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Renewable energy drivers in the European Union – evidence from the panel data threshold regression model

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Abstract

The study examines the effect of increasing energy prices on the growth rate of the share of renewable energy in gross final energy consumption across EU member states under different GDP growth regimes in the years 2009–2017. The issue is addressed by means of the non-dynamic panel threshold regression model with individual-specific fixed effects as proposed by Hansen (1999). Empirical results of the study suggest the existence of a GDP growth rate threshold (3.1%) for the influence of increases in energy prices on the growth rate of the share of renewables in gross final energy consumption across EU member states.

Keywords: renewable energy consumption, the European Union, panel data, threshold

JEL: C33, Q42

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1 Introduction

Concerns over the environmental impact of carbon emissions and energy security have resulted in growing interest in renewable energy sources. This world-wide trend is particularly evident in Europe, where the European Union (hereinafter the EU) is implementing ambitious climate change policies. Renewable energy is one of the key elements in EU climate change policy. The EU strives to become a global leader in renewables.

One of the main goals of the EU in combating climate change is to increase the share of renewable energy in the final consumption of energy since renewable energy gives rise to fewer carbon dioxide emissions than fossil fuels and, in some cases, even zero emissions. The effect is confirmed by the findings of a number of various studies (cf. Hernández et al. 2004; Kelly 2006).

In 2009, the EU adopted the so-called climate and energy package. The package includes the Renewable Energy Directive, which provides a framework for promoting renewable energy across the EU and has started a period of intensive actions across Europe to increase the deployment of renewables. The directive stipulates the legally binding national targets for the share of energy from renewable sources in gross final energy consumption in 2020. Those targets are consistent with the EU's objective of increasing the share of renewable energy in gross final energy consumption in 2020 to 20%.

In December 2018, the revised renewable energy directive entered into force as an element of the Clean Energy for all Europeans package. The new directive stresses the need for the EU to maintain its position as the world leader in renewables and defines a new renewable energy target for the EU in 2030 (i.e. 32% of the gross final energy consumption). The implementation of such an ambitious climate change policy implies involving a lot of economic resources, both private and public, in order to transform energy systems towards renewables.

Based on the above-mentioned arrangements and targets, a question arises: what drives the share of renewable energy in gross final energy consumption across EU member states? The question is important from the viewpoint of macroeconomics, public policy and environmental economics.

The empirical objective of the study is to examine the influence that energy prices exert on the growth rate of the share of renewable energy in gross final energy consumption across EU member states under different gross domestic product growth rate regimes. The asymmetric effect of energy prices on the contribution of renewables to energy consumption has been already reported in the literature. However, the occurrence of this effect has not yet been investigated in the EU.

The issue is addressed by means of the non-dynamic panel threshold model with individual--specific fixed effects. This method not only offers all the advantages of fixed-effects panel data models, but it also enables the capture of asymmetric effects and non-linear relationships.

The remaining part of the paper is structured as follows. The section 2 presents a literature review on the relationship between renewables and economic variables. The next section gives an overview of the methods used. Next, the data sources and summary statistics for all the variables are presented. The penultimate section deals with the results and findings of the analysis. The final section provides space for conclusions.

2 Literature review

The literature focusing on renewable energy consumption and the share of renewable energy in the gross final energy consumption has expanded greatly over the last decade. Some of the researchers are mostly interested in the nexus between renewable energy and economic growth (the most recent and most comprehensive survey on the energy-growth nexus is owed to Tiba and Omri (2017)). However, there is also a growing literature regarding the relationship between renewable energy consumption and energy prices.

Sadorsky (2009a) used panel cointegration techniques to examine the factors influencing renewable energy consumption in the G7 countries. He demonstrated that the impact of real GDP per capita and carbon dioxide emissions per capita on renewable energy consumption per capita in the G7 countries were positive, while the effect of oil prices on renewable energy consumption was negative. Using similar methods, Sadorsky (2009b) also found empirical evidence for the positive relationship between GDP and renewable energy consumption in some 18 emerging economies. Apergis and Payne (2010a, 2010b) used the multivariate panel data framework to demonstrate the long-run equilibrium relationship between real GDP, renewable energy consumption, real gross fixed capital formation and the labour force in 20 OECD countries and 13 countries within Eurasia.

An interesting study is by Chang, Huang and Lee (2009), who found empirical evidence for the existence of a GDP threshold for the influence of increases in energy prices on the contribution of renewable energy to energy supply. They also found that the effect of energy prices on the contribution of renewable energy to energy supply is asymmetric.

Omri and Nguyen (2014) examined a global panel of 64 countries (and three subpanels) over the years 1990–2011 using a dynamic system-GMM panel model. They found that the increases in carbon dioxide emissions and trade openness were the major drivers of renewable energy consumption. The effect exerted by the increasing oil prices was found smaller and negative.

3 Methods

The empirical objective of the study is to examine the influence that energy prices have on the growth rate of the share of renewable energy under different economic growth regimes.

The research addresses this issue by means of the non-dynamic panel threshold regression model with individual-specific fixed effects as proposed by Hansen (1999).

Fixed effects are justified on the grounds of conducting a cross-country study. They are expected country-specific levels of RES growth rates assuming all other variables are equal to zero. Thus, it can be stated that they comprise all the time-invariant factors that affect the growth rate of renewable energy share in a given country (such as the abundance of renewable energy sources in a given country, the overall policy approach towards developing renewable energy expressed in specific regulations and financial incentives which at least in the short-term are assumed to be constant, etc.). Therefore, using individual-specific fixed effects is beneficial to our study as they allow control of all the time-invariant variables.

Within the panel threshold regression model the observations are divided into two 'regimes', depending on whether the threshold variable (the annual growth rate of GDP, year over year) is smaller or larger than the estimated threshold (it is possible to develop models with multiple thresholds). The regimes are differentiated on the grounds of different regression slopes.

The terms $gRES_{it}$, $gGDP_{it}$, and $HICP_{it}$ denote, respectively, the logarithmic growth rate of the share of renewables in the gross final energy consumption in a given year (the dependent variable), the annual GDP growth rate, and the HICP as it relates to energy (the independent variables).

The model takes the following form:

$$gRES_{it} = \mu_i + \beta_1^{'} gGDP_{it} + \beta_2^{'} HICP_{it} I\left(gGDP_{it} \leq \gamma\right) + \beta_3^{'} HICP_{it} I\left(gGDP_{it} > \gamma\right) + e_{it} \qquad (1)$$

where the intercept term μ_i refers to the individual-specific mean, and the subscript i indexes the individual country, while the subscript t indexes time. $I(\cdot)$ is the indicator function. γ is the optimal threshold parameter that distinguishes two regimes (lower and higher) for which the specific estimates of the slope coefficients are $\beta_2^{'}$ and $\beta_3^{'}$. The error term e_{it} is assumed to be independent and identically distributed (iid) with mean zero and finite variance σ^2.

The above-stated model specification is justified on the basis of the findings of the previous studies that stressed the relationships between renewable energy consumption, energy prices and economic growth (cf. the literature review section). Although energy prices are reported to be a significant factor affecting renewable energy consumption, there is no consensus regarding the nature of the relationship, with various studies revealing either a negative or positive relation (cf. Chang, Huang, Lee 2009; Omri, Nguyen 2014). Therefore, further research is still needed. Including economic growth in modelling energy consumption has already become a standard since it is perceived as the main economic constraint (Tiba, Omri 2017). Initially, the model was estimated in such a way that it included some control variables for factors that were considered in previous studies (i.e. the growth rate of greenhouse gas emissions and energy intensity). However, their coefficients were statistically insignificant, thus they were not included in the final model presented in this paper.

Following Hansen's approach, a threshold and regression slopes are estimated by means of fixed-effects transformations and least squares.

A traditional method to estimate the fixed effect panel data model is to remove individual effect μ_i by computing averages over time:

$$\overline{gRES}_{it} = \mu_i + \beta_1^{'} \overline{gGDP}_{it} + \beta_2^{'} \overline{HICP_{it} I\left(gGDP_{it} \leq \gamma\right)} + \beta_3^{'} \overline{HICP_{it} I\left(gGDP_{it} > \gamma\right)} + \overline{e}_{it} \qquad (2)$$

Taking the difference between equation (1) and equation (2) produces:

$$gRES_{it}^{*} = \beta_1^{'} gGDP_{it}^{*} + \beta_2^{'} HICP_{it}^{*} I\left(gGDP_{it} \leq \gamma\right) + \beta_3^{'} HICP_{it}^{*} I\left(gGDP_{it} > \gamma\right) + e_{it}^{*} \qquad (3)$$

Now let

$$x_{it}^{*}(\gamma)=\begin{pmatrix} gGDP_{it}^{*} \\ HICP_{it}^{*}I(gGDP_{it}\leq\gamma) \\ HICP_{it}^{*}I(gGDP_{it}>\gamma) \end{pmatrix},\ y_{it}^{*}=gRES_{it}^{*},\text{ and }\beta=\left(\beta_{1}^{'}\beta_{2}^{'}\beta_{3}^{'}\right)^{'}$$

Equation (4) equals now

$$y_{it}^{*}=\beta' x_{it}^{*}(\gamma)+e_{it}^{*} \tag{4}$$

Let y_{i}^{*}, $x_{i}^{*}(\gamma)$, and e_{i}^{*} be vectors of y_{it}^{*}, $x_{it}^{*}(\gamma)'$, and e_{it}^{*} respectively with the first observation deleted. Finally, let Y^{*}, $X^{*}(\gamma)$, and e^{*} denote the data stacked over all individuals. Our equation of interest is now represented by:

$$Y^{*}=X^{*}(\gamma)\beta+e^{*} \tag{5}$$

For any given γ, the slope coefficients β can be estimated by ordinary least squares method (OLS) in the following way:

$$\hat{\beta}(\gamma)=\left(X^{*}(\gamma)'X^{*}(\gamma)\right)^{-1}X^{*}(\gamma)'Y^{*} \tag{6}$$

Once $\hat{\beta}(\gamma)$ is estimated, the vector of residuals can be computed:

$$\hat{e}^{*}(\gamma)=Y^{*}-X^{*}(\gamma)\hat{\beta}(\gamma) \tag{7}$$

The sum of squared errors is calculated by:

$$S_{1}(\gamma)=\hat{e}^{*}(\gamma)'\hat{e}^{*}(\gamma) \tag{8}$$

The estimation of γ as recommended by Hansen (2000) is the minimization of the concentrated sum of squared errors $S_{1}(\gamma)$. The estimator of γ is:

$$\hat{\gamma}=\arg\min_{\gamma}S_{1}(\gamma) \tag{9}$$

The estimators of the slope coefficients are $\hat{\beta}=\hat{\beta}(\hat{\gamma})$.

In order to determine whether the threshold effect is statistically significant the non-standard asymptotic theory and the bootstrap method are employed as recommended by Hansen (1999).

Let us test the null hypothesis of no threshold effect in equation (1), so $H_{0}:\beta_{2}=\beta_{3}$. Since the threshold is not identified, classical tests have non-standard distributions. For fixed-effects models, Hansen (1996) recommends to apply a bootstrap method to simulate the asymptotic distribution of the likelihood ratio test. The likelihood ratio test statistic is:

$$F_1(\gamma)=\frac{S_0-S_1(\hat{\gamma})}{\hat{\sigma}^2} \tag{10}$$

where the sum of squared errors S_0 is yielded by OLS under the null hypothesis of no threshold effect. The asymptotic distribution of $F_1(\gamma)$ is non-standard and depends upon moments of the sample.

Hansen (1996) has shown that the bootstrap method attains the first-order asymptotic distribution, therefore p-values constructed from the bootstrap are asymptotically valid (the description of the bootstrap method falls out of the scope of this paper).

If the alternative hypothesis (H_1: $\beta_2 \neq \beta_3$) is true and there is a threshold effect, $\hat{\gamma}$ is consistent for γ_0 and the asymptotic distribution is highly non-standard (Hansen 2000; Chan 1993). Hansen (2000) recommends to use the likelihood ratio statistic for tests on γ to form confidence intervals for γ. The null hypothesis is $\gamma = \gamma_0$, and the likelihood ratio test statistic is:

$$LR_1(\gamma)=\frac{S_1(\gamma)-S_1(\hat{\gamma})}{\hat{\sigma}^2} \tag{11}$$

Based on the theorem $LR_1(\gamma)\rightarrow d\xi$, as $n\rightarrow\infty$, where ξ is a random variable with the following distribution function:

$$P(\xi\leq x)=\left(1-\exp\left(-\frac{x}{2}\right)\right)^2 \tag{12}$$

Hansen (1999) argues that the asymptotic distribution of the likelihood ratio statistic is non--standard but free of nuisance parameters. The asymptotic distribution may be used for valid asymptotic confidence intervals. The distribution function (10) has the inverse:

$$c(\alpha)=-2\log\left(1-\sqrt{1-\alpha}\right) \tag{13}$$

from which one can compute critical values. The 5% critical value is 7.35.

4 Data

The empirical panel data encompasses all EU member states and covers the period of nine years between 2009 and 2017 (252 observations in total). In 2009, the climate and energy package was adopted and this act can be viewed as a milestone in the EU climate change policy and a declaration to switch to widespread use of renewables. Thus, 2009 marked the beginning of a new era of promoting renewables across the EU.

The data used forms a balanced panel and has been sourced from the Eurostat database.

Table 1 presents summary statistics for each of the four variables. The sample means of all the variables are found to be positive. All the variables have relatively great standard deviations compared to their mean values.

Table 1
Summary statistics

Variable	Mean (%)	Standard deviation	Minimum	Maximum	Jarque-Bera test (p-value)
Growth rate of the share of renewables in gross final energy consumption	6.76457	12.41582	-13.16837	151.95429	59217.08258 (0.0000)
GDP growth rate	1.16111	3.85846	-14.8	25.1	674.19401 (0.0000)
The HICP of energy	1.58514	7.42951	-15.85658	30.35544	3.63239 (0.16264)

Source: author's own computation based on Eurostat data.

The greatest negative growth rate of the share of renewables in gross final energy consumption was observed in 2011 in France (-13.16837%). In turn, the greatest increase in the variable was observed in 2010 in Malta (151.95429%). However, one should bear in mind that Malta had a very low initial level of the share of renewables in gross final consumption of energy (in 2009, the figure was below 1%). On average, EU member states were reporting a growth rate of the share of renewables in gross final energy consumption of 6.76457% annually in the years 2009–2017.

In 2009, all the Baltic states underwent severe economic difficulties as a result of the burst of the housing bubble in their markets and the global financial crisis. Estonia, Lithuania, and Latvia reported negative GDP growth rates below 14%, with Lithuania reporting the greatest drop at 14.8% year over year. The highest growth rate was observed in 2015 in Ireland (25.1%), mainly as a product of Irish taxation policy aimed at attracting large companies and encouraging them to relocate their intellectual property to Ireland. On average, in the given period, EU economies were growing by 1.16% annually.

In the years 2009–2017, energy prices were increasing by 1.59% on average. The maximum value of annual HICP of energy (30.36%) was reported in Greece in 2010 as a consequence of a sharp increase in taxes and adjustments in regulated tariffs aimed at closing the gap between them and costs. In turn, the greatest decrease in energy prices (-15.86%) was reported in Luxembourg in 2009.

The Jarque-Bera statistical tests indicate that one should reject the normal distribution hypothesis at the 1% level for all the variables, except for the HICP of energy.

5 Empirical results and discussion

Table 2 shows the results of the threshold estimation. The results suggest the existence of the threshold effect of the GDP growth rate on the relationship between the growth rate of the share of renewables in gross final energy consumption and the HICP of energy. The threshold value is 3.1%. The test $F_1(\gamma)$ for a single threshold is 38.98218, which is greater than the 95% critical value that equals 24.638 (p-value = 0.038). The results provide evidence for a single threshold effect and asymmetric influence of increases in energy prices on the growth rate of the share of renewable energy in gross final energy consumption. It should be noticed that the confidence interval falls within a relatively narrow range.

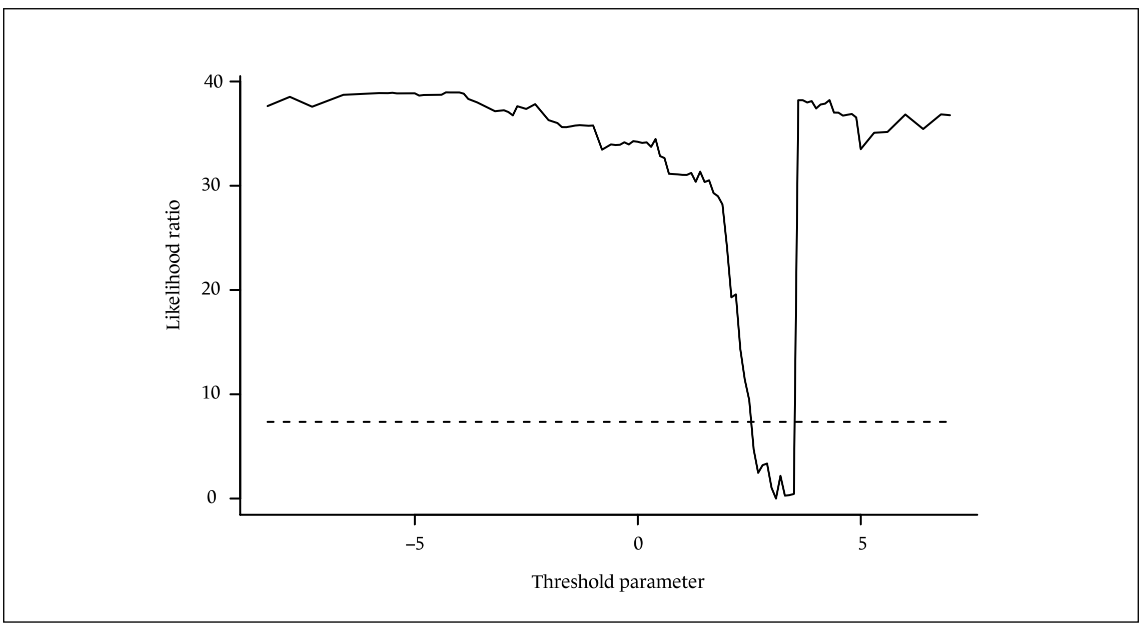
Table 2
Threshold estimate

Threshold parameter	Estimate	95% confidence interval	$F(\gamma)$ (10%, 5%, 1% critical values)
$\hat{\gamma}$	3.1	(2.6, 3.5)	38.98218 (15.0308, 24.638, 163.5019)

Source: author's own computation based on Eurostat and World Bank data.

Figure 1 presents the construction of the confidence interval for the single threshold model. The horizontal axis represents the estimation of the threshold parameter and the vertical axis represents the concentrated likelihood function LR(γ). The 95% confidence interval for γ can be found from LR(γ) based on the value of γ, for which the likelihood ratio lies beneath the dashed line at 7.35 (cf. equation (11)).

Figure 1
Confidence interval construction in single threshold model



Source: author's own work based on Eurostat data (using pdR package in R).

Table 3 shows regression slope estimates including OLS standard errors and White corrected standard errors.

Table 3
Regression estimates

Variable	Coefficient	OLS standard error	White standard error	t-statistic
GDP_{it}	-0.79792***	0.17129	0.19985	-3.99266
$HICP_{it}I\left(GDP_{it} \leq \gamma\right)$	-0.01540	0.09067	0.06895	-0.22333
$HICP_{it}I\left(GDP_{it} > \gamma\right)$	1.25055*	0.19285	0.73779	1.69500

*, **, and *** denote statistical significance at 10%, 5%, and 1% levels, respectively.

Source: author's own computation based on Eurostat data.

The results suggest that the relationship between the HICP of energy and the growth rate of contribution of renewables to energy consumption in non-linear and GDP growth rate plays a crucial role when assessing the effect of the HICP of energy on the growth rate of the share of renewables in gross final energy consumption. When GDP growth rate is equal to or lower than the optimal threshold parameter $\hat{\gamma}$, the estimation of the slope coefficient β'_2 equals -0.01540, which means that increases in energy prices have a small and negative effect on the growth rate of the share of renewables in gross final energy consumption. However, this effect is not statistically significant. In the higher regime (when GDP growth rate is higher than the optimal threshold parameter $\hat{\gamma}$) the slope coefficient β'_3 is 1.25055 (the effect is statistically significant). The results suggest that, in the higher regime, increasing energy prices may indeed enhance the growth rate of the share of renewables in gross final consumption of energy.

The observed asymmetric effect is similar to the one detected by Chang, Huang and Lee (2009) for OECD countries over the period 1997–2006. They reported no relationship between energy prices and the contribution of renewables to energy supply in a lower GDP growth rate regime and a positive relationship in a higher regime. However, their threshold estimation was slightly higher, i.e. 4.13%.

In terms of the EU growth patterns, the value of the observed threshold is high since the mean growth rate is 1.16% for the period of the analysis. There are some EU member states (usually the most developed ones) that never experience such a high economic growth rate. A question arises whether this phenomenon translates into a finding that the increase in RES is not possible without growth. The answer to this question should be negative. The model refers to growth rates and thus it should be read that in high economic growth rate circumstances, the growth of RES can be advanced by increasing energy prices. However, for every country there is a constant (intercept) in the RES growth rate model that occurs when both the GDP and HICP of energy growth rates are equal to zero.

The existence of the threshold effect and asymmetric influence of increases in energy prices on the growth rate of the share of renewable energy can be accounted for on the grounds of energy availability and its production cost. As in most cases fossil fuels and fossil fuels-derived products are considered to be substitutes for renewables, it is expected that increasing energy prices will trigger the substitution effect. However, it seems that this effect is not unconditional, since the infrastructure for using fossil fuels is usually already in place and initial investments needed to deploy renewables are relatively high. In turn, low-growth countries may tend to concentrate their resources on other policies, and in some cases they may even consider decreasing their investment in deploying renewables to mitigate the impact of increased energy prices. On the other hand, when energy prices increase, countries enjoying fast economic development are able to respond to price increases by switching to renewables to meet their extra energy needs, to avoid the negative relationship between fossil fuels prices and GDP, and to reduce their dependency on the import of fossil fuels.

What is quite surprising, compared to the results of Chang, Huang and Lee (2009), is the sign of the GDP growth rate coefficient. The coefficient β'_1 = -0.79792 for the regressor GDP_{it} is statistically significant and negative. However, as mentioned earlier, in the EU, increasing the share of renewables has become an important goal of the climate change policy. EU member states are obligated to implement the climate change policy regardless of their economic condition. The other explanation is that more fossil fuels are being consumed as economic growth proceeds since, compared to renewables, they are more stable and more efficient energy sources, or it is simply easier to meet extra energy needs by making use of them.

6 Conclusions

The empirical results of the study suggest the existence of a GDP growth rate threshold for the influence of energy prices on the growth rate of the share of renewables in gross final energy consumption in EU member states. When GDP growth rate is more than 3.1% annually, increasing energy prices has a positive impact on the growth rate of the share of energy from renewable sources in gross final energy consumption. The results are statistically significant.

The empirical findings support the idea of promoting renewable energy sources by means of a carbon tax or any other taxation resulting in increases in energy prices. However, the positive effect of increasing energy prices on the growth rate of renewables' contribution to energy consumption occurs only when economic conditions are favourable.

The research is valuable in a number of ways. First of all, the study covers all the EU member states and examines a relatively long period after the adoption of the climate and energy package which initiated EU enhanced efforts to replace fossil fuels with renewables. Secondly, the empirical findings are of practical importance and contribute to the overall knowledge supporting the shaping the EU climate change policy. Thirdly, the study confronts the results of previous studies and sheds light upon the changes that have happened over the years.

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Czynniki rozwoju energii odnawialnej w Unii Europejskiej – wnioski z analizy regresji progowej danych panelowych

Streszczenie

Celem niniejszego artykułu jest identyfikacja czynników makroekonomicznych kształtujących tempo wzrostu udziału energii odnawialnej w finalnej konsumpcji energii w państwach członkowskich Unii Europejskiej w krótkim okresie. W szczególności w artykule skupiono się na wpływie wzrostu cen energii na stopę wzrostu udziału energii odnawialnej w finalnej konsumpcji energii. Postawiono hipotezę, uzasadnioną wynikami wcześniejszych badań, że relacja ta ma charakter nieliniowy i zależy od tempa wzrostu PKB.

Przeprowadzone badanie empiryczne objęło wszystkie państwa członkowskie Unii Europejskiej i dotyczyło okresu 2009–2017. Początek okresu analizy uzasadniony jest przyjęciem pakietu energetyczno-klimatycznego, tworzącego ramy promowania odnawialnych źródeł energii w Unii Europejskiej. W badaniu empirycznym wykorzystano statyczny model regresji progowej dla danych panelowych, zgodnie z procedurą zaproponowaną przez Hansena (1999). Metoda ta pozwala na identyfikację nieliniowego związku między zmienną objaśnianą a zmienną objaśniającą w zależności od wartości innej zmiennej objaśniającej. Dodatkową zaletą tego modelu jest zastosowanie efektów stałych, które pozwalają na uwzględnienie specyficznych dla danego kraju niezmiennych w czasie czynników, takich jak np. jego uwarunkowania naturalne determinujące dostępność odnawialnych źródeł energii.

W wyniku przeprowadzonego badania empirycznego wykazano istnienie istotnego statystycznie pozytywnego związku między tempem wzrostu cen energii a tempem wzrostu udziału energii odnawialnej w finalnej konsumpcji energii w przypadku przekroczenia 3,1% tempa wzrostu PKB. Z kolei dla wolniejszego tempa wzrostu PKB zidentyfikowano zależność negatywną (niemniej nie jest ona istotna statystycznie). Oznacza to, że związek między stopą wzrostu udziału energii odnawialnej w finalnej konsumpcji energii a tempem wzrostu cen energii w państwach Unii Europejskiej ma charakter asymetryczny i zależy od stopy wzrostu gospodarczego. Wyjaśnienia zaobserwowanych zjawisk należy szukać w przynajmniej częściowej substytucyjności paliw kopalnych i odnawialnych źródeł energii. Jednakże koszt pozyskania energii ze źródeł odnawialnych, w szczególności początkowe nakłady inwestycyjne umożliwiające rozpoczęcie produkcji energii odnawialnej, powoduje, że jedynie państwa o wysokiej stopie wzrostu są w stanie wygospodarować środki na mobilizację zasobów energii odnawialnej. Z punktu widzenia polityki gospodarczej uzyskane wyniki oznaczają, że decydenci, odpowiedzialni za projektowanie ścieżki wzrostu udziału energii odnawialnej w finalnej konsumpcji energii i dobór narzędzi jej promowania (np. w postaci tzw. podatku węglowego), powinni brać pod uwagę uwarunkowania ogólnogospodarcze.

Słowa kluczowe: konsumpcja energii odnawialnej, Unia Europejska, dane panelowe, próg