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Determinants of 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 which determine energy policy in the EU countries in the middle of 1990s. This objective is achieved in three stages. First, the changes in the distribution of RES in 26 EU countries in the period between 1995 and 2014 are investigated. The analysis demonstrates that over the last 20 years the EU countries diversify the RES they use, which results in substantial changes in their distribution. Second, the distribution of energy sources in 1995 is described, as it is assumed that the distribution might be a crucial factor influencing energy policy in each country. Third, several other factors related to energy security, environmental concerns, economy and politics are considered as potential determinants of renewable energy development.

Two statistical methods of variable selection, namely, the best subset regression and the LARS method, reveal 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. The distribution of energy sources in 1995 is the crucial determinant of renewable energy development. Countries without their own fossil fuel sources are the ones which develop renewable energy to the greatest extent. Other important factors boosting RE development include: GDP per capita, concentration of energy supply (SWI), and the costs of consumption of energy obtained from fossil fuels in relation to GDP.

1. Introduction

Fossil fuels lay the foundation of energy balance in the European Union 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 and renewable energy (hereafter RE) – 12.5%. In 2014 the TPES in the EU countries equalled to 1606 Mtoe, while net import constituted 54.8% of the TPES and increased in comparison with 1995, when it amounted to 44%. A growing dependence of the EU on imported energy coupled with diminishing deposits of its own resources and the necessity to provide energy at acceptable prices increase the role of 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 introducing relevant directives in the area of energy policy. The first one, Directive 2001/77/EC [1], issued in 2001, requires each member state to take appropriate measures to achieve a specific indicative target for the consumption of electricity produced from RES. The global target was to reach the indicative share of gross national energy consumption (12%) with the 22% indicative share of electricity produced from RES by 2010. Another one, Directive 2003/30/EC [2], aimed at the promotion of the use of biofuels and other renewable fuels for transport (5.75% share of biofuels in the consumption of transport fuels). In accordance with Directive 2009/28/EC [3], the EU countries should increase the share of energy obtained from renewable sources in their overall energy consumption. European climate and energy package includes targets to be achieved by 2020: a 20% reduction in the EU greenhouse gas emissions below the 1990 levels, raising the share of the EU energy consumption produced from RES to 20%, and a 20% improvement in the EU's energy efficiency. Additionally, at least 10% of the final consumption of energy in transport should come from RES.

Specifying energy policy targets requires an insight into economic,

Abbreviations: TPES, Total primary energy supply; RE, Renewable energy; RES, Renewable energy sources; PCA, Principal component analysis; BSR, Best subset regression; AT, Austria; BE, Belgium; BG, Bulgaria; CY, Cyprus; CZ, Czech Republic; DE, Germany; DK, Denmark; EE, Estonia; ES, Spain; FI, Finland; FR, France; GR, Greece; HR, Croatia; HU, Hungary; IE, Ireland; IT, Italy; LT, Lithuania; LU, Luxembourg; LV, Latvia; MT, Malta; NL, Netherlands; PL, Poland; PT, Portugal; RO, Romania; SE, Sweden; SI, Slovenia; SK, Slovak Republic; UK, United Kingdom

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technical and geographical factors that both stimulate and hinder RE development. Painuly et al. [4] list several factors which should be taken into account while assessing development of RE: an adequate resource base for RES, available technologies and their costs, commercial viability and financing (public, private, international), environmental impact and benefits, socio-economic impact (including job creation), and coverage of both centralised and decentralised options. They distinguish techno-economic and economic factors and introduce six different types of the RES potential including theoretical, geographical, technical, techno-economic, economic and market potential. There are studies devoted to technical methods and tools of evaluating the potential of renewable energy sources (e.g. Izadyar et al. [5] present the review of these studies), but only several of them use statistical approaches to investigate the determinants of such development (e.g. [6–14]).

The aim of the study is to identify the main determinants of RE development in the EU countries, with emphasis on the impact of the distribution of energy sources in the middle of 1990s on RES in 2014.

The study covers 26 EU countries; Malta and Cyprus are excluded from the analysis, due to their almost non-existent share of RE in the TPES, and the fact that they import all energy sources they need. The share of RE in the TPES is selected as the dependent variable because, as stated by Aguirre and Ibikunle [9], 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 progressively displace more polluting energy sources in the energy mix.

The underlying assumption of the study states that RE development is a long-lasting process, and current RES development is a consequence of decisions made several years ago. It would be interesting to discover the reasons behind decisions that shaped energy policy in the past and their consequences which can be noticed at present. That is why, instead of using a panel model approach commonly employed in other studies (see, e.g. [6–15]), this study is based on cross-sectional regression. This empirical strategy, which includes different variable selection methods, is aimed at finding crucial determinants of RES and allows for analysing the impact of determinants related to environment, security of supply, economy, and politics.

Choosing the year 1995 as a reference point is dictated by the fact that it was the year in which the EU initiated legal procedures aimed at promoting RE development. That year the European Commission published *Green Paper* [16], which delineated the European Union energy policy and listed three basis targets connected with gas and electricity monopolies. That year also another official document, *White Paper. An Energy Policy for the European Union* [17], was issued by the Commission of the European Communities. It contained a detailed set of regulations within the area of energy policy and stated general frameworks of this policy in the EU countries (i.e. globalisation of energy markets, ecological problems, technology, institutional responsibility of the Community, etc.).

The study is divided into three main stages.

The objective of the first stage is to evaluate the changes in the distribution of RES in the period between 1995 and 2014. Principal component analysis (hereafter PCA) is used to describe the share of different RES in total RE. The comparison of the results obtained for 1995 and 2014 indicate which renewable sources gain in importance during the last 20 years. PCA also allows for describing RE development and identifying the direction of progress in this area, including progress resulting from technological advances.

The second stage of the study focuses on the distribution of energy sources, which seems a crucial factor in RE development. Several factors make it significant. Firstly, it is inextricably linked to national energy security, as most EU countries have to import energy sources (mainly oil and natural gas) from countries outside the EU, and only few EU countries have adequate domestic supplies of energy sources they need. 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 power is not. A high share of coal in the energy mix usually entails high employment in the mining industry, so a potential change in this area (i.e. reducing coal mining) will definitely entail socio-political consequences. Some researchers (see, e.g. [18,19]) support the hypothesis that strong lobbying has led to a strong position of traditional energy sources in both politics and economy. This lobbying of traditional energy industries can be noticed in the capital markets, in the military industry, and, in general, in the political decision-making process. Additionally, introducing changes in the distribution of energy sources is connected with high financial investments. As opposed to earlier studies [6–8,10,13,14,20], which consider only the shares of particular energy sources in the overall energy consumption, this study employs PCA.

The objective of the third stage is to identify the key determinants of RE development. The study takes into consideration a large set of potential variables in an attempt to follow the reasoning employed by policy makers. When they make decisions regarding the distribution of energy sources, they consider various factors including 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. Together with four categories of potential determinants mentioned above, the impact of the distribution of energy sources in 1995 is investigated and described using PCA. In order to distinguish the key determinants of RE development, two statistical methods are employed: the best subset regression (hereafter BSR) and the lasso method [21].

The paper contributes to the literature in several aspects.

Firstly, it is based on the assumption that changes in the shares of energy sources in the energy mix require a relatively long period of time. The examples supporting this assumption include e.g. problems with investments in a nuclear power plant in Poland [22], the decision to shut down nuclear power plants by 2022 in Germany [23,24] and by 2034 in Switzerland [23], or the NCB's *New Strategy for Coal* in the UK, which was issued in 1985, and which is still the source of changes in the coal industry [25]. Thus, it seems reasonable to assume that the present distribution of energy sources, including the share of RES, is the net result of decisions made years ago. Making important strategic decisions in the past was based on the adequate assessment of energy security (including its uninterrupted availability), the need to match the strategy to the internal situation of a given country (including the labour market or budget capacity to invest in the energy sector), or the protection of the natural environment. The decision to choose a cross-sectional regression instead of a panel regression most frequently used in previous studies stems from the assumption that the distribution of energy sources is a long-lasting process.

Secondly, in order to explain the current level of RE development, the following determinants belonging to four categories describing the EU countries in the middle of 1990s were selected: the distribution of energy sources, economic conditions, energy security and climate protection. They are likely to have influenced the decisions affecting energy policy made at that period.

However, such a substantial set of variables poses a challenge to statistical procedures. They are often collinear, which renders the interpretation difficult and makes the estimation of parameters inefficient. In order to identify the determinants of RE development, it is necessary to limit the number of variables used in the study and to select only the ones which exert actual influence on this development. That is why, and this is the third novel aspect of the study, two methodological approaches rarely used before are employed, namely, the BSR and the lasso method [21]. The lasso method is considered the best method for variable selection, but, surprisingly, is not frequently used in energy economics studies.

Fourthly, the study considers the share of the main energy sources in the energy mix as the determinant of RE development and uses PCA to describe it, which is an approach not taken before. Such choice is motivated by two reasons. First, the determinants of interest (the shares of coal, oil, nuclear energy, natural gas, and RE in energy mix) are not independent, thus, when PCA is used instead of the original ones, correlations between them are taken into account. Second, by assessing the importance of particular dimensions of principal components, their significance for RE development can be examined.

Finally, the study includes factors which have not been considered in previous studies, such as the costs of importing energy and the costs of fossil fuels consumption, which take into account different income per capita across countries.

The remainder of the paper is organized as follows. Section 2 contains the review of literature, Section 3 briefly presents the empirical methodology used in the study, while the description of the data can be found in Section 4. Section 5 reports and comments on the empirical results, and the last section contains final conclusions.

2. Review of literature

Studies devoted to the impact of particular determinants of RE development usually analyse the period after 1990 and consider various groups of countries. Marques et al. [6], Marques and Fuinhas [7], Cadoret and Padovano [13], Lucas et al. [14] and Papież et al. [26] investigate the impact of selected determinants on RE development in the EU countries. The studies conducted by Popp et al. [9]; Polzin et al. [15] and Biresselioglu et al. [12] analyse European and non-European countries belonging to the OECD. Aguirre and Ibikunle [11] investigate the EU and OCED countries together with five BRICS countries, while Kilinc-Ata's [27] study also includes 50 US states.

Most studies use panel datasets to conduct an econometric analysis of the determinants which have an impact on RE development. Their authors adopt panel data techniques such as: the fixed effects with vector decomposition estimator (FEVD) [6,11], the panel corrected standard error (PCSE) estimator [10,11,13,15], the Feasible Generalized Least Squares (FGLS) estimator [9] or the Least Squares Dummy Variable Corrected (LSDV) estimator [7,13]. Marques and Fuinhas [7] apply panel dynamic estimators such as GMM-dif and GMM-sys. Similarly, Biresselioglu et al. [12] use the System Generalized Method of Moments (GMM) estimator. Marques et al. [8] apply the quantile technique to investigate factors promoting RE in European countries, while Menz and Vachon [28] use Ordinary Least Squares to study wind power development.

Most studies which analyse the impact of diverse determinants on RE development use the share of RE in the TPES as the dependent variable (see, e.g. [6–8,10,11,14]). Dependent variables used by other authors include: the share of renewable electricity capacity in total electricity supply from non-hydro renewable sources [27], the installed wind capacity development [12], or aggregated newly installed capacity (in MW) in a given country and year in a specific subsector (e.g. solar, wind, biomass) [15].

Numerous studies indicate different factors which exert an impact on RE development. Marques et al. [6], Marques et al. [8], Marques and Fuinhas [7], Marques and Fuinhas [9] and Aguirre and Ibikunle [11] consider three categories of important determinants of this development. The first category includes political factors, such as a dummy variable to identify the EU countries, a dummy variable for the ratification of the Kyoto Protocol, public policies supporting RE development, R&D incentive programmes, investment incentives, and incentive taxes. The second category includes socio-economic factors, such as prices of oil, natural gas and coal, carbon dioxide (CO_2) emissions (carbon intensity per capita), the contribution of coal, oil, natural gas and nuclear energy to electricity generation, the contribution of net energy import, income (GDP growth or GDP per capita), energy consumption, and primary energy intensity. The third category, which describes RE potential, consists of country-specific factors, such as the contribution of RE equal to or greater than 10%, deregulation of the electricity market, and RE potential (estimated biomass quantities, solar/wind/hydro potential). Lucas et al. [14] distinguish three categories of indicators and classify them according to their links with each energy policy dimension: environmental sustainability (signing the Kyoto Protocol, energy intensity, carbon intensity), security of supply (net energy import dependency, the degree of diversification of energy sources, and the degree of diversification in the electricity mix) and competitiveness (coal, natural gas and oil prices, GDP per capita). Polzin et al. [15], Biresselioglu et al. [12] and Kilinc-Ata [27] consider macroeconomic, energy security, environmental and energy market data as control variables and examine their impact on RE capacity. Cadoret and Padovano [13] analyse the role played by political factors in RE deployment. They divide explanatory variables into three categories related to: political economy, economy, and energy and environment. Political variables are also used by Nesta et al. [29], Marques and Fuinhas [7], Aguirre and Ibikunle [11], Zhao et al. [30] and Polzin et al. [15]. Johnstone et al. [31] and Popp et al. [9] assess the impact of technological advancements, measured by the number of patents for each technology, on investment in the RE capacity. Their control variables include the share of imported energy in total energy supply and the production per capita of coal, natural gas, and oil.

Marques et al. [6], Marques and Fuinhas [7], Marques et al. [8], Marques and Fuinhas [9] and Lucas et al. [14] find that the larger CO_2 emissions, the smaller RE commitments, so pollution does not play a strong enough role in encouraging RE development. Contrary to the previous work, Aguirre and Ibikunle [11] and Cadoret and Padovano [13] confirm a positive relation between CO_2 emissions and RE development.

Marques et al. [6], Marques and Fuinhas [7], Marques et al. [8], Marques and Fuinhas [9] and Lucas et al. [14] find that high consumption of energy per capita exerts pressure on the production of energy generated from local renewable sources. Aguirre and Ibikunle [11] reveal that energy use is negatively correlated with RE participation, implying that - under high pressure to ensure sufficient energy supply - countries have a tendency to employ less RE and more fossil fuels, as it is more cost effective.

Marques et al. [6], Marques and Fuinhas [7], Marques et al. [8] and Marques and Fuinhas [9] also find that the larger the proportion of energy generated from fossil sources, the smaller RE deployment. As noted by Sovacool [19], the lobby effect delays the growth of the RE sector.

The impact of GDP on RE development is inconclusive. Papers investigating the linkages between RE consumption and economic growth (see, e.g. for European countries: [26,32–35], for OECD countries: [36–39]) confirm different hypotheses (conservation, feedback, growth, and neutrality). While analysing the impact of various factors on RE development in all EU countries, Marques et al. [6] confirm that income appears to support investments in RE, but they find the opposite relationship for non-EU countries in 2000. Similarly, Marques et al. [8], Cadoret and Padovano [13] and Lucas et al. [14] argue that per capita income has a negative impact on RE development.

Marques et al. [6], Marques et al. [8] and Cadoret and Padovano [13] confirm that high energy dependence on import has a positive effect on RE development, but Marques and Fuinhas [7], Marques and Fuinhas [10] and Lucas et al. [14] demonstrate that high energy dependence on import hampers RE deployment. This dependence is mainly based on traditional sources of energy, which is a sign that the productive infrastructure in the analysed countries depends on fossil sources, which is a significant obstacle to RE development.

Finally, most authors (see, e.g. [6–8,10,13,14,18–20]) confirm that the higher contribution of traditional energy sources (coal, oil, natural gas and nuclear) in electricity production, the weaker RE development. In their opinion, it is caused by the existence of industrial lobbying, which hinders RE development.

Table 1
Summary statistics – the share of renewable energy sources in the renewable energy mix.

	Mean		Min		Max		SD	
Variable/year	1995	2014	1995	2014	1995	2014	1995	2014
HYDRO	0.2750	0.1463	0.0000	0.0002	0.8434	0.4278	0.2072	0.1311
WIND	0.0064	0.0993	0.0000	0.0000	0.0778	0.4599	0.0163	0.1038
SOLAR	0.0040	0.0428	0.0000	0.0000	0.0636	0.2118	0.0121	0.0520
TIDE	0.0001	0.0001	0.0000	0.0000	0.0026	0.0019	0.0005	0.0004
BIOMASS	0.6937	0.6962	0.1566	0.3828	1.0000	0.9371	0.2226	0.1623
GEOTHERMAL	0.0207	0.0154	0.0000	0.0000	0.4103	0.1975	0.0802	0.0392

3. Methodology

Three stages of the study consist of the following steps.

In the first stage, the distribution of RES in the EU countries in 1995 and in 2014 is compared. In order to capture the correlations between different sources of RE, the distribution is obtained via classical principal component analysis (PCA).

In the second stage, PCA is used again (for the same reason as given above) to determine the main contributors to the energy mix in 1995.

In the final stage, the impact of the key factors in RE development is analysed. Taking into account both the significant correlation between the variables and a relatively large number of them, two methods of limiting the set of predictors described below are implemented in the study.

3.1. A variable selection problem

The main challenge of the study is to find the key determinants of RE development. The study analyses 15 (some highly correlated[1]) variables describing various aspects of the condition of European countries in 1995 (outside the area of energy policy) which could be related to the share of RE in the TPES in 2014. The analysis is conducted with the use of a standard linear regression framework. The model is given by:

$$Y = X\beta + \varepsilon$$

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

Limiting the number of predictors allows for (see [40]):

1. estimating or predicting at lower costs thanks to reducing the number of variables for which data are collected,
2. predicting accurately by eliminating uninformative variables,
3. describing a multivariate data set parsimoniously,
4. estimating regression coefficients with small standard errors (particularly when certain predictors are highly correlated),
5. interpreting the estimated parameters (a conditional interpretation when variables are correlated is useless, thus, a smaller subset is preferred, as it exhibits the strongest effects).

Statistical literature offers two convenient approaches to limiting the number of variables in the regression model.

The first one is 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)[2]). 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: $2^p - 1$. Furnival and Wilson [41] propose an efficient algorithm (the leaps and bounds procedure) to overcome this drawback, nevertheless, the methodology is still inconvenient when even moderate-sized (more than 40 variables) sets of predictors are considered. What is more, the BSR is, as Efron et al. ([42] p.409) claim, "overly greedy, impulsively eliminating covariates which are correlated with" other covariates.

To avoid this problem, Tibshirani [21] proposes the lasso (the least absolute shrinkage selection operator) method, which, in order to estimate regression parameters, minimizes the sum of squares of residuals with a constraint for parameters:

$$\hat{\beta}(\lambda) = \arg\min_{\beta} ||Y - X\beta||_2^2 + \lambda||\beta||_1, \tag{1}$$

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, $||\cdot||_2$ is the standard L_2 norm. For $\lambda = 0$, Eq. (1) is the standard Ordinary Least Squares (without any regularizations). For large λ, $\hat{\beta}$ are shrunk 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 the second methodological approach used in the study.

In 2002 Efron et al. [39] 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. This method is considered one of the most effective ways of solving variable selection problems in regression applications (see, e.g. [43,44]) and is particularly useful for large datasets, even in the presence of noisy variables (see, e.g. [45]).

Recently the lasso method has also been used for forecasting electricity prices by Ziel et al. [46], Ludwig et al. [47], Ziel [48,49].

4. Data description and preliminary statistics

The empirical analysis is conducted using the data which describe the share of RES in the TPES in a sample of 26 European Union countries: Austria, Belgium, Bulgaria, Croatia, the Czech Republic, Denmark, Estonia, Finland, France, Hungary, Greece, Germany, Ireland, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom. The analysis covers the period between 1995 and 2014, and the data are obtained from the European Commission websites.[3] The study does not include Cyprus and Malta due to the fact that, in the analysed

[1] see Table A1 in Appendix A.

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

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

	AT	BE	BG	CZ	DE	DK	EE	ES	FI	FR	GR	HR	HU	IE	IT	LT	LU	LV	NL	PL	PT	RO	SE	SI	SK	UK
GEOTHERMAL	-18.1	-4.8	-26.3	-9.8	-26.6	-0.2	0.2	-17.1	-6.8	-11.6	-7.8	6.9	-0.3	-33.0	-23.1	-3.8	-18.1	-9.5	-0.6	-1.9	2.6	-24.9	-13.9	-8.8	-59,0	-18.5
BIOMASS	3.4	11.6	6.4	1.1	11.5	17.6	6.1	24.8	0.9	7.0	12.7	3.1	2.9	45.3	4.9	4.3	3.7	0.7	11.7	7.7	18.8	8.7	5.5	0.0	0.1	20.9
TIDE	1.9	7.8	7.1	5.4	9.9	1.4	0.0	17.0	0.0	2.7	14.8	0.6	0.6	1.2	7.8	0.5	5.8	0.0	2.2	0.2	1.9	2.3	0.0	2.7	4.0	2.8
SOLAR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WIND	12.5	-14.1	10.9	3.2	4.7	-18.8	-6.3	-24.7	5.9	1.7	-20.0	-11.2	-0.1	-12.9	31.7	-1.1	8.6	8.7	-14.4	-6.2	-25.6	13.5	8.4	3.5	54.2	-5.1
HYDRO	0.3	-0.5	1.8	0.0	0.5	0.0	0.0	0.0	0.0	0.3	0.3	0.5	-3.2	0.0	-21.3	0.2	0.0	0.0	1.1	0.2	2.3	0.5	0.0	2.6	0.5	0.0

Fig. 1. Changes [in pp] of the share of RES in total RES in the EU countries between 1995 and 2014.

period, the share of RES in the TPES in these countries is almost zero.

Three stages of the study use different datasets: the first contains variables that describe the distribution of RES in the EU countries, the second analyses the distribution of all energy sources in them, and the third includes potential determinants of RE development.

The first dataset demonstrates the share of different RES in total RE. The main types of RES include: hydropower (HYDRO), wind power (WIND), solar energy (SOLAR), tide, wave and ocean (TIDE), biomass and renewable wastes (BIOMASS), and geothermal resources (GEOTHERMAL). The descriptive statistics are reported in Table 1. As the Table demonstrates, the share of RES in total RE in the period between 1995 and 2014 undergoes significant changes. Biomass constitutes he greatest share in total RE: both in 1995 and in 2014 its share in the EU is on average 69%. The second most common RES is hydropower, whose share in total RE decreases from 28% in 1995 to almost 15% in 2014. A substantial increase can be noticed in the share of wind power, whose average share in total RE for the EU countries increases from 0,6% in 1995 to almost 10% in 2014. The greatest - over a tenfold - growth can be noticed in the average use of solar energy: in 1995 solar energy in the EU constitutes only 0.4% of total RE, while 20 years later - over 4% (see also [50]).

Fig. 1 presents the changes of the share of RES in total RE in the EU countries between 1995 and 2014. The data regarding the share of RES in total RE can be found in Appendix A (Table A1). All countries experience an increase in the share of wind energy and solar energy in total RE and a decrease in the share of hydropower (except Estonia, where it increases by 0.2 pp and Croatia, where it increases by 6.9 pp). The share of biomass diminishes in half of the countries analysed (Portugal by 26 pp, Estonia by 25 pp, Greece by 20 pp and Denmark by 19 pp), although in some of them it grows (Slovakia by 54 pp and Italy by 32 pp).

The data used in the second stage reflect the share of energy sources in the 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). A detailed description of these variables is presented in Table 2. As Table 2 demonstrates, in the analysed period the share of RES in the energy mix increases, on average, from 8% to almost 16%. The average share of crude oil and petroleum products in the energy mix declines slightly (39% in 1995 and 35% in 2014 on average). The average share of nuclear energy and natural gas in the energy mix in the EU remains unchanged, with the exception of the average share of solid fuels in the energy mix, which decreases remarkably from 23% to 17%.

What is important for further analysis, the pace of renewable energy development is not the same in all EU countries. The minimum share of RES in 2014 is 0.04% for the Netherlands, and maximum – 36% for Latvia. This means that some countries hardly use RES, while others markedly increase the share of RES in their energy mix.

Fig. 2 presents the changes in the share of energy sources in the TPES in the EU countries between 1995 and 2014. The data regarding the share of particular RES in the TPES can be found in Appendix A (Table A2). All countries experience an increase in the share of RES in the TPES (between 1.7 pp in Italy and 21.1 pp in Denmark). The rise of the share of RES leads to a decrease in the share of coal in the TPES, which can be noticed in Poland (a decline in the share of coal by 19 pp), in Denmark (a decline by 18 pp) and in the Czech Republic (a decline by 16 pp). In Lithuania an increase in the share of RES is accompanied by a significant decrease in the share of nuclear energy (a decline by 36 pp). A reduction in the share of oil is noted in Italy (by 21 pp) and Portugal (by 20 pp).

In the third stage, following the literature, a set of potential factors influencing renewable energy development is proposed and verified. This set is further expanded by principal components describing the distribution of energy sources in 1995 obtained in the second stage of the study.

As mentioned above in Section 2, there are many different factors

Table 2
Summary statistics – the share of energy sources in the energy mix.

	Mean		Min		Max		SD	
Variable/year	1995	2014	1995	2014	1995	2014	1995	2014
COAL	0.2311	0.1724	0.0223	0.0126	0.7114	0.6690	0.1723	0.1552
OIL	0.3863	0.3467	0.1517	0.1635	0.6577	0.6339	0.1314	0.1054
GAS	0.1904	0.2003	0.0024	0.0166	0.4567	0.3783	0.1138	0.0910
NUCL	0.1013	0.1014	0.0000	0.0000	0.4025	0.4531	0.1228	0.1240
RES	0.0801	0.1588	0.0083	0.0443	0.2721	0.3623	0.0799	0.0953

which exert impact on RE development. Following Marques et al. [6], Marques et al. [8], Cadoret and Padovano [13] and Lucas et al. [14], a set of potential predictors has been selected and then divided into four categories: environmental, security of supply, economic and political. The first category contains environmental variables. Most authors [6–8,10,13,14] claim that environmental concerns serve as incentives for a widespread use of RE. Two determinants with a potential influence on RE development are carbon intensity of energy use and CO_2 emissions per capita. The first one, carbon intensity of energy use (CITPES), measures the amount of CO_2 emissions per unit of energy consumed (which is associated with the TPES). This determinant is mentioned in the European Commission Occasional Paper "Member States Energy Dependence: An Indicator-Based Assessment" and by Chuang and Ma [51] and is used to reflect the intensity of high-carbon fossil fuels (such as coal and oil) in the energy mix. The higher its value, the higher the proportion of high-carbon fossil fuels in the energy mix, and hence its negative impact on the quality of the environment. The second one, CO_2 emissions per capita (carbon intensity per capita – CICAP), has been chosen following Marques et al. [6].

The next category is linked to the security of energy supplies and contains eight determinants which can influence RE development. The first one measures the dependence of each country on net energy import in relation to the TPES (DEP). An expected impact of this variable on RE development is ambiguous. Following Marques et al. [6], it could be expected that the higher the dependency on energy import of a country, the higher its investment in its own renewable sources as a way of improving its energy security. However, Marques and Fuinhas [10] demonstrate that high energy dependence hampers RE development. They claim that this dependence rests mostly on traditional energy sources, which indicate a "productive infra distribution in these countries mainly based on fossil fuels, acting as a significant barrier to RE development". Energy self-sufficiency rate (ESS) is a similar determinant: it measures the share of domestic production of coal, crude oil, natural gas, RE and nuclear energy in the TPES.

The next three determinants measure: the degree of concentration of energy mix (SWI), the degree of diversification of energy mix (HHI), and the degree of diversification of energy sources in electricity generation (HHIE). These indicators are mentioned by the authors of the European Commission Occasional Paper "Member States Energy Dependence: An Indicator-Based Assessment" and by Lucas et al. [14]. The Shannon–Wiener index (SWI) is used to measure the concentration of energy supply [52,53]. If the proportions of all energy sources are relatively equal, the index reflects the fact that energy supply does not rely on any particular type of energy. Inversely, the Herfindahl–-Hirschman Index[4] (HHI) is used to measure the degree of diversification of energy sources [14,52]. Similarly, the Herfindahl–Hirschman Index in electricity generation (HHIE) is used to measure the degree of diversification in the electricity mix. Most authors (see, e.g. [6–8,10,13,14,18,19]) confirm the finding that the greater contribution of traditional energy sources to electricity generation, the lower the rate of RE development. They explain this relation by the lobbying power of fossil fuel technologies, which hinders RE development.

The next two determinants measure the volume of net energy import to GDP (NDEPGDP) and the volume of net energy import per capita (NDEPCAP). The higher these volumes, the higher the costs associated with the purchase of net energy imported and the more a country has to pay to obtain the energy it needs.

Most authors (see, e.g. [6–8,10,13,14]) assume that the prices of conventional energy sources, such as natural gas, oil, coal, and nuclear energy, are potential determinants of RE development, but they do not take into account the difference in income per capita across countries. In order to overcome this limitation, net energy import in relation to GDP (VNTDEPGDP) is used as an additional determinant in this category. It is defined as follows: the sum of net import of coal/natural gas/oil multiplied by the average price of coal/natural gas/oil in $ divided by GDP in $.

The next category is related to economic conditions and includes four determinants potentially influencing RE development. The first one measures income as GDP per capita (GDPCAP). The results of previous studies indicate that the impact of GDP on RE development is significant but inconclusive, as mentioned in Section 2. The other two determinants measure energy intensity: energy consumption per capita (EICAP), and energy consumption per GDP (EIGDP). Both of them are often used as indicators of economic development.

The fourth determinant measures the consumption of energy obtained from fossil fuels in relation to GDP (VEIFFGDP). This determinant, as does VNTDEPGDP, takes into account the difference in income per capita across countries. It is defined as follows: the sum of consumption of coal/natural gas/oil multiplied by the average price of coal/natural gas/oil in $ divided by GDP in $, and indicates the importance of fossil fuel consumption in GDP. Higher energy prices (*ceteris* paribus) should promote policy choices aimed at reducing energy intensity and dependence on import; moreover, higher prices may make RE more economically viable, thus, encourage investment in RE.

Following Marques et al. [6], a dummy variable is used to identify the EU countries in the year 1995 (EU) in the category of political variables.

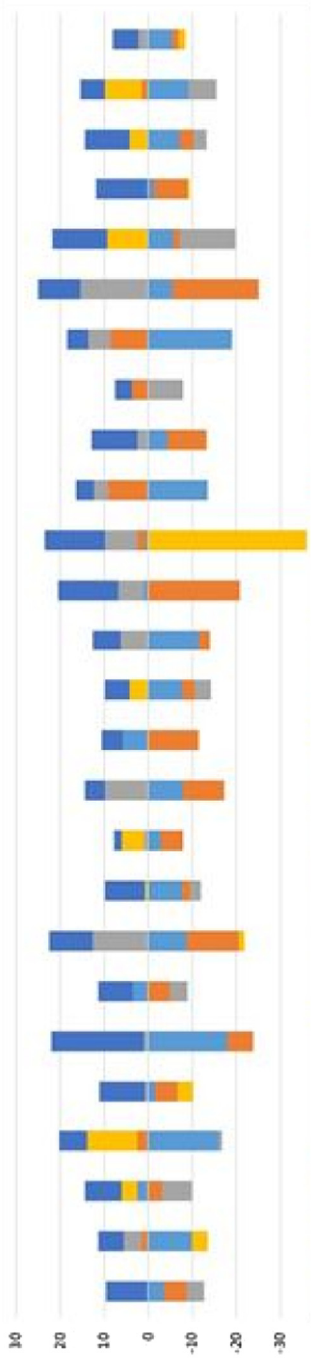
Detailed descriptive statistics of all variables are provided in Table 3. The correlation matrix can be found in Appendix A (Table A3).

5. Results and discussion

As mentioned in Section 4, the share of RES in the TPES in the analysed period increases twofold (from 8% in 1995 to 16% in 2014). Thus, it might be interesting to find out which types of RES develop faster than others, so PCA is used to describe and compare the distribution of RES. Table 4 presents the results of PCA for RES in 1995 and 2014.

In 1995 only two first principal components are sufficient to explain about 92% of the total variance in the original variables. The results also demonstrate that in 1995 these two principal components are related to only three types of RES: hydropower, biomass and geothermal. In 2014, however, it is necessary to use three first principal components in order to explain 90% of total variance in the original variables. These principal components are related to all types of RES excluding tide. The

[4] The HHI index for five determinants (coal, oil, natural gas, nuclear energy and RES) ranges from 0.2 (the most diversified) to 1.0 (the most concentrated).



	AT	BE	BG	CZ	DE	DK	EE	ES	FI	FR	GR	HR	HU	IE	IT	LT	LU	LV	NL	PL	PT	RO	SE	SI	SK	UK
RES	-3.5	-9.9	2.5	16.0	-1.5	-18.0	3.6	-8.8	-7.7	-2.9	-7.8	5.7	-7.7	-11.4	1.1	0.7	-13.4	-4.4	-0.1	-18.9	-5.3	-5.5	-1.2	-7.0	-9.3	-5.4
NUCL	-5.2	1.6	-3.0	2.5	-5.1	-5.7	-4.9	-11.7	-1.8	-4.9	-9.5	-11.4	-2.8	-2.4	-20.8	1.9	9.1	-8.8	3.7	8.5	-19.7	-1.7	-7.8	-3.2	1.4	-1.4
GAS	-4.0	3.9	-6.9	-0.8	0.7	0.9	-4.1	12.6	-2.4	0.9	9.9	0.0	-3.8	6.4	5.8	7.4	3.3	2.5	-7.8	5.1	15.4	-12.6	0.1	-2.9	-6.1	2.3
OIL	0.0	-3.5	3.5	11.4	-3.6	0.0	0.0	-1.3	0.7	5.1	0.0	0.0	4.3	0.0	0.0	-36.0	0.0	0.0	0.0	0.0	0.0	9.3	-0.3	4.3	8.3	-1.6
COAL	9.5	5.8	8.4	6.4	10.5	21.1	7.7	9.8	9.2	1.7	4.5	5.0	5.6	6.2	13.5	13.6	3.9	10.5	3.9	4.8	9.7	12.4	11.7	10.0	5.7	5.8

Fig. 2. Changes [in pp] of the share of energy sources in the TPSE in the EU countries between 1995 and 2014.

results indicate that the distribution of RES in the EU countries changes significantly over the last 20 years.

The results obtained for 1995 (Table 4) reveal that the first principal component ($PCr_{95}1$) is linked to two types of RES: biomass and hydropower. Hydropower is positively correlated with the first principal component ($Pcr_{95}1$), while biomass is negatively correlated with the first principal component ($PCr_{95}1$). It means that in 1995 the first principal component ($PCr_{95}1$) divides the European countries into the ones which use hydropower but not biomass as their main RES, and the ones which use biomass but not hydropower. In 2014 the first principal component ($PCr_{14}1$) differentiates the countries which either use a lot of hydropower and wind power but little biomass from the countries which use little hydropower and wind power and a lot of biomass. In 1995 three types of RES - hydropower, biomass and geothermal energy - are correlated with the second principal component ($PCr_{95}2$). However, hydropower and biomass are positively and geothermal energy is negatively correlated with the second principal component ($PCr_{95}2$). It means that certain EU countries use either hydropower along with bioenergy or geothermal energy as their main RES. In contrast, in 2014 the highest value of the factor loadings for the second principal component ($PCr_{14}2$) is obtained for hydropower and wind energy. The component corresponds to solar, biomass and geothermal energy, as well. Thus, the second principal component ($PCr_{14}2$) characterizes the countries which either use hydropower or wind power. The third principal component ($PCr_{14}3$) points at these European countries which use solar as well as geothermal energy.

Fig. 3 demonstrates the results of PCA for RES in 1995 and Fig. 4 - the results obtained in 2014. The results presented in Fig. 3 reveal a large concentration of countries close to the average values of all variables. There are, however, some exceptions: Italy, Greece, and Slovakia are the countries which drive large values of the second, first and fourth principal component, respectively. In 1995 in most EU countries biomass and hydropower are the main contributors to RES. Slovakia and Italy have the highest shares of hydropower in total RES (about 85% and 42%, respectively, see Table A1) and, at the same time, a low share of biomass (about 16% and 17%, respectively). Estonia, the Netherlands, Poland, Belgium, Lithuania, and Denmark display a high share of biomass in total RES (about 100%, 96%, 96%, 94%, 94% and 92%, respectively) and a low share of hydropower. The variance of the second principal component results from a high share of geothermal energy in total RES in Italy (about 41%) and in Hungary (10%). Greece stands out from other countries due to its relatively high share of renewable energy obtained from solar energy (6% share of solar energy in RES in Greece, which is 10 times more that in Germany, the forerunner). On the other hand, Denmark is characterised by a relatively high share of wind power (8%) in its RE mix.

Fig. 4 reveals a significantly greater diversity in the share of different types of RES in the EU countries in 2014 than in 1995. The countries from one group are characterised by a high share of biomass in total RES but a low share of hydropower (Estonia – 94% and 0%, Lithuania – 92% and 3%, Poland – 90% and 2%, Hungary – 88% and 1%, the Czech Republic – 89% and 5%). Another group contains countries with a low share of biomass and a high share of hydropower (Spain – 38% and 19%, Slovenia – 52% and 43%, Croatia 57% and 39%, Portugal – 51% and 24%). In the analysed period the share of wind power in total RES increases in the following countries: Ireland from 1% to 46%, Denmark from 8% to 25%, Spain from 0% to 25%, United Kingdom from 2% to 23%. As far as solar energy is concerned, Greece (with 21% of the share of solar energy in RES) maintains its leading position, while geothermal energy again is the most important energy source in Italy (20%) (compared to other countries). These results indicate that the selection of renewable energy sources in the analysed countries is generally related to their potential, which includes natural and climatic factors as well as their geographical limitations.

In a nutshell, two types of renewable energy sources, i.e. wind power and solar energy, develop the most in the analysed period. Due

Table 3
Data and summary statistics (for 1995).

Dimension	Variable	Definition	Mean	Min	Max	SD
Environmental						
	CITPES	CO_2 emissions per TPES	2687.79	1247.88	4222.46	625.40
	CICAP	CO_2 emissions per capita	9383.06	3787.89	23976.42	4203.08
Security of supply						
	DEP	Net energy import per TPES	0.51	− 0.16	0.98	0.26
	ESS	Energy self-sufficiency rate	0.51	0.01	1.15	0.27
	SWI	The Shannon–Weiner index (SWI) concentration of the energy supply	1.24	0.86	1.54	0.19
	HHI	The Herfindahl–Hirschman Index (HHI) primary energy diversity index	0.34	0.21	0.54	0.08
	HHIE	The Herfindahl–Hirschman Index in electricity	0.47	0.26	0.91	0.18
	NDEPGDP	Net energy import to GDP	148.90	− 27.87	534.937	124.677
	NDEPCAP	Net energy import per capita	1889.46	− 634.71	7931.62	1559.24
	VNTDEPGDP	Cost of net energy import in relation to GDP	0.02	0.00	0.09	0.02
Economic						
	GDPCAP	GDP per capita	17.74	2.85	54.86	12.48
	EICAP	Energy consumption per capita	3540.38	1689.24	8117.22	1460.82
	EIGDP	Energy consumption to GDP	306.76	103.97	945.99	213.18
	VEIFFGDP	Cost of energy consumption from fossil fuels in relation to GDP	0.03	0.01	0.11	0.03
Political						
	UE	Dummy variable to identify EU Members in the year 1995	0.58	0.00	1.00	0.49

Table 4
Principal component analysis for renewable energy sources in 1995 and 2014.

	1995						2014					
	$PCr_{95}1$	$PCr_{95}2$	$PCr_{95}3$	$PCr_{95}4$	$PCr_{95}5$	$PCr_{95}6$	$PCr_{14}1$	$PCr_{14}2$	$PCr_{14}3$	$PCr_{14}4$	$PCr_{14}5$	$PCr_{14}6$
HYDRO	0.675	0.471	− 0.326	0.128	0.183	0.408	0.533	0.608	− 0.355	− 0.143	0.183	0.408
WIND			0.755	0.48	0.182	0.408	0.150	− 0.745	− 0.470		0.182	0.408
SOLAR			0.277	− 0.851	0.182	0.408		− 0.127	0.706	− 0.525	0.182	0.408
TIDE					− 0.913	0.408					− 0.913	0.408
BIOMASS	− 0.734	0.349	− 0.353	0.121	0.183	0.408	− 0.826	− 0.212	− 0.212	− 0.120	0.183	0.408
GEOTHERMAL		− 0.810	− 0.350	0.121	0.183	0.408		0.331	0.331	0.830	0.183	0.408
Cumulative variance	0.703	0.924	0.969	0.999	1.000	1.000	0.461	0.768	0.904	0.999	1.000	1.000

to geographical conditions, the countries from southern Europe invest in solar energy, and the ones from northern Europe - in wind power. The increase in the share of these two types of RES results in a decrease in the share of hydropower and - in some countries - biomass. At the same time, in several countries the share of biomass in total RES increases.

The results obtained in the second stage of the study, i.e. the analysis of the distribution of energy sources in 1995 in the EU countries, are presented in Table 5, and Fig. 5 reports the results of principal components analysis for five main energy sources in 1995.

The results demonstrate that the first principal component (PC1) is related to COAL and OIL variables, which means that it divides the analysed countries into the ones using or not using coal or crude oil as their main energy sources. Consequently, two groups of countries are identified: the ones using dirty energy and the ones using clean energy. Similarly, the fourth principal component (PC4)[5] represents European countries which use clean energy as their main energy source and only limited amounts of dirty energy sources.

Crude oil consumption is positively and nuclear energy consumption is negatively correlated with the second principal component (PC2), i.e. the second principal component (PC2) describes European countries which use oil as their main energy source and do not use nuclear energy.

The third principal component (PC3) 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.

Fig. 5 presents the results of PCA for five main energy sources in 1995. The analysis reveals a large diversity of countries related to their distribution of energy sources. The biplot for PC1 and PC2 (the left panel of Fig. 5) allows for distinguishing several groups of countries. The first one includes countries with a high concentration of coal in their energy mix: Poland, Estonia, and the Czech Republic (the share of coal in the TPES in these countries in 1995 amounts to: 71%, 63% and 54%, respectively). The second group covers countries which use mainly nuclear energy: France, Lithuania, and Sweden (40%, 36%, 35%, respectively). Another group clusters countries in which crude oil is the main energy source: Portugal (66%), Italy (58%), Luxembourg (54%), Estonia (54%), Croatia (50%). The right panel of Fig. 5 presents the biplot for PC3 and PC4 and reveals that: the highest concentration of natural gas consumption in the energy mix in 1995 is observed in the Netherlands (46%), Romania (42%) and Hungary (35%); RES are used mainly in Latvia (27%), Austria (23%), Sweden (25%), and Finland (21%); and Spain (14%; 54%), France (40%; 36%), and Greece (0%; 59%) use both nuclear power and crude oil energy sources. It is worth noting that countries primarily use their local sources (see Table A4, e.g. Poland and the Czech Republic mostly use coal, while the Netherlands and Romania use natural gas).

The determinants of RE development described in Table 3 are assumed to be potentially significant and the third stage of the analysis verifies their role. At first, the results of the BSR models are presented.

In order to select relevant variables, all their possible subsets are considered. Fig. 6 presents variables that appear in the best model of size $k \in \{1, 2, .., 8\}$ when Bayesian information criterion (BIC) is applied. The consecutive lines in Fig. 6 represent variables (the dark rectangle), which constitute the best model with a given number of regressors. The number of dark rectangles (in a raw) indicates the number of variables used. Generally, when BIC is taken into account, the models with a limited (small) number of variables are inferior to more extensive

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

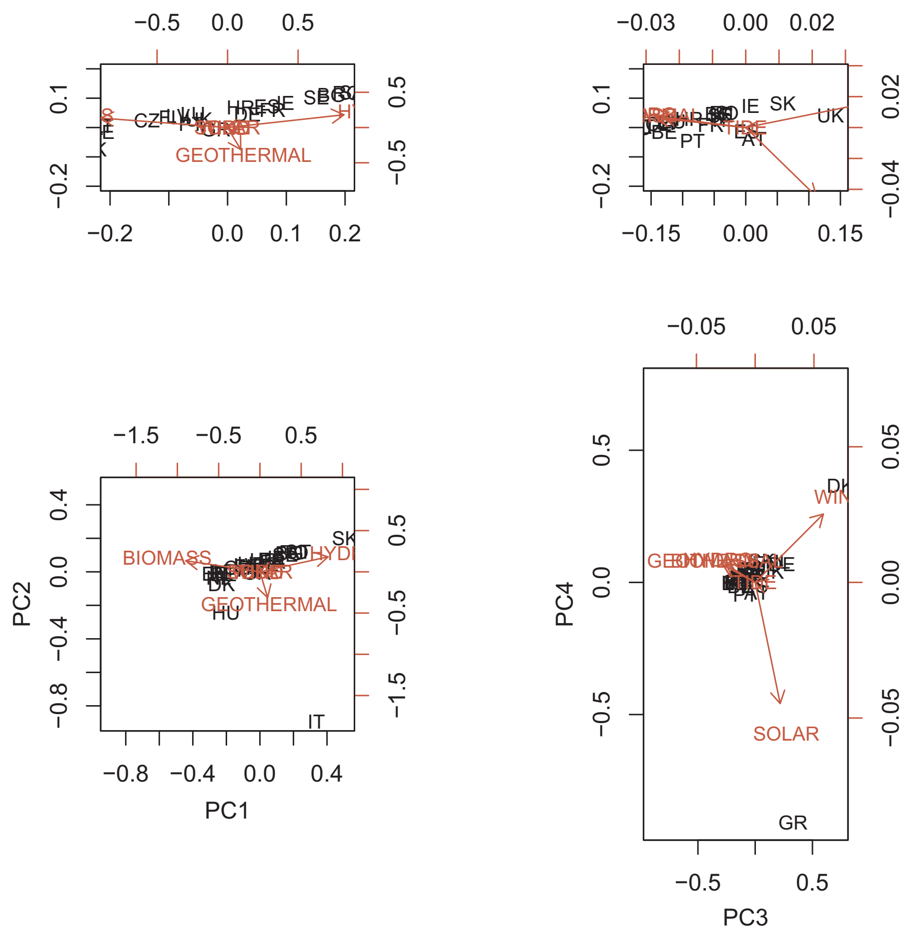


Fig. 3. The results of PCA for renewable energy in the EU countries in 1995.

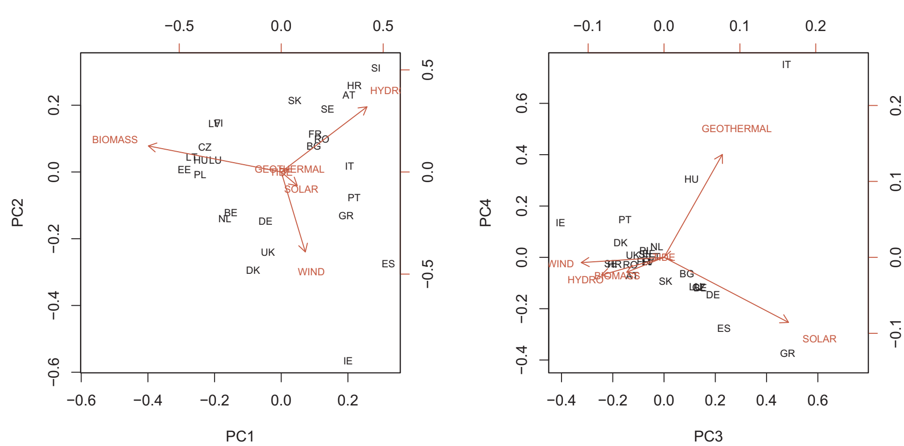


Fig. 4. The results of PCA for renewable energy in the EU countries in 2014.

Table 5
Principal components analysis for five main energy sources in 1995.

	PC1	PC2	PC3	PC4	PC5
COAL	0.865	0.178	0.123	− 0.112	− 0.439
OIL	0.444	0.632	0.196	− 0.386	− 0.465
GAS		− 0.157	− 0.868		− 0.461
NUCL	− 0.155	− 0.738	0.384	− 0.338	− 0.412
RES	− 0.154		0.212	0.850	− 0.457
Cumulative variance	0.352	0.607	0.834	0.980	1.000

models. Out of all the models used in the study, the model including a single variables (PC4) has the largest BIC (− 17.53), and the models with seven or eight variables have the smallest BIC (− 34.11). The final BSR model is composed of seven variables. Two most parsimonious models include variables related to the fourth principal component (PC4) and the first principal component (PC1), so these two variables seem to represent information crucial for RE development. What is more, the fourth principal component (PC4) is present in all remaining BSR models of sizes from 1 to 8. Most BSR models include the third and the first principal component (PC3, PC1), thus, these variables seem to represent information important for RE development. What is

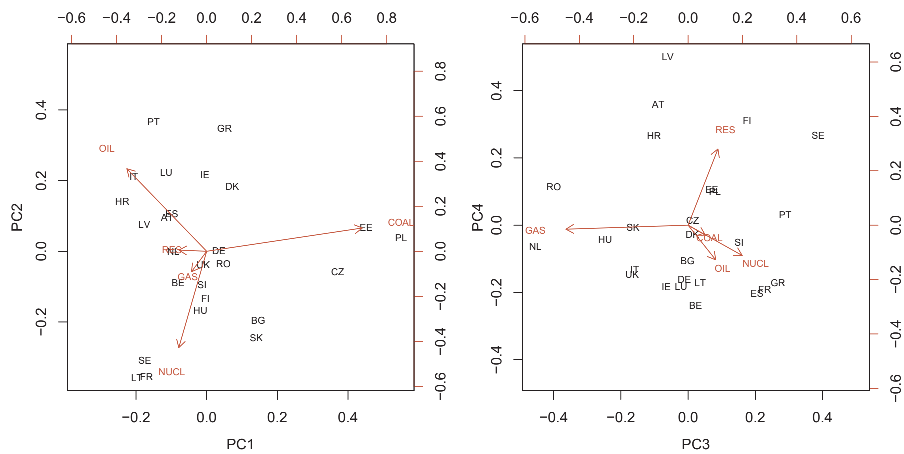


Fig. 5. The results of PCA for energy sources in the EU countries in 1995.

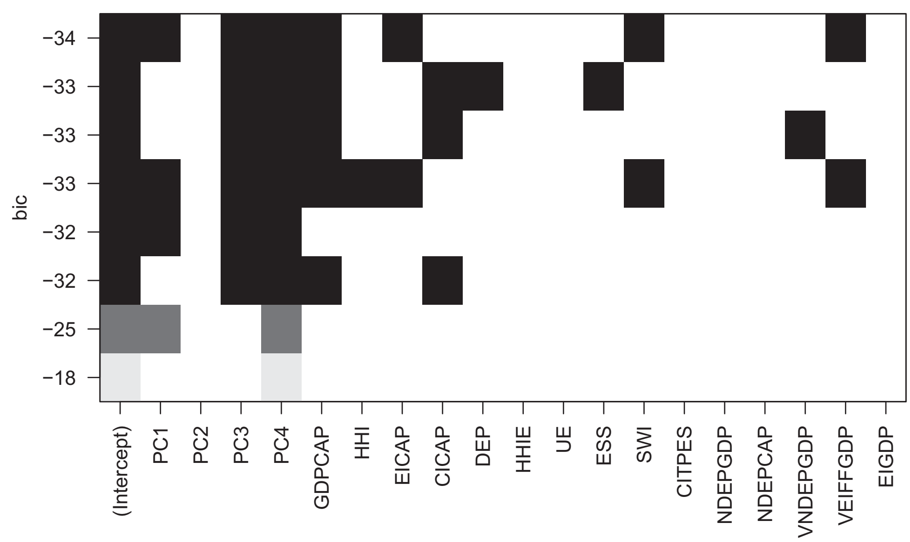


Fig. 6. The best subset regression results.

Table 6
The results of the final best subset regression model.

	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-squared: 0.9012.
Adjusted R-squared: 0.8628; F-statistic: 23.45 on 7 and 18 DF, p-value: 8.069e-08.
***, ** Represent significance at the 1% and 5% levels respectively.

interesting, each BSR model includes one of two highly correlated variables PC1 or CICAP, which are related to a high share of coal consumption in the country.

CICAP appears in the BSR models including three, five and six variables. EICAP, SWI and VEIFFGDP are used twice, ESS and VNTDEPGDP appear in one of the BSR models (with eight and five variables respectively), and two variables - ESS and VNTDEPGDP - are used once.

The remaining covariates (PC2, EIGDP, HHIE, EU, CITPES, NTDEPGDP, NDEPCAP) do not appear in any BSR model, thus they seem to be poor predictors of RE development.

The final BSR model (as it was mentioned above) includes seven variables. The detailed results for this model are presented in Table 6. 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 consumption (see Table A3 in Appendix A), which means that RE development is not a priority for countries with a high share of coal consumption in their energy mix: that the countries with high energy consumption per capita in 1995 are not interested in investing in RES. These results are in line with Aguirre and Ibikunle [11], but in contrast to Marques et al. [6], Marques and Fuinhas [7], Marques et al. [8], Marques and Fuinhas [9] and Lucas et al. [14], 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. The 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). The countries with such a profile of energy consumption reveal considerable development of their RES. There are several reasons why the countries with significant shares of RES in 1995 develop them further, e.g. already existing legal regulations, technological facilities or favourable geographical and climatic conditions.

However, it is possible to offer a convincing interpretation of a

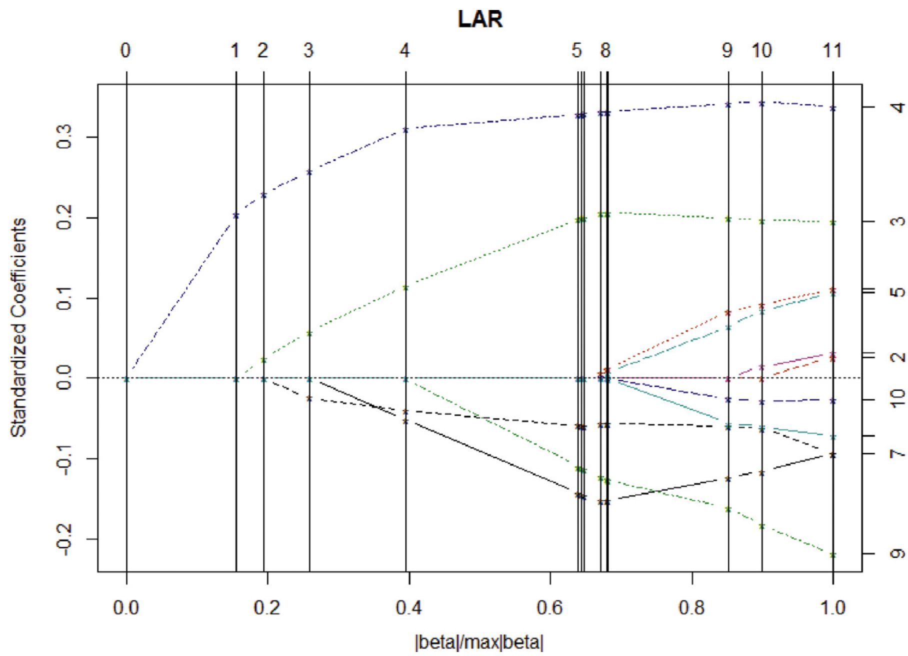


Fig. 7. The results of the lasso method.

Table 7
The estimates of the most influential variables indicated by lasso shrinkage.

	M1	M2	M3	M4	M5	M6	M7	M8	M9
PC4	0.436	0.489	0.549	0.560	0.620	0.663	0.688	0.701	0.744
PC3		0.040	0.095	0.104	0.173	0.216	0.245	0.280	0.313
CITPES			− 0.00008	− 0.000008	− 0.00008	− 0.00009	− 0.00006	− 0.00007	− 0.00006
PC1				− 0.00511	− 0.04965	− 0.06306	− 0.07762	− 0.10002	− 0.15143
CICAP					− 0.000002	− 0.000002	− 0.000002	− 0.000002	− 0.000001
HHIE						− 0.02459	− 0.03061	− 0.0337	− 0.0267
HHI							− 0.03733	− 0.06056	0.083197
NTDEPCAP								− 0.000004	− 0.000007
SWI									0.075

Table 8
The order of introducing variables to the model.

Model	Variables present in the models
M1	PC4
M2	PC4 PC3
M3	PC4 PC3 CITPES
M4	PC4 PC3 CITPES PC1
M5	PC4 PC3 CITPES PC1 CICAP
M6	PC4 PC3 CITPES PC1 CICAP HHIE
M7	PC4 PC3 CITPES PC1 CICAP HHIE HHI
M8	PC4 PC3 CITPES PC1 CICAP HHIE HHI NTDEPCAP
M9	PC4 PC3 CITPES PC1 CICAP HHIE HHI NTDEPCAP SWI
M10	PC4 PC3 CITPES PC1 CICAP HHIE HHI NTDEPCAP SWI GDPCAP
M11	PC4 PC3 CITPES PC1 CICAP HHIE HHI NTDEPCAP SWI GDPCAP EICAP
M12	PC4 PC3 CITPES PC1 CICAP HHIE HHI NTDEPCAP SWI GDPCAP EICAP NTDEPGDP
M13	PC4 PC3 CITPES PC1 CICAP HHIE HHI NTDEPCAP SWI GDPCAP EICAP NTDEPGDP ESS
M14	PC4 PC3 CITPES PC1 CICAP HHIE HHI NTDEPCAP SWI GDPCAP EICAP NTDEPGDP ESS VEIFFGDP
M15	PC4 PC3 CITPES PC1 CICAP HHIE HHI NTDEPCAP SWI GDPCAP EICAP NTDEPGDP ESS VEIFFGDP PC2

negative impact of a high share of natural gas on RE development. Countries which use natural gas as their main energy source (the Netherlands, the United Kingdom, Romania, see Table A4) are the largest natural gas producers in the UE, and, as such, do not depend 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 directly 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 likely to invest in RE: they can afford to invest in development of expensive RE technologies and to support subsidies for promoting and regulating RE. A positive impact of income (GDP per capita) on the promotion of RE is also found by Marques et al. [6].

The parameter of energy security factor (SWI) is positive as well. It means that the more diversified energy sources a country has, the more it is interested in developing RE. As a consequence, a relatively even distribution of energy sources in the energy mix motivates the EU countries to promote development of RE. Similar results are obtained by Lucas et al. [14].

Finally, the cost of 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.

In order to find the key determinants, the LARS method is used next. As a result, the variables of interest are ordered according to their importance as predictors of RE development.

Fig. 7 summarizes the results obtained using the LARS method. The colour lines represent the standardized coefficients of the model for different tuning parameters.[6] The more on the left the line begins, the earlier the variable (related to the coefficient) appears in the model and the more important the variable is for predicting RE development. When tuning parameter λ decreases, regression includes successive variables. Table 7 presents the estimates of the most influential variables indicated by lasso shrinkage. The subsets of variables in subsequent models are presented in Table 8. It is worth noting here that the variables which appear in the model of a particular size are also present in more extensive models. So, the earlier the variable enters the model, the more important it is for RE development.

PC4 turns out to be the most influential variable (see Table 8), as it enters the model first (M1). The estimates of the coefficients are positive (Table 7) and remain positive when the tuning parameter increases (for models M2–M9 including from two to eight variables). 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 CO_2 emissions per capita (carbon intensity per capita) (CICAP) are negatively correlated with RE development. All these variables are linked to high concentration of coal in the energy mix, which means that, apart from having a negative impact on the environment, they 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. These results are in line with the results obtained in studies conducted by Marques et al. [6], Marques and Fuinhas [7], Marques et al. [8], Marques and Fuinhas [9] and Lucas et al. [14].

The other two variables included in the model, namely, the degree of diversification in the electricity mix (HHIE) and the degree of diversification of energy sources (HHI), characterise energy supply security, since they both represent diversification of energy sources. As their parameters are negative, the results indicate that the countries with more diversified energy sources develop RE faster than others.

The volume of net energy import per capita (NDEPCAP) and the concentration of energy supply (SWI), both related to the distribution of energy sources, enter the model next. The parameter of the volume of net energy import per capita (NDEPCAP) is negative, while the parameter of the concentration of energy supply is positive, which again points to reluctance of countries with high concentration of energy sources to invest in RE development.

Finally, it is worth noting that the results obtained with the use of the BSR method and the lasso methods are, to some extent, similar. Most variables which are included in the BSR when the BIC criterion is applied (Table 6) are the ones which enter the regression model first when the lasso approach is used 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 BSR, the final model includes SWI, while the lasso approach includes HHI, which is strongly correlated with SWI, and HHIE, which provides 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. High values of PC1 and remaining variables related to high coal consumption are obstacles for RE development. Finally, high levels of diversification of energy sources (low values of HHI, HHIE and a high value of SWI) encourage RE development.

6. Conclusions

The study reveals that RE development in the EU countries is relatively diverse. In the analysed period all EU countries increase their shares of RES in the energy mix, however, this growth is uneven. The shares of particular RES in total RES in different countries also differ considerably. The aim of the study is to identify factors determining development of RES in the EU countries in the middle of 1990s.

This objective is achieved in three stages. In the first one, using PCA, the changes in the distribution of RES in 26 EU countries in the period between 1995 and 2014 are investigated. The analysis demonstrates that over the last 20 years the EU countries substantially change their distribution of RES. Three types of RES - hydropower, biomass and geothermal energy - predominate in the EU in 1995. Over the next years the share of RE in the energy mix increases, and the distribution of RES changes, including a notable growth in the share of wind power and solar energy in the total RE consumption.

In the next stage PCA is used to identify the distribution of five main energy sources in the EU countries in 1995, and its results indicate their energy mix profile. There are countries which use dirty energy (coal and oil) as their main energy source, and countries which mostly depend on clean energy. The use of nuclear energy is negatively correlated with the use of crude oil. Natural gas consumption does not depend on other energy sources. The profile of the energy mix, defined by principal components, is next used as potential determinants of RE development.

Finally, in the third stage the key determinants of RE development are identified. Several factors which potentially influence decisions in the area of energy policy are considered. The determinants include factors related to energy security, environmental concerns, economy and politics.

The main determinants of RE development identified by both methods of variable selection used in the study are similar, and the results can be summarised in the following way.

Firstly, the results indicate that the present (in 2014) share of RES in the energy mix to a great extent depends on a set of circumstances in the EU member states in the middle of 1990s. This relatively long period in which particular factors have shaped RE development is most probably connected with the nature of the energy sector (investments in infrastructure or legal regulations) and the long-term objectives of *energy policy* in the EU countries. The decisions regarding energy security, economic potential, and environment protection taken 20 years ago have been shaping (and will probably continue to do so) the energy market.

Secondly, the study reveals that the distribution of five main energy sources in the energy mix in 1995 is a crucial factor affecting RE development. In contrast to other papers, this paper uses PCA to reflect the distribution of energy sources, and this choice is justified by the following arguments. First, the distribution of energy sources relates (directly or indirectly) to almost all aspects of energy security. It reflects national energy sources, energy self-sufficiency, diversification and impact on the natural environment. Thus, the situation of particular countries in 1990s described by principal components is already indicative of their potential in the area of development of particular RES. However, this argument seems less valid when one realizes that wind and solar power were not used 20 years ago, and that now technological advancements allow for using new energy sources. Additionally, by definition, principal components represent independent portions of information. Including subsequent principal components in the regression extends the information which could be important for RE development.

The most general conclusion of the study states that countries with the lowest shares of RE are the ones 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: the countries with coal resources (Poland, the Czech Republic, Bulgaria, Estonia) and the countries with natural gas resources (the Netherlands, the United Kingdom, Romania). They do not face the threat of having export of energy supplies suspended. Consequently, they do not need to

[6] The figure presents changes of parameters for different λ. For the largest λ, parameters β are shrunk to zero, thus $||\beta||/\max||\beta||$ are close to zero, too. For smaller λ, parameters β are larger (according to the L_1 norm) and $||\beta||/\max||\beta||$ are close to one.

develop their RE sectors to the extent the countries without their own energy sources should if they want to minimize their dependence on energy export. Moreover, countries with their own energy sources have a well-developed mining industry, which generates employment. A sudden transformation from local fossil fuels to RES would entail far-reaching changes in the labour market, which might prove risky for both the country's policy and economy.

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

Certain general conclusions that follow from this study may be pertinent to non-EU countries. First, development of solar and wind power in all EU countries indicates that countries can match RES to their individual needs. Even without particularly favourable climatic or geographical features, investing in new RES might prove beneficial. Moreover, sunny countries (e.g. in Africa) or countries with a lot of wind can benefit greatly from investing in solar or wind power. On the other hand, financial aspects might be a major obstacle in RE development.

Second, the analysis could prove valuable in understanding energy policy decisions made in democratic countries. The key obstacles to renewable energy development, as the study suggests, are connected with various aspects of the existing structure of energy production. Politicians governing the country at a given moment are subjected to a strong pressure from their voters, and it is difficult to make decisions that are contrary to their interests.

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Appendix A

See Appendix Tables A1–A4

Table A1
The share of different RES in total RE.

	1995						2014					
	HYDRO	WIND	SOLAR	TIDE	BIOMASS	GEOTHERMAL	HYDRO	WIND	SOLAR	TIDE	BIOMASS	GEOTHERMAL
AT	0.54	0.00	0.01	0.00	0.45	0.00	0.36	0.03	0.03	0.00	0.58	0.00
BE	0.05	0.00	0.00	0.00	0.94	0.01	0.01	0.12	0.08	0.00	0.79	0.00
BG	0.48	0.00	0.00	0.00	0.52	0.00	0.22	0.06	0.07	0.00	0.62	0.02
CY	0.00	0.00	0.69	0.00	0.31	0.00	0.00	0.12	0.56	0.00	0.31	0.02
CZ	0.14	0.00	0.00	0.00	0.86	0.00	0.05	0.01	0.05	0.00	0.89	0.00
DE	0.31	0.02	0.01	0.00	0.66	0.00	0.05	0.14	0.11	0.00	0.70	0.01
DK	0.00	0.08	0.00	0.00	0.92	0.00	0.00	0.25	0.02	0.00	0.73	0.00
EE	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.06	0.00	0.00	0.94	0.00
ES	0.36	0.00	0.00	0.00	0.63	0.00	0.19	0.25	0.17	0.00	0.38	0.00
FI	0.18	0.00	0.00	0.00	0.82	0.00	0.11	0.01	0.00	0.00	0.88	0.00
FR	0.37	0.00	0.00	0.00	0.62	0.01	0.25	0.07	0.03	0.00	0.64	0.01
GR	0.24	0.00	0.06	0.00	0.70	0.00	0.16	0.13	0.21	0.00	0.50	0.00
HR	0.32	0.00	0.00	0.00	0.68	0.00	0.39	0.03	0.01	0.00	0.57	0.01
HU	0.02	0.00	0.00	0.00	0.88	0.10	0.01	0.03	0.01	0.00	0.88	0.07
IE	0.39	0.01	0.00	0.00	0.59	0.00	0.06	0.46	0.01	0.00	0.46	0.00
IT	0.42	0.00	0.00	0.00	0.17	0.41	0.19	0.05	0.08	0.00	0.48	0.20
LT	0.06	0.00	0.00	0.00	0.94	0.00	0.03	0.04	0.00	0.00	0.92	0.00
LU	0.23	0.00	0.00	0.00	0.77	0.00	0.05	0.04	0.06	0.00	0.86	0.00
LV	0.20	0.00	0.00	0.00	0.80	0.00	0.11	0.01	0.00	0.00	0.89	0.00
MT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56	0.00	0.44	0.00
NL	0.01	0.03	0.01	0.00	0.96	0.00	0.00	0.15	0.03	0.00	0.81	0.01
PL	0.04	0.00	0.00	0.00	0.96	0.00	0.02	0.08	0.00	0.00	0.90	0.00
PT	0.22	0.00	0.00	0.00	0.77	0.01	0.24	0.19	0.02	0.00	0.51	0.03
RO	0.51	0.00	0.00	0.00	0.49	0.00	0.26	0.09	0.02	0.00	0.62	0.00
SE	0.46	0.00	0.00	0.00	0.54	0.00	0.32	0.06	0.00	0.00	0.63	0.00
SI	0.52	0.00	0.00	0.00	0.48	0.00	0.43	0.00	0.03	0.00	0.52	0.03
SK	0.85	0.00	0.00	0.00	0.16	0.00	0.25	0.00	0.04	0.00	0.70	0.00
UK	0.23	0.02	0.01	0.00	0.75	0.00	0.04	0.23	0.03	0.00	0.70	0.00

Table A2
The share of energy sources in TPES.

	1995					2014				
	COAL	OIL	GAS	NUCL	RES	COAL	OIL	GAS	NUCL	RES
AT	0.13	0.42	0.24	0.00	0.23	0.09	0.36	0.20	0.00	0.32
BE	0.16	0.42	0.20	0.20	0.02	0.06	0.44	0.24	0.16	0.08
BG	0.34	0.25	0.20	0.20	0.02	0.36	0.22	0.13	0.23	0.10
CY	0.01	0.97	0.00	0.00	0.02	0.00	0.94	0.00	0.00	0.06
CZ	0.54	0.19	0.16	0.08	0.03	0.38	0.22	0.15	0.19	0.09
DE	0.27	0.40	0.20	0.12	0.02	0.25	0.35	0.20	0.08	0.13
DK	0.32	0.45	0.16	0.00	0.08	0.14	0.39	0.17	0.00	0.29
EE	0.63	0.21	0.11	0.00	0.06	0.67	0.16	0.06	0.00	0.14
ES	0.19	0.54	0.08	0.14	0.06	0.10	0.42	0.20	0.13	0.15
FI	0.21	0.29	0.10	0.17	0.21	0.13	0.28	0.07	0.18	0.30
FR	0.07	0.36	0.12	0.40	0.07	0.04	0.31	0.13	0.45	0.09
GR	0.35	0.59	0.00	0.00	0.06	0.27	0.49	0.10	0.00	0.10
HR	0.02	0.50	0.25	0.00	0.20	0.08	0.39	0.25	0.00	0.25
HU	0.18	0.29	0.35	0.14	0.03	0.10	0.27	0.31	0.18	0.09
IE	0.26	0.51	0.21	0.00	0.01	0.15	0.49	0.27	0.00	0.08
IT	0.08	0.58	0.28	0.00	0.05	0.09	0.37	0.34	0.00	0.18
LT	0.03	0.35	0.23	0.36	0.06	0.04	0.37	0.31	0.00	0.19
LU	0.15	0.54	0.17	0.00	0.01	0.01	0.63	0.20	0.00	0.05
LV	0.06	0.41	0.22	0.00	0.27	0.01	0.32	0.24	0.00	0.38
MT	0.00	1.00	0.00	0.00	0.00	0.00	0.98	0.00	0.00	0.02
NL	0.12	0.38	0.46	0.01	0.02	0.12	0.42	0.38	0.01	0.05
PL	0.71	0.15	0.09	0.00	0.05	0.52	0.24	0.14	0.00	0.10
PT	0.17	0.66	0.00	0.00	0.16	0.12	0.46	0.16	0.00	0.26
RO	0.23	0.28	0.42	0.00	0.07	0.18	0.27	0.29	0.09	0.19
SE	0.06	0.33	0.02	0.35	0.25	0.04	0.25	0.02	0.35	0.37
SI	0.23	0.38	0.12	0.20	0.09	0.16	0.35	0.09	0.25	0.19
SK	0.30	0.19	0.29	0.17	0.04	0.21	0.20	0.23	0.25	0.10
UK	0.21	0.38	0.29	0.10	0.01	0.16	0.36	0.32	0.09	0.07

Table A3
Correlation matrix.

	PC1	PC2	PC3	PC4	GDPCAP	HHI	EICAP	CICAP	DEP	HHIE	UE	ESS	SWI	CITPES	NDEPGDP	NDEPCAP	VNDEPGDP	VEIFFGDP	EIGDP
PC1	1																		
PC2	0.00	1																	
PC3	0.00	0.00	1																
PC4	0.00	0.00	0.00	1															
GDPCAP	− 0.34	0.23	0.08	− 0.25	1														
HHI	0.35	0.62	0.20	− 0.10	− 0.09	1													
EICAP	− 0.04	− 0.16	0.12	− 0.13	0.79	− 0.25	1												
CICAP	.25	0.24	− 0.06	− 0.32	0.73	0.08	0.82	1											
DEP	− 0.49	0.25	0.24	− 0.15	0.24	− 0.09	0.09	0.07	1										
HHIE	0.45	0.02	0.22	0.14	− 0.1	0.53	0.01	0.15	− 0.25	1									
UE	− 0.42	0.33	0.25	− 0.29	0.81	0.06	0.48	0.39	0.26	− 0.26	1								
ESS	0.46	− 0.21	− 0.25	0.11	− 0.21	0.12	− 0.10	− 0.05	− 0.99	0.27	− 0.22	1							
SWI	− 0.14	− 0.76	− 0.07	0.05	− 0.08	− 0.92	0.13	− 0.20	− 0.06	− 0.43	− 0.14	0.02	1						
CITPES	0.59	0.68	− 0.10	− 0.33	0.01	0.63	− 0.15	0.40	− 0.10	0.23	0.05	0.14	− 0.61	1					
NDEPGDP	− 0.02	− 0.34	− 0.04	0.05	− 0.48	− 0.34	− 0.23	− 0.28	0.40	− 0.02	− 0.54	− 0.4	0.29	− 0.25	1				
NDEPCAP	− 0.30	0.12	0.18	− 0.22	0.67	− 0.18	0.71	0.64	0.72	− 0.10	0.40	− 0.72	− 0.02	− 0.08	0.11	1			
VNDEPGDP	0.11	− 0.34	− 0.09	0.12	− 0.62	− 0.22	− 0.34	− 0.35	0.21	0.13	− 0.67	− 0.22	0.20	− 0.19	0.96	− 0.07	1		
VEIFFGDP	0.48	− 0.28	− 0.27	0.16	− 0.71	0.00	− 0.38	− 0.27	− 0.20	0.27	− 0.80	0.18	0.05	0.05	0.69	− 0.32	0.82	1	
EIGDP	0.50	− 0.41	− 0.15	0.17	− 0.72	− 0.07	− 0.31	− 0.27	− 0.19	0.29	− 0.81	0.16	0.16	− 0.04	0.76	− 0.29	0.87	0.96	1
RES	− 0.36	0.03	0.30	0.78	− 0.08	− 0.16	− 0.17	− 0.45	0.12	− 0.01	− 0.01	− 0.14	0.12	− 0.46	0.07	− 0.11	0.07	− 0.07	− 0.07

Table A4
Production (million tonnes oil equivalent).

	1995			2014		
Country	Oil	Gas	Coal	Oil	Gas	Coal
BG			5.9			5.1
CZ			27.3			16.8
DE		14.5	79.0		7.0	44.1
DK	9.1	4.8		8.1	4.1	
ES			9.7			1.6
GR			7.5			6.4
HU			2.8			1.6
IT	5.2	16.3		5.8	5.9	
NL		60.9			52.1	
PL		3.2	92.2		3.7	54.0
RO	7.0	14.4	7.9	4.1	8.8	4.4
UK	129.9	63.7	32.8	40.0	33.1	7.3

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