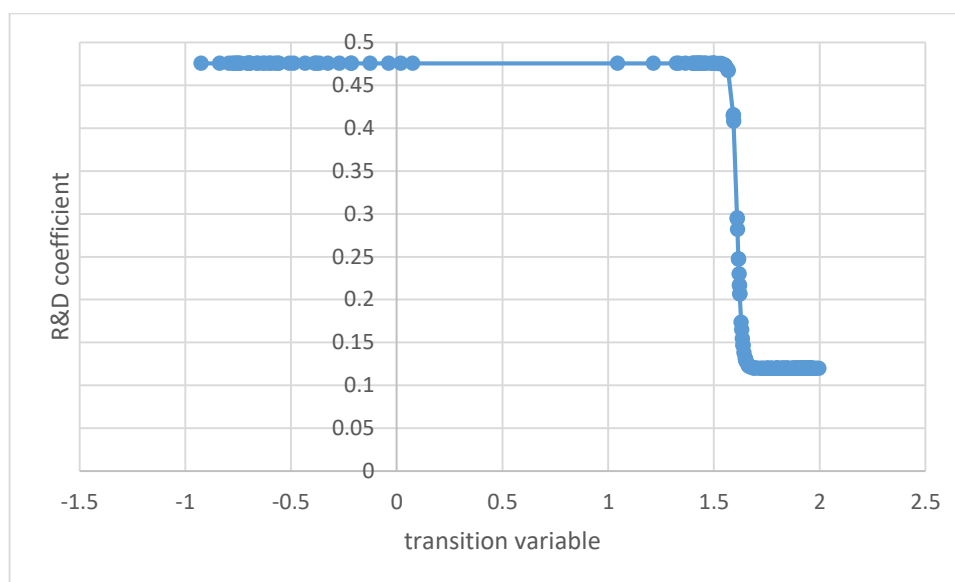


Figure 2. Research and Development Coefficients

Source: Research findings.

Export diversification has a significant and negative effect ($\alpha_5 = -0.0319$) in the first regime and a significant and positive effect ($\alpha_5 + \beta_5 = -0.0319 + 0.0985 = 0.0666$) in the second regime. In other words, with an increase in export diversification, the consumption of renewable energy initially rises in the first regime, and then, after the political and governance index exceeds the threshold level of 1.6091, further increases in export diversification reduce renewable energy usage. This finding indicates that in the first regime, the increase in the export of new and traditional products has strengthened renewable energy consumption in these countries. This could be because, to increase export earnings, these countries have improved their export portfolio, which raised the demand for energy, especially renewable energies. However, as we move to the second regime and the number of exports surpasses a certain threshold, renewable energies are no longer sufficient to meet the energy demand, and the consumption of fossil fuels increases while the consumption of clean energies decreases.

The significant and positive coefficient of the Gini index in the first regime ($\alpha_7 = 1.5139$) and the significant and positive coefficient in the second regime ($\alpha_7 + \beta_7 = 1.5139 - 0.7865 = 0.7274$) indicate that in both regimes, an increase in the Gini index raises the renewable energy consumption. However, the coefficient of the Gini index in the first regime ($\alpha_7 = 1.5139$) is higher than that of the second regime ($\alpha_7 + \beta_7 = 0.7274$), which means the effect of an increase in the Gini index in

the second regime declines compared to before the threshold parameter (first regime). One explanation for this result is that the production of renewable energies has very high initial and basic infrastructural costs; thus, huge financial resources are needed. The accumulation of such a large amount of wealth and monetary resources in the hands of the private sector, such as entrepreneurs and factory owners who can actively participate in energy transition, may increase the unequal income distribution and, subsequently, the Gini coefficient. Therefore, in the first regime, the Gini index can positively affect the consumption and production of renewable energies if the government makes the proper decisions regarding the promotion of cleaner energy solutions. However, as we enter the second regime, the positive effect of this variable decreases. In this regard, it can be argued that increased income inequality may have forced society to use cheap, non-renewable energies, such as coal, crude oil, and wood, for commercial and domestic consumption.

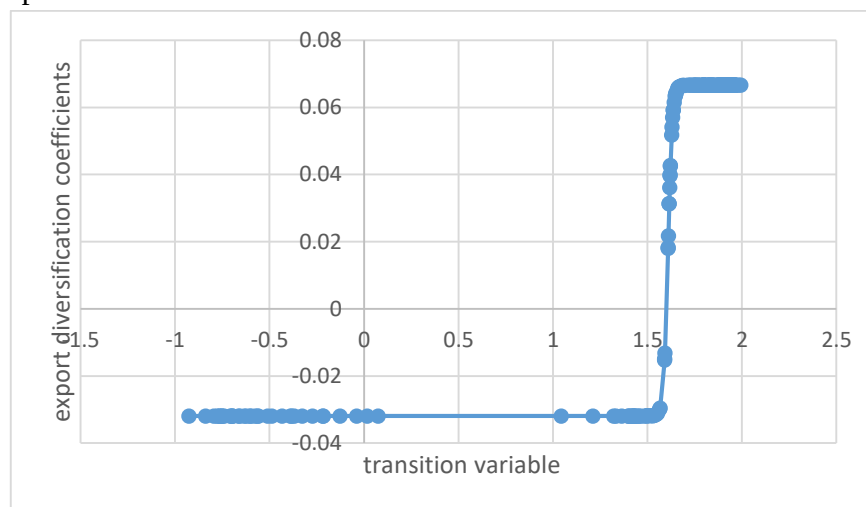


Figure 3. Export Diversification Coefficients

Source: Research findings.

Conclusion and Policy Implications

In recent decades, renewable energies have attracted significant attention due to their role in solving environmental challenges, preventing the waste of fossil fuels, protecting natural resources for future generations, and their importance in the green economy and sustainable development. As a result, many experts and researchers have studied renewable (clean) energies and the factors affecting them. Export diversification and technological innovation are among the factors influencing renewable energies, identified in some studies as relating to the

demand and consumption of renewable energies. Various econometric techniques and models have been adopted to investigate the effects of export diversification and technological innovation on renewable energy consumption. However, due to the novelty of these issues, further research is required to obtain more accurate and reliable information. This led us to focus our attention on this particular problem. This study aimed to explore the role of different levels of political and governance indices in the impact of various variables on renewable energy consumption using the econometric approach of PSTR models for 10 selected countries from 1996 to 2014. Since previous studies have evaluated the linear relationship between the desired variables, this study examined the non-linear relationship between the variables to provide more valid results and address the limitations of the literature. According to the estimation, using one transition function with one threshold parameter (regime-switching location) was sufficient to specify the non-linear behavior. The results indicated that if the political and governance index (governance quality) exceeds 1.6091 with a speed of 88.1237, it leads to regime-switching. The results related to the coefficients of the variables also revealed that export diversification changes and becomes positive after crossing the threshold limit. On the other hand, the ratio of trade to GDP, the log value of OPEC oil prices, research and development expenditures, the political and governance index, and Gini index had positive coefficients in both regimes. Additionally, carbon dioxide emissions per capita had a negative coefficient in both regimes.

Passing the threshold caused the positive effect of research and development expenditures on renewable energy consumption to decline. This might be because the high production levels and their significant role in international trade and market share reduce the effect of technological innovation on renewable energy consumption in the second regime. Regarding export diversification, the negative coefficient of this variable changed to a positive one by transitioning from the first to the second regime. This can be explained by the fact that in the first regime, a rise in the production of traditional and new products increases the demand and consumption of renewable energy. However, with the transition to the second regime and further production increases, renewable energies became insufficient to meet the energy demand. As a result, the demand and consumption of fossil fuels increased, which had a negative effect on the consumption of renewable energies.

Based on the findings of this study, the following policy recommendations can be made to increase renewable energy consumption in countries: (i), Governments should adopt policies that facilitate the import and export of

renewable energy technologies and components. Lowering tariffs and removing trade barriers on renewable energy goods can promote the global exchange and adoption of clean energy solutions. (ii), By maintaining higher oil prices, international cooperation can make renewable energy sources more competitive. This economic incentive can drive greater investment and consumption in renewables. (iii), Significant boosts in funding for research and development in renewable energy technologies are essential. This investment can lead to innovations that reduce costs and improve the efficiency and effectiveness of renewable energy sources. Improving research and development enables industries that export new products to produce them using clean energy and efficient production processes. Otherwise, the engines of economic growth may be derailed, leading to decreased employment, industrial production, and demand for renewable energy. (iv), Strengthening institutional frameworks to enhance governance quality is critical. Transparent, accountable, and efficient governance creates a conducive environment for the implementation and enforcement of renewable energy policies. (v), Developing and enforcing stringent regulations and incentives aimed at reducing CO₂ emissions are vital. Carbon pricing mechanisms, such as carbon taxes or cap-and-trade systems, can encourage a shift from fossil fuels to renewable energy sources, also governments can provide tax exemptions for units willing to switch from fossil fuels to renewable energies. (vi), Investment in public awareness campaigns and educational programs to highlight the benefits of renewable energy is crucial. Increased public support can drive policy changes and boost the adoption of renewable technologies. (vii), Encouraging collaborations between the public and private sectors to fund and deploy renewable energy projects is important. These partnerships can leverage private sector efficiency and innovation with public sector support and regulation. (viii), Implementing policies that support decentralized renewable energy projects, such as community solar and wind projects, can drive grassroots adoption. (ix), Designing the export pattern to ensure that economic development does not disregard environmental commitments or create negative externalities that impose social and environmental costs. (x), Export earnings should be used to promote renewable energy sources. Otherwise, efforts to increase export earnings may intensify fossil fuel consumption, and society may continue to bear environmental costs. Finally, households' financial ability and environmental awareness should be improved to expand renewable energies in all aspects of life, including the household sector. Governments can enhance the production and consumption of renewable energy by considering these points.

Limitation and Recommendation

This research was conducted on only 10 oil-producing countries, namely Argentina, Canada, Colombia, Denmark, Finland, France, Germany, Norway, Sweden, and the United States, between 1996 and 2014. By adding more countries or altering the period, the results can be compared with the findings in the literature to test their validity. Future studies that consider demographic features such as age, race, sex, birth rate, death rate, and income and geopolitical uncertainty as factors influencing renewable energy can provide a broader perspective to the scientific community and policymakers.

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