Determinants of the renewable energy development in the EU countries. A 20-year perspective

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Abstract

The objective of the paper is to identify factors shaping energy policy in the EU countries in the middle of 1990s. This objective is achieved in two stages. During the first one, using PCA, we describe the distribution of energy sources in 26 EU countries in 1995. We find four main principal components distinguishing countries in terms of energy source consumption in 1995, and then, during the second stage, use them as potential determinants of renewable energy development. We also consider several factors related to energy security, environmental concerns, economy and politics.

Applying two methods of variable selection, namely, the best subset regression and the lasso method, we demonstrate that the present (in 2014) share of RES in the energy mix significantly depends on the condition of the EU countries in the middle of 1990s. Our study reveals that the distribution of energy sources in 1995 is the main determinant of renewable energy development. Countries without their own fossil fuel sources are the ones with the greatest development of renewable energy. Other factors affecting RE development include: GDP per capita, the Shannon–Wiener index (SWI) reflecting the concentration of energy supply, and the cost of the consumption of energy obtained from fossil fuels in relation to GDP.

Keywords: *Renewable energy, European Union, LASSO, PCA*

JEL Classification: C31, C38, N74, Q2

1 Introduction

Fossil fuels lay the foundation of energy balance in the European Union member countries. Their share in the total primary energy supply (hereafter TPES) in 2014 amounted to 34.4% for oil, 21.4% for natural gas and 16.7% for coal. Nuclear energy constituted 14.1% of the TPES, while renewable energy (hereafter RE) – 12.5%. In 2014 the TPES in the EU member countries equalled to 1606 Mtoe, and net import constituted 54.8% of the TPES and increased in comparison with 1995, when it constituted 44%. A growing dependence of the EU on imported energy, diminishing deposits of its own resources, and the necessity to provide energy at acceptable prices lead to the increase of the significance of the factors connected

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with energy security and energy policy. The EU dependence on import of energy sources contributes to the growing interest in renewable energy sources (hereafter RES), which is reflected in the introduction of relevant directives in the area of energy policy. Specifying realistic energy policy targets requires thorough knowledge of this area, including knowledge of factors influencing RE development. One might expect abundant subject literature addressing this important issue, however, only several papers directly investigate the determinants of such development (e.g. Marques et al., 2010; Marques and Fuinhas, 2011; Aguirre and Ibikunle, 2014; Cadoret and Padovano, 2016; Lucas et al., 2016, Frodyma, 2017).

The aim of the paper is to identify the main determinants of RE development in the EU countries, with emphasis on how the distribution of energy sources in the middle of 1990s influences RES in 2014. The year 1995 is used as a reference point because it was the year in which the EU initiated legal procedures aimed at promoting RE development and in which the European Commission published *Green Paper* (1995) delineating the European Union energy policy and listing three basis targets connected with gas and electricity monopolies.

The share of RE in the TPES is selected as the dependent variable. This particular variable is chosen because, as stated by Aguirre and Ibikunle, 2014, firstly, policy targets are focused on achieving a certain share of energy from renewable sources in the energy mix, and, secondly, it is expected that RE will successively displace more-polluting energy sources in the energy mix.

In our study it is assumed that RE development is a long-lasting process, and this is why we decide to replace a panel approach commonly used in other studies (see: Marques et al., 2010; Marques and Fuinhas, 2011; Aguirre and Ibikunle, 2014; Cadoret and Padovano, 2016; Lucas et al., 2016), with a cross-sectional regression and a reliable method of variable selection to investigate to what extent the determinants from 1995 influence RE development in 2014. This approach allows us to analyse the impact of a set of determinants connected with the environment, security of supply, economy, and politics.

The first stage of our study focuses on the distribution of energy sources, which seems a key factor in RE development. Several factors contribute to its significant role. Firstly, it is inextricably connected with national energy security, as most EU countries have to import energy sources (mainly oil and gas) from countries outside the EU, and only several of them have sufficient domestic energy sources. Secondly, the share of energy sources in the energy mix in a given country exerts a direct influence on the natural environment, since using e.g. coal is connected with high emissions of pollutants, while using solar energy is not. As opposed to earlier studies (Marques et al., 2010; Marques and Fuinhas, 2011; Lucas et al., 2016; and Cadoret and Padovano, 2016; Frodyma, 2015), which consider only the share of particular energy sources in the overall energy consumption, in our study we use PCA.

During the second stage, we analyse a relatively large set of potential variables, which includes the ones taken into consideration by policy makers when they make decisions regarding the distribution of energy sources, such as energy security, energy self-sufficiency, environmental costs, international treaties and commitments, political costs of potential changes in the structure of energy production, or the political power of interest groups, including miners. In order to distinguish the key determinants of RE development, we use two statistical methods: the best subset regression (hereafter BSR) and the lasso method (Tibshirani, 1996).

2 Methodology

In order to find the determinants of RE development, we analyse 15 (some highly correlated[4]) variables which describe various aspects of European countries in 1995 (outside the area of energy policy) and could be related to the share of RE in the TPES in 2014. The analysis is conducted with the use of standard linear regression framework. The model is given by:

$$Y = X\beta + \varepsilon, \qquad (1)$$

where $\varepsilon = (\varepsilon_1, ..., \varepsilon_n)'$ is a vector of i.i.d. random variables with mean zero and variance σ^2. Y is a $n \times 1$ vector of response, $X = (X_1, ..., X_p)$ is the $n \times p$ matrix of predictors, and β is a *p*-dimensional vector of model parameters.

There are two approaches to limiting the number of variables in the regression model.

The first one is known as the best subset regression (BSR) model. In this approach, each possible subset of predictors of size *k* is considered, where $k \in \{1,2,.., p\}$, and *p* is the total number of variables. Each model is estimated by least squares and then compared to other models by applying a specific criterion (usually adjusted R^2, Akaike information criterion (AIC) or Bayesian information criterion (BIC)[5]). The best subset of variables (and the best model) is the one which maximizes the criterion used. However, this method is time consuming since the total number of combinations of *p* variables is given by: $2^p - 1$. The BSR is, as Efron et al. (2004, p.409) claim, "overly greedy, impulsively eliminating covariates which are correlated with" other covariates.

To avoid this problem, Tibshirani (1996) proposes the lasso (the least absolute shrinkage selection operator) method, which, in order to estimate regression parameters, minimizes the

[4] Detailed results of correlations are available from the authors upon request.

[5] BIC generally places a heavier penalty on models with many variables, and hence results in the selection of more parsimonious models.

sum of squares of residuals with a constraint for parameters:

$$\hat{\beta}(\lambda) = \arg\min_{\beta} \| Y - X\beta \|_2^2 + \lambda \| \beta \|_1, \tag{2}$$

where $\| \cdot \|_1$ is the L_1 norm (the sum of absolute values of the vector's entries), $\lambda \geq 0$ is a tuning parameter which controls the amount of shrinkage applied to the estimates, and $\| \cdot \|_2$ is the standard L_2 norm. For $\lambda = 0$, Eq. (1) is the standard Ordinary Least Squares (without any regularizations). For large λ, $\hat{\beta}$ shrinks to 0, which results in the empty model. Due to the form of the penalty in the lasso (L_1 norm), for moderate λ there are only several non-zero estimates (among all possible choices), thus, the method is useful in the variable selection problem and is our second methodological approach. In 2002 Efron et al. (2002) proposed the LARS (least angle regression) algorithm, which provides an efficient way of using the lasso method and connects the lasso with forward stagewise regression. That is why this method is considered to be one of the most effective ways of solving the variable selection problem in regression applications.

3 Data description and preliminary statistics

We conduct our empirical analysis with the data describing the share of RES in TPES in a sample of 26 European Union member countries. The analysis covers the period between 1995 and 2014, and the data are obtained from the European Commission websites[6]. The study does not include Cyprus and Malta due to the fact that in the analysed period the share of RES in TPES in these countries is almost zero. The first dataset describes the distribution of energy sources. The variables analysed reflect the share of energy sources in TPES and include: solid fuels (including hard coal) (COAL), crude oil and petroleum products (OIL), natural gas (GAS), nuclear energy (NUCL) and renewable energy sources (RES). The second stage of our study is devoted to the search for the determinants of the share of RES. On the basis of literature, we have compiled a list of potential determinants whose role in renewable energy development is verified in our study. Additionally, a set of determinants is expanded by principal components describing the distribution of energy sources in 1995 obtained in the second stage of the study. Following Marques et al. (2010), Cadoret and Padovano (2016) and Lucas et al. 2016, we have chosen a set of potential predictors and divided them into four categories: environmental variables (carbon intensity of energy use - CITPES; the CO_2

[6] Energy datasheets: EU-28 countries (https://ec.europa.eu/energy/en/data-analysis/country, accessed on 30.10.2016 r.

emissions per capita - CICAP), security of supply variables (net energy import in relation to the TPES - DEP; energy self-sufficiency rate - ESS; energy mix concentration - SWI; energy mix diversification - HHI; diversification of energy sources in electricity generation - HHIE; net energy import to GDP - NDEPGDP; net energy import per capita - NDEPCAP; net energy import in relation to GDP – VNTDEPGDP), economic variables (GDP per capita - GDPCAP; energy consumption per capita – EICAP; energy consumption per GDP - EIGDP; consumption of energy obtained from fossil fuels in relation to GDP – VEIFFGDP), and political variables (a dummy variable to identify the EU countries in the year 1995)[7].

4 Results and discussion

The first stage of our study focuses on the analysis of the distribution of energy sources in 1995 in the EU countries and reveals that the first principal component is related to coal and oil variables, which means that it distinguishes countries which either use or do not use coal or crude oil as their main energy sources. Consequently, these countries can be described as countries using either dirty or clean energy. Similarly, the fourth principal component[8] represents the European countries which primarily use clean energy as their main energy source and limited amounts of other energy sources. Crude oil is positively and nuclear energy is negatively correlated with the second principal component, i.e. the countries which use oil as their main energy source and do not use nuclear energy are described by the second principal component. The third principal component is related to all variables, but the factor loading is negative only for natural gas, which means that this component distinguishes countries using natural gas as their main energy source[9].

The second stage of our analysis is devoted to finding determinants of RE development. All variables described in Section 3 are assumed to be potentially important. At first, we present the results of BSR models.

The final BSR model includes seven variables. The detailed results obtained for this model are presented in Table 1. All variables included in the model are significant. Two variables, PC1 and energy consumption per capita (EICAP), have negative parameters and are highly related to high coal consumptions. Thus, it seems obvious that for the countries with a large share of coal consumption in the energy mix RE development is not a priority. It

[7] Detailed information regarding variable definitions and descriptive statistics are available from the authors upon request.

[8] The fifth principal component represents only 1.2% of total variance, thus, is not taken into account.

[9] Detailed data on principal components are available from the authors upon request.

means that countries with high energy consumption per capita in 1995 are not interested in investing in RES. Our results are confirmed by Aguirre and Ibikunle (2014), but not confirmed by Marques et al. (2010), and Lucas et al. (2016), who report opposite relations.

Two other determinants in the model reflect the distribution of energy sources in 1995, namely PC3 and PC4. Both have positive parameters in the final BSR. Countries with large values of these two principal components have either a low share of natural gas consumption in the energy mix (PC3) or a high share of RES (PC4). Countries with such a profile of energy consumption reveal a considerable development of their RES. It is not difficult for countries with significant shares of RES in 1995 to continue their development because they already have relevant legal regulations, technological facilities or conductive geographical and climatic conditions.

However, there is a convincing interpretation of a negative impact of high share of natural gas on RE development. Countries which use natural gas as their main energy source (the Netherlands, the United Kingdom, Romania) are the largest natural gas producers in the UE, and, as such, are not dependent on import of energy sources. Since they can satisfy their basic energy needs with energy they produce themselves, they are not affected by political risks resulting from other energy producers suspending their fossil fuel supplies. Thus, as they already are energy self-sufficient, they are not interested in developing RE. What is more, natural gas is a relatively clean energy source, so, even if a country reduces its consumption, it will not translate into a substantial reduction of CO_2 emissions (which happens when coal consumption is reduced). A positive parameter for GDP per capita (GDPCAP) means that the richest countries are more prone to invest in RE: they can afford expensive RE technologies and support subsidies for promoting and regulating RE. A positive impact of income on the promotion of RE is also found by Marques et al. (2010). Energy security parameter SWI, which describes concentration of energy supply, is also positive. The more diversified energy sources a country has, the more it is interested in developing RE. This means that the relatively even distribution of energy sources in the energy mix motivates the EU countries to promote the development of RE, and this relation is confirmed by Lucas et al. (2016). Finally, the cost of the consumption of energy obtained from fossil fuels in relation to GDP (VEIFFGDP) parameter is positive. Higher prices may make RE more economically viable, thereby encouraging countries to invest in RE.

	Coef	Stand. Error	t-stat	p-value
Intercept	0.05750	0.0556	1.035	0.3146
PC1	-0.13190	0.0457	-2.885	0.0098 ***
PC3	0.30430	0.0615	4.949	0.0001 ***
PC4	0.96170	0.0922	10.428	0.0000 ***
GDPCAP	0.00520	0.0016	3.169	0.0053 ***
EICAP	-0.00004	0.0000	-3.500	0.0026 ***
SWI	0.08880	0.0418	2.126	0.0476 **
VEIFFGDP	0.90800	0.4056	2.239	0.0380 **

Note: Residual standard error: 0.03599 on 18 degrees of freedom, Multiple R^2: 0.9012, Adjusted R-squared: 0.8628; F-statistic: 23.45 on 7 and 18 DF, p-value: 0.0000;
***, ** Represent significance at the 1% and 5% levels respectively

Table 1. The results of the final best subset regression model.

In order to find crucial predictors, the lasso method is used next, and the variables of interest are ordered according to their importance as predictors for RE development. PC4 turns out to be the most influential variable (see Table 2), as it enters the model first (M1). The estimates of the coefficient are positive and remain positive when the tuning parameter increases (for models M2 – M6 including from two to six variables[10]). The second most influential variable, PC3, has positive coefficients, which again remain positive for other models. The next three variables: carbon intensity of energy use (CITPES), PC1 and the CO_2 emissions per capita (CICAP) are negatively related to RE development. All these variables are linked with high concentration of coal in the energy mix. This means that these determinants, apart from having a negative impact on the environment, also have a negative impact on RE development. It is a rather surprising effect, as it might be reasonably expected that high pollutant activity will act as a powerful motivator for investing in RE. Our results are confirmed by studies conducted by Marques et al. (2010), Marques and Fuinhas (2011), and Lucas et al. (2016). The next two variables which characterise security of energy supplies included in the model represent diversification of energy sources: HHIE and HHI. As the parameters of these variables are negative, the results confirm that the countries with less diversified energy sources are not interested in RE development. The volume of net energy import per capita (NDEPCAP) and the SWI are related to the distribution of energy sources.

[10] The table contains selected models, all results are available from the authors upon request.

The parameters of NDEPCAP are negative, while the parameters of SWI are positive, which again confirms the unwillingness of countries with high concentration of energy sources to invest in RE development. Finally, it is worth noticing that the results obtained with the use of BSR and the lasso methods overlap to some extent. Most variables which are included in the BSR when BIC criterion is applied are the ones which enter the regression model first after the application of the lasso approach or are strongly correlated with these variables. The most significant determinants include three variables describing the distribution of energy sources: PC4, PC3, PC1. In case of the best subset method, the final model includes SWI, while the lasso approach includes HHI, which is strongly correlated with SWI, and HHIE, which carries similar information. The direction of the impact of variables obtained in both methods is the same for the most significant variables. High values of PC3 and PC4 stimulate RE development. Large values of PC1 and remaining variables related to large coal consumption are obstacles for RE development, while high diversification of energy sources (small values of HHI, HHIE and a large value of SWI) encourage RE development.

	M1	**M2**	**M3**	**M4**	**M5**	**M6**
PC4	0.436	0.489	0.549	0.560	0.620	0.663
PC3		0.040	0.095	0.104	0.173	0.216
CITPES			-0.00008	-0.000008	-0.00008	-0.00009
PC1				-0.00511	-0.04965	-0.06306
CICAP					-0.000002	-0.000002
HHIE						-0.02459

Table 2. The estimates of the most influential variables indicated by lasso shrinkage.

Conclusions

Our analysis reveals that RE development in the EU member countries is relatively diverse. In the analysed period all EU countries increase their shares of RES in the energy mix, however, the increase is uneven, and the shares of particular RES in particular countries are not the same. The objective of the study is to identify factors determining energy policy in the EU member countries in the middle of 1990s.

This objective is achieved in two stages. During the first one we use PCA to identify the distribution of five main energy sources in 1995. We find four main principal components distinguishing countries in terms of energy sources consumption in 1995. These principal components allow us to indicate groups of countries with particular energy mixes: the ones which either use both coal and crude oil as their main energy sources (i.e. dirty energy) use or clean energy, or the ones which use mainly RES or other energy sources. Principal components also describe the contrast between the countries which use nuclear energy and do not use crude oil, the countries which use mainly crude oil and do not use nuclear energy, and the countries with natural gas as their main energy source with little share of other sources. Principal components are used during the next stage of our study as potential determinants of RE development.

During the second stage we identify the potential determinants of RE development, which include factors related to energy security, environmental concerns, economy and politics. We use two methods of variable selection to identify the main determinants of RE development, and both of them yield similar results, which can be summarised in the following way.

Firstly, the results indicate that the present (in 2014) share of RES in the energy mix significantly depends (high R^2 obtained for regression) on the set of circumstances in the EU member countries in the middle of 1990s. Secondly, the distribution of five main energy sources in the energy mix in 1995 is a key factor affecting RE development.

The most general conclusion of our study states that countries with the lowest shares of RE are the countries with relatively high energy self-sufficiency, i.e. countries with high shares of their domestic fossil fuel resources in the energy mix. There are two groups of such countries: countries with coal resources (Poland, Czech Republic, Bulgaria, Estonia) and countries with natural gas resources (the Netherlands, the United Kingdom, Romania, Hungary), which are not threatened with other countries' suspension of the export of energy supplies. Consequently, they do not need to develop their RE sector to the extent the countries without their own energy sources do if they want to minimize their dependence on energy import. Moreover, countries with their own energy sources have a well-developed mining industry, which generates employment, thus a sudden transformation from their own fossil fuel market to RES would entail huge changes in the labour market, which might prove risky for both: the country's policy and its economy.

Not only do we demonstrate that the distribution of energy sources is the main determinant of RE development, but we also identify other factors conductive to the increase of the share of RES in the energy mix: GDP per capita, the Shannon–Weiner index (SWI), concentration of the energy supply, and the cost of the consumption of energy obtained from fossil fuels in relation to GDP. Energy consumption per capita hinders RE development. Our study reveals that decisions regarding energy policy are of pragmatic nature and tend to accommodate the needs and requirements of the local environment (the country's energy security and care of its labour market) rather than universal values connected with climate protection.

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References

Aguirre, M., & Ibikunle, G. (2014). Determinants of renewable energy growth: A global sample analysis. *Energy Policy, 69*, 374-384.

Cadoret, I., & Padovano, F. (2016). The political drivers of renewable energies policies. *Energy Economics, 56*, 261-269.

Efron, B., Hastie, T., Johnstone, I., & Tibshirani, R. (2004). Least angle regression. *The Annals of Statistics*, 32(2), 407-499.

EU Commission. (1995). Green Paper: For a European Union Energy Policy. European Commission, COM(94) 659, Brussels 1995.

Frodyma, K. (2015). Rynek energii ze źródeł odnawialnych w Unii Europejskiej–analiza statystyczna. *Zeszyty Naukowe Uniwersytetu Ekonomicznego w Krakowie*, 941, 63-78.

Frodyma, K. (2017). The analysis of changes in the distribution of renewable energy consumption in the EU countries. In M. Papież & S. Śmiech (Eds.). *The 11th Professor Aleksander Zelias International Conference on Modelling and Forecasting of Socio-Economic Phenomena*. Cracow: Foundation of the Cracow University of Economics, 280-289.

Furnival, G. M., & Wilson, R. W. (2000). Regressions by Leaps and Bounds. *Technometrics, 42*(1), 69-79.

Lucas, J. N., Francés, G. E., & González, E. S. (2016). Energy security and renewable energy deployment in the EU: Liaisons Dangereuses or Virtuous Circle? *Renewable and Sustainable Energy Reviews, 62*, 1032-1046.

Marques, A. C., & Fuinhas, J. A. (2011). Drivers promoting renewable energy: A dynamic panel approach. *Renewable and Sustainable Energy Reviews*, *15*(3), 1601-1608.

Marques, A. C., Fuinhas, J. A., & Manso, J. P. (2010). Motivations driving renewable energy in European countries: A panel data approach. *Energy Policy,38*(11), 6877-6885.

Tibshirani, R. (1996). Regression shrinkage and selection via the lasso. *Journal of the Royal Statistical Society. Series B (Methodological)*, 267-288.