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PROGRESS OF RENEWABLE ENERGY USE IN EU COUNTRIES – STATISTICAL ANALYSIS OF TRENDS AND FACTORS

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Abstract

The use of renewable energy sources is an important aspect of economic development throughout the world, including Europe, as it provides clean energy and contributes significantly to environmental transformation. Three clusters of EU countries are identified concerning their progress of the share of renewable energy (SRE) use in gross energy consumption for 2004 – 2022 applying cluster analysis based on the SRE trends in the period. Effects of important factors for expanding SRE are analyzed by developing a set of econometric models of renewable energy use in main sectors of energy balance – electricity, transport and cooling&heating.

Keywords: share of renewable energy (SRE), sustainability, cluster analysis, trends, econometric models, EU members

JEL: C33, C38, O13; O14, P28, Q01

Introduction

Humanity is faced with the problems of climate change and environmental pollution, which are the result of its quest for a better life. The dominant cause of the increase in the Earth‘s average temperature is the greenhouse gas (GHG) emissions accumulating from the production of energy used in industry and for domestic purposes. This makes people look for a way to meet their energy needs in an environmentally friendly way. Striving for a clean environment people have to reduce the GHG emissions, the dependence on traditional energy sources such as coal, oil, etc. and improve the energy efficiency. The shift towards energy provided by renewable sources leads to a reduction in both greenhouse gas emissions and dependence on traditional energy sources such as coal, oil, etc.

The need to change the attitude towards nature and climate forms the basis of many documents at World and European level, starting with the United Nations

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(UN) Framework Convention on Climate Change, signed in 1992, and updated with the Paris Agreement which has entered into force in 2016. World leaders adopted the 2030 Agenda for Sustainable Development at the UN General Assembly in 2015. It is a global framework for sustainable development that integrates in a balanced manner the economic, social and environmental dimensions of sustainable development. The Sustainable Development Goals (SDGs), and especially the seventh goal for achieving affordable, reliable, sustainable and modern energy for all, are the backbones of the Agenda. The European Union (EU) has committed itself to support the implementation of the 2030 Agenda and strives for a sustainable future for all. The European Commission proposed the reduction of GHG emissions in all sectors of the economy and took initiatives to boost clean energy transition (European Comission, 2016). Increasing energy efficiency and the use of renewable energy sources are among the main of these initiatives. The European Union and Member States regularly monitor progress towards achieving the SDGs, including the energy transition.

A number of studies have been conducted to investigate and analyze the use of renewable energy sources, GHG emissions, and energy efficiency (Chipeva, 2022; Ivanova and Slavova, 2018). Empirical studies on the expansion of the use of renewable energy in general, in specific sectors of the economy or in households in EU countries, as well as the impact of economic and environmental factors on this process, are, however, still limited.

One of the key indicators of energy transition and increase of energy efficiancy is the Share of Renewable Energy in gross energy consumption (SRE). There are several studies on the use of renewable energy, the dynamic of its use in different economic sectors as well as on the factors that influence the increase of its use, which are worth mentioning here. Clusterization of European countries in terms of the share of renewable energy use in their gross energy consumption and comparative analysis have been conducted by a couple of researchers (Simionescu, Strielkowski and Tvaronavičienė, 2022; Kosowski, Kosowska and Janiga, 2023; Rybak, Rybak and Kolev, 2021). Progressive trends of renewable energy use in all economic sectors and households of member states (EU-27) have been established for the period from 2000 to 2019 as the greatest consumption in the countries as a whole is observed in the transport sector (Tutak and Brodny, 2022).

Different hypotheses about the relationship between renewable energy consumption and economic growth for European and OECD countries are confirmed (Papież, Śmiech and Frodyma, 2018). Evidence for the dependence of economic growth on the renewable energy use has been presented for different countries and groups of them (Inglesi-Lotz, 2016; Tutak and Brodny, 2022; Rafindadi and Oztur, 2017). Tutak and Brodny (2022) analyzed the impact of renewable energy use increase on the country economy and reduction of GHG emissions. The correlation between the share of renewable energy use and several macroeconomic indicators, mainly GDP, has been the focus in a range of studies.

A range of factors that boost the expansion of renewable energy use has been explored. One of the main reasons that made people look for alternative sources of energy at the end of the last century, in particular renewable energy sources, is the lack of their own fossil fuel sources or the very limited resources. Countries without their own fossil fuel sources or with very limited ones are mainly the first using renewable energy sources expanding the share of this energy in gross energy consumption very extensively. Concentration of energy supply, GDP and costs of energy consumption obtained from fossil fuels in relation to GDP are other important factors for the renewable energy development (Papież, Śmiech and Frodyma, 2018). The positive effect of GDP growth on the expansion of SRE in final energy consumption in EU countries has been established using a panel data model for EU-28 countries for the period 2007 to 2017 (Simionescu, Strielkowski and Tvaronavičienė, 2022). A study of the factors influencing the renewable energy consumption in selected European countries during 2000 –2018 applying fixed-effects regression models and models based on the generalized method of moments, provides proof for a positive, statistically significant effect of GDP on the SRE in gross final energy consumption (Polcyn et al., 2022).

The renewable energy use impact on reducing GHG emissions have been proved for a group of countries (Busu and Nedelcu, 2021; Dong, Sun and Hochman, 2017). A similar effect of the SRE in final energy consumption has been statistically proved for the agriculture sector in the E7 countries (Aydoğan and Vardar, 2020) and for the transport sector in China (Godil et al., 2021).

The aim of the present study is to analyze the progress of the share of renewable energy (SRE) in gross energy consumption of the EU countries for the period 2004-2022 and to identify the factors that have a significant impact on it.

Methodology and data

Data

The empirical data used in the analyses are publicized on the Eurostat website for each country – EU member for period from 2004 to 2022. Annual data is used for all the indicators under consideration. The current composition of EU-27 countries, excluding the UK, is taken into account in the study.

Research methodology

Cluster analysis

Multinomial classification of EU countries was carried out by applying cluster analysis using a set of 7 selected key variables. Classification variables are actually the same indicator SRE in the final energy consumption, but taken for 7 key years in the studied period 2004 – 2022: 2004, 2008, 2015, 2019, 2020, 2021, 2022.

Selected variables aim to classify countries by their progress in terms of SRE during the period under review. Years are chosen considering data availability for all the counties, the period of world economy crisis and the years after the EU Green Pact was signed. Hierarchical cluster analysis was applied first, to establish the appropriate number of clusters. Based on the results, EU countries were classified into 3 clusters applying non-hierarchical cluster analysis. The classical K-Means algorithm was applied. Clusters have been formed according to distance between points and center of clusters. Distance between members of the data set and center were estimated using the Euclid distance criterion. Final clusters were formed by an iterative procedure. Statistical significance for the classifying ability of the selected indicators is proven using ANOVA tests at a 5% significance level.

Econometric analysis

Econometric models for the share of energy from renewable sources (SRE) used in the main sectors of energy balance – electricity, transport and cooling & heating, are developed based on panel data. Multivariate linear models are specified for the SRE in each of the sectors mentioned. Seven factors are included in the models. Factors are chosen considering their significance regarding the expansion of the renewable sources of energy use. A description of all the variables included in the models are presented in table 1.

Table 1: Variables including in the econometric models

Variables script	**Variables name**	**measure**
sre_e	Share of energy from renewable sources used in gross final consumption of electricity	Percentage
sre_tr	Share of energy from renewable sources used in gross final consumption of transport	Percentage
sre_ch	Share of energy from renewable sources used in gross final consumption of cooling&heating	Percentage
sdg_07_50	Energy import dependency	Percentage
sdg_07_30	Energy productivity	Euro/KGOE
ten00124	Final energy consumption	Thousand tonnes/ oil equivalent
sdg_13_10	Net GHG emissions	Index (1990)
sdg_09_70	Air emission intensity from industry	Grams/euro
sdg_09_10g	Gross domestic expenditure on R&D by government	% of GDP
sdg_09_10b	Gross domestic expenditure on R&D by business enterprises	% of GDP

Source: Own elaboration

Three types of econometric multivariate linear models are elaborated and analyzed for each of resultant indicators – SRE used in electricity, SRE used in transport and SRE used in cooling & heating:

- Models without effects of unobserved factors identified (an ordinary regression model)
- Models with random effects of unobserved factors identified (a random effect model)
- Models with fixed effects of unobserved factors identified (a fixed effect model)

All factors mentioned above are included in each of the models and the parameters related to them are tested for statistical significance using Student's *t*-test. Models are tested for goodness-of-fit using Fisher's *F*-test. Correlation between unobserved factors and factors included in the models, i.e. correlation of random effects and the regressors in the model, is tested using the Hausman Test of Endogeneity, known also as the Hausman Specification Test. The null hypothesis of the test is that there is no correlation between errors caused by unobserved factors and regressors in the model. Confirmation of the null hypothesis means that the random-effects model is more appropriate since it provides consistent parameter estimates. In case of rejecting the null hypothesis, the fixed-effects model is recommendable.

Models are estimated for the current set of European member states (EU-27), for a 10-year period: from 2013 to 2022. Empirical data used in the analysis is based on available data published on the Eurostat website for each country-EU member for 2013 and 2022 excluding the UK. Annual data for the mentioned years about all the indicators under consideration in the study is used.

Results and discussion

Cluster Analysis

Application of the hierarchical cluster analysis showed that the optimal grouping of EU countries in terms of SRE in the gross final consumption is into 3 clusters. The clusters obtained after applying a 3-cluster nonhierarchical analysis with the countries included in them are presented in table 2.

Table 2: Clusters of EU countries in terms of SRE in the gross energy consumption

Clusters	Countries in the cluster
1st cluster	Belgium, Bulgaria, Czech, Germany, Ireland, Greece, Spain, France, Italy, Cyprus, Luxembourg, Hungary, Malta, Netherlands, Poland, Slovakia
2nd cluster	Denmark, Estonia, Croatia, Lithuania, Austria, Portugal, Romania, Slovenia
3rd cluster	Latvia, Finland, Sweden

Source: Own elaboration

The classification ability of the selected years as key variables in the cluster analysis is presented in table 3. The results of F-test provide statistical proof at a 5% significance level for the classifying ability of all the variables used in the analysis.

Table 3: Cluster means of SRE in the gross energy consumption, respective standard errors and results of the F-test for the classifying ability of the key variables

Key variables	Fisher's F-test		1st cluster		2nd cluster		3rd cluster	
	F Stat	Sig.(F)	Mean	St. Error	Mean	St. Error	Mean	St. Error
2004	128,7	0,000	5,09	0,748	18,86	1,017	33,48	1,982
2008	74,8	0,000	7,12	0,864	20,97	1,285	34,93	2,015
2015	72,7	0,000	12,16	1,114	28,23	1,237	43,00	2,271
2019	62,5	0,000	14,54	1,085	29,17	1,799	46,51	2,294
2020	65,7	0,000	16,99	0,923	29,94	1,515	48,73	2,210
2021	55,9	0,000	16,66	0,850	31,92	2,119	49,21	2,372
2022	57,0	0,000	17,55	0,784	31,82	2,317	52,4	2,457

Source: Own elaboration

The first cluster is the largest one and includes 16 of observed EU countries (table 2). Bulgaria also falls in this cluster. The countries in the cluster start with a very small share of renewable energy in total energy consumption at the beginning of the study period and reach a share of around 17.5% at the end of the period (table 3). A more intensive growth of SRE in these countries is observed in the recovery of the economy after the global crisis.

Eight countries fall in the second cluster (table 2). The SRE in them is higher at the beginning of the study period compared to the countries in the 1st cluster – almost 19% (table 3). The growth of SRE in the years under review is similar overall to that of the countries in cluster 1, as the most significant growth in them is also observed after the world crisis. At the end of analyzed period, they reach almost 32% use of renewable energy.

The greatest progress of SRE in gross energy consumption is established for the countries in the 3rd cluster, where only 3 countries fall: Latvia, Finland, Sweden (table 2). One third of the gross energy consumption in these countries came from renewable sources already at the beginning of the study period and exceed 50% in 2022 (table 3).

Econometric models

Multivariate linear econometric models are developed for the share of renewable energy used in the main sectors of energy balance – (1) electricity; (2) transport; and (3) cooling&heating. All the models are estimated using panel data. As it is mentioned in the methodology part, three types of models were estimated for each of sectors: a model without unobserved factors effects identified; model with random effects; model with fixed effects.

Models of SRE in gross energy consumption in the electricity sector

Estimated *Model without unobserved factors effects identified* is[3]:

SRE_E = 10.09 * [4,85] + 2,15 * [0,33].SDG_07_30 – 0,11 * [0,05].SDG_07_50 + 12,86 * [1,86].SDG_09_10_B + 50.45 * [6,73].SDG_09_70 – 0.08 * [0,04].SDG_13_10 – 12.8[11,8].SDG_09_10_G – 0,00002[0,00002].TEN00124

The model is proven to fit well empirical data at a 5% significance level, but the explanatory ability of the model is rather insufficient – 44.43%. The effect of 5 included factors turns out to be statistically significant. Only 2 factors have an insignificant effect on the SRE, namely final energy consumption and gross domestic expenditures by government.

The estimated *Model with random effects* is:

SRE_E = 2,85[4,83] + 2,97 * [0,21].SDG_07_30 + 0,08 * [0,02].SDG_07_50 + 8,21 * [1,35].SDG_09_10_B – 9.47 * [3,88].SDG_09_70 – 0.03[0,02].SDG_13_10 + 12.3 * [5,04].SDG_09_10_G – 0,0001 * [0,00005].TEN00124

[3] Values in brackets are stand. errors of parameters; asterisk „*“ denotes statistically significant parameters at 5% significance level.

The model also fits well empirical data and the explanatory ability of the model is better compared to this one of the previous model (R-squared = 59,9). Parameters related to all factors in the model are statistically significant at a 5% significance level, excluding the common intercept, presenting the average effect of the unobserved factors. At the same time, the corpus hypothesis of the Hausman test is rejected, which means there is a correlation between the random effects and the regressors (factors identified in the model) in the model. In this case, the Fixed Effect Model is recommendable for application.

The estimation of *Fixed-effects model* is as follows:

SRE_E = 15,68 * [4,13] + 1,76 * [0,23] * .SDG_07_30 + 0,06 * [0,02]. SDG_07_50 + 2,6 * [1,33].SDG_09_10_B – 1.11[3,52].SDG_09_70 – 0.03[0,02]. SDG_13_10 + 19,63 * [4,6].SDG_09_10_G – 0,0001 * [0,00007].TEN00124

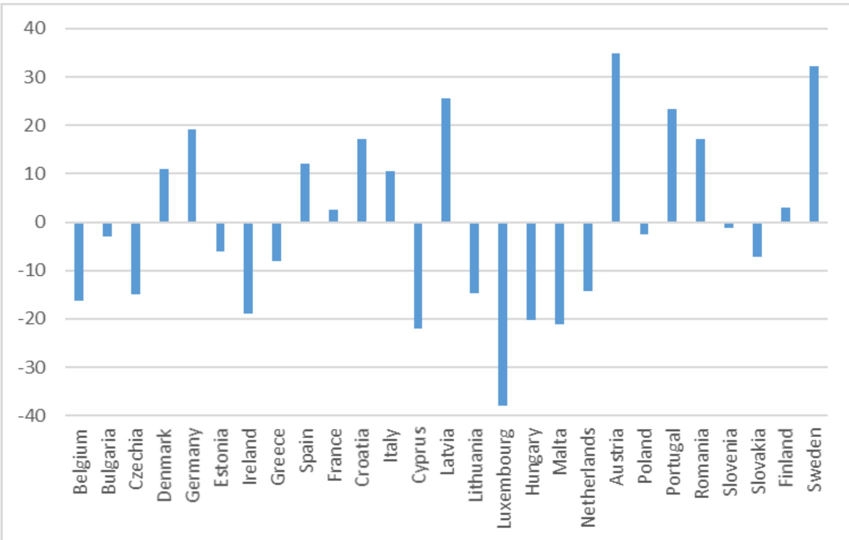
The results show that there are 2 factors in the model that are not statistically significant at a 5% significance level – air emission intensity from industry (SDG_09_70) and net GHG emissions (SDG_13_10). Fisher's *F*-test provides proof for model goodness-of-fit at a 5% sig. level. The R-square for the model is extremely high (99.2%), indicating that the factors included in the model could almost entirely explain the SRE variation in the electricity sector.

When the effect of the unobserved factors related to the specificities of the countries and to their SRE trends are identified and ignored, the effects of the factors identified in the model can be interpreted as follows:

- SRE in the electricity sector will grow averagely per year with 1.76 percentage points per 1 euro/KGOE increase of energy productivity
- SRE in the electricity sector will grow averagely per year with 0.06 percentage points per 1 percentage point increase of energy import dependency
- SRE in the electricity sector will grow averagely per year with 2.6 percentage points per 1 percentage point increase of expenditures for R&D by business
- SRE in the electricity sector will grow averagely per year with 19.6 percentage points per 1 percentage point increase of expenditures for R&D by government
- But SRE in the electricity sector will reduce averagely per year with 0.00015 percentage points per final energy consumption increase with 1 thousand tonnes/oil equivalent

The effects of the remaining 2 factors included in the model are not statistically significant since the parameters associated with these factors are statistically insignificant, as noted above. Thus, these effects are not discussed here.

The average effect of the unobserved factors on the SRE in the electricity sector is presented by the common intercept in the model. Considering the results, the average effect of the unobserved factors on the SRE in the electricity sector is 15.68%, that is, averagely 15.68% of the share of renewable energy used in the electricity sector is formed by the unobserved factors in the model. The effects of the unobserved factors related to the specifics of the countries and to the time period under review in the electricity sector are presented on figures 1 and 2 respectively. These effects are actually the deviations from the mean effect of the individual effects caused by the unexamined factors for individual countries and with respect to the trend. The most significant effect of unobserved factors that are specific for each country under consideration, is established for Luxemburg, Austria and Sweden (figure 1). The positive effect of the trend in the modeled variable (SRE) concerning all the countries as a whole is also well presented by the time effects.



Source: Own elaborated

Figure 1: Effects of the unobserved factors on SRE in electricity sector related to the specifics of the EU countries

The trend of the time effect of the unobserved factors is clearly presented from regressively negative in the first years of the analyzed period to progressively positive in the last years.

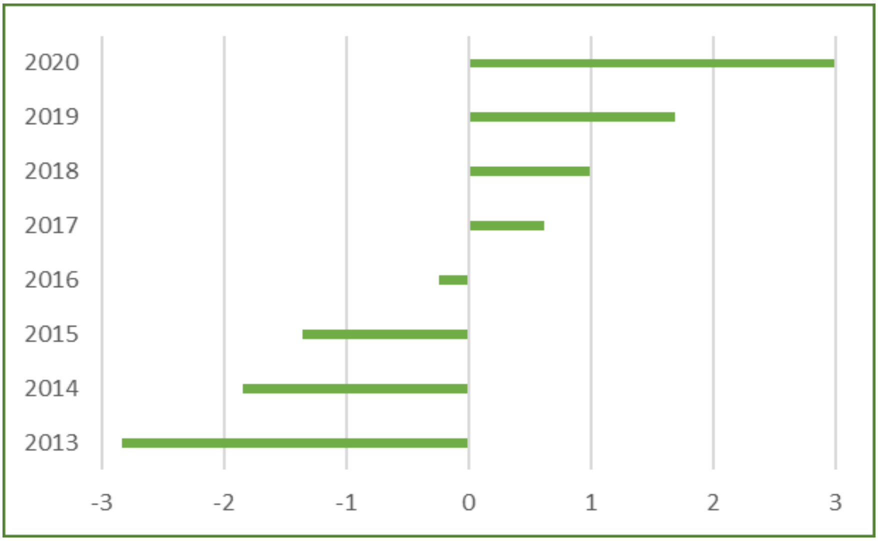


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Figure 2: Effects of the unobserved factors on SRE in the electricity sector related to the time period reviewed

Models of SRE in gross energy consumption in the transport sector

The estimated *Model without unobserved factors effects identified* is:

SRE_TR = 7,46 * [1,3] – 0,04[0,09].SDG_07_30 + 0,03 * [0,01].SDG_07_50 + 5,4 * [0,5].SDG_09_10_B + 0,1[1,81].SDG_09_70 – 0,06 * [0,01].SDG_13_10 – 11,8 * [3,18].SDG_09_10_G – 0,000007[0,000006].TEN00124

The model fits well the empirical data but the model's explanatory power presented by R-square is rather low (R-square = 44.99%). Three parameters in the model are statistically insignificant at a 5% significance level, which means that the factors associated with them, namely energy productivity (SDG_07_30), air emission intensity from industry (SDG_09_70) and final energy consumption (TEN00124), have no impact on the SRE in the transport sector.

The estimated *Random Effects Model* is:

SRE_TR = 4,17[2,38] + 0,56 * [0,09].SDG_07_30 + 0,01[0,02].SDG_07_50 + 4,57 * [0,88].SDG_09_10_B – 5,14[2,96].SDG_09_70 – 0,05 * [0,01].SDG_13_10 – 0,26[4,15].SDG_09_10_G – 0,00005[0,00001].TEN00124

Four parameters along with the intercept in the random effect model are proven to be statistically insignificant at a 5% significance level. These are parameters associated with energy import dependency (SDG_07_50), air emission intensity from industry (SDG_09_70), gross domestic expenditure on R&D by government

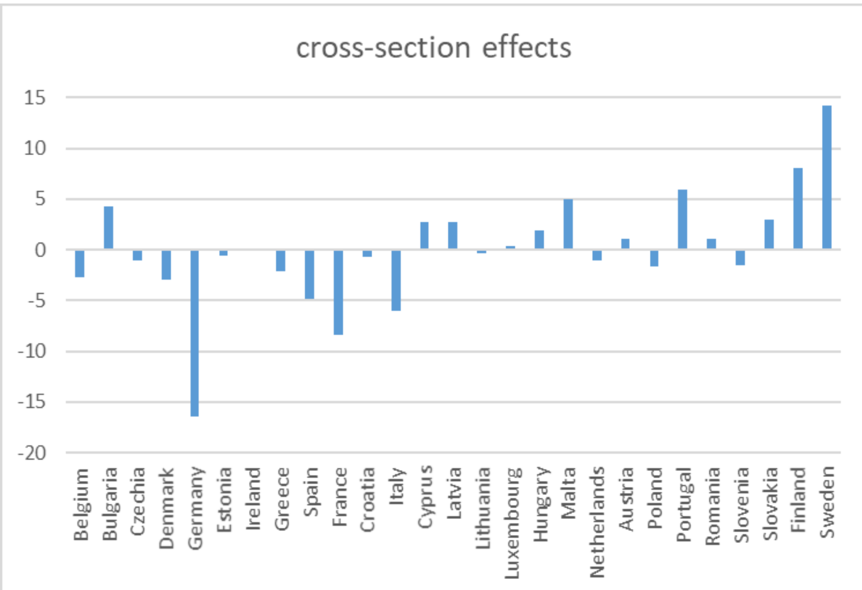
(DG_09_10_G) and final energy consumption (TEN00124). The factors pointed do not impact the SRE in the transport sector. Fisher's test provides evidence for model goodness-of-fit but the explanatory ability of the model is notably low – R-square is 26.93%. Results clearly show that this model cannot represent well the correlation between SRE and the defined factors in the analysis. The null hypothesis of the applied Hausman test was rejected and that provides one more proof that this model is not appropriate for presenting the studied correlation since the factors in the model (the regressors) correlate with unobserved factors.

The estimated *Fixed Effect Model* is:

SRE_TR = 2,69[4,51] + 0,27[0,25].SDG_07_30 – 0,009[0,03].SDG_07_50 + 1,89[1,45].SDG_09_10_B – 4,86[3,84].SDG_09_70 – 0,02[0,02].SDG_13_10 + 8,02[5,03].SDG_09_10_G + 0,00007[0,00008].TEN00124

Although the F-test provides evidence for model goodness-of-fit, all parameters in the model are statistically insignificant at a 5% significance level. The explanatory ability of the model is shown relatively high (R-square = 87%) but the effect of none of the factors in it could be proven statistically.

The average effect of the unobserved factors that is presented by the model is quite small and statistically insignificant. The effects of the unobserved factors related to the specifics of the countries and to the time period under review in the transport sector are presented on figures 3 and 4 respectively.



Source: Own elaborated

Figure 3: Effects of the unobserved factors on SRE in the transport sector related to the country-specifics

The effects of unobserved factors related to the country-specifics are quite small for most of the EU countries, as can be seen on figure 3. The most significant negative effect of unobserved factors stands out for Germany while the most positive – for Sweden (figure 3). The time-effect of unobserved factors on the SRE changes itself from strongly negative to strongly positive over the period considered (figure 4).

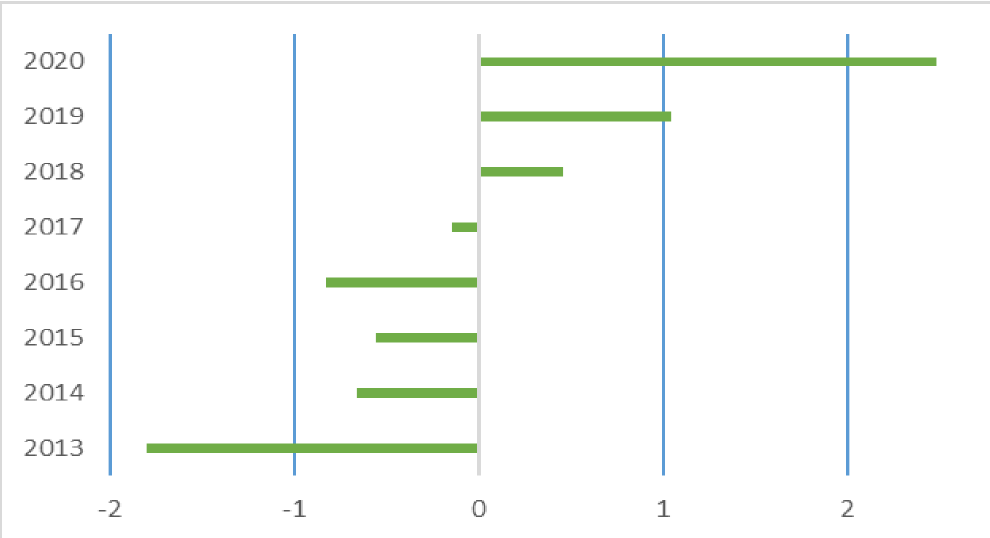


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Figure 4: Effects of the unobserved factors on SRE in the transport sector related to the time period reviewed

(1) *Models of SRE in gross energy consumption in cooling & heating*

The estimated *Model without unobserved factors effects identified* is:

SRE_CH = 38,07 * [1,3] – 0,45[0,29].SDG_07_30 – 0,14 * [0,04].SDG_07_50 + 9,56 * [1,64].SDG_09_10_B + 34,33 * [5,93].SDG_09_70 – 0,08 * [0,03]. SDG_13_10 – 20,32 * [10,4].SDG_09_10_G – 0,0001 * [0,00002].TEN00124

Since the effect of unobserved factors is not taken into account in the model, its explanatory ability presented by R-square (R-square = 43.19%) is also quite low, as in the models of the same type in the other two sectors. The model fits well the empirical data at a 5% significance level. Only one of the parameters, this one associated with energy productivity (SDG_07_30), is not statistically significant, that is only this factor has no impact on the SRE in the cooling and heating sector.

To take into account the effect of unobserved factors on the SRE in the cooling and heating sector, the next two models are estimated – with random and fixed effects.

The estimated *Random Effect Model* is:

SRE_CH = 26,47 * [5,2] + 0,8 * [0,25].SDG_07_30 + 0,02[0,03].SDG_07_50 + 4,49 * [1,54].SDG_09_10_B – 15,78 * [4,5].SDG_09_70 – 0,01[0,02]. SDG_13_10 – 14,37 * [5,82].SDG_09_10_G – 0,0001 * [0,00005].TEN00124

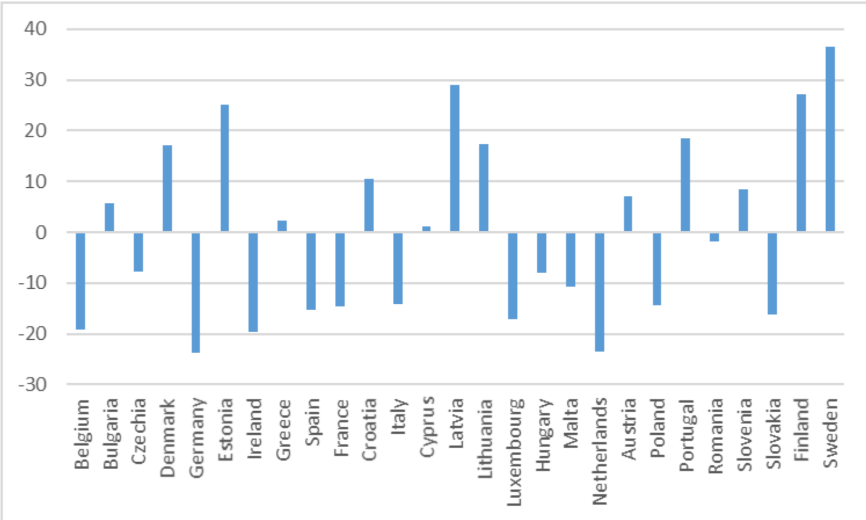
Two of the model parameters associated with the dependence on energy imports (SDG_07_50) and net greenhouse gas emissions (SDG_13_10) are statistically insignificant at a 5% significance level. The model fits well empirical data but the explanatory power of the model is quite small (R-square is 21.49%). The Hausman test by rejecting the null hypothesis provides evidence that this model is not appropriate since there is correlation between random effects and regressors in the model.

Finally, the estimated *Fixed Effect Model* is:

SRE_CH = 31,38 * [5,12] – 0,3[0,29].SDG_07_30 – 0,004[0,03].SDG_07_50 – 1,24[1,64].SDG_09_10_B – 9,93 * [4,36].SDG_09_70 + 0,006[0,02]. SDG_13_10 – 6,18[5,7].SDG_09_10_G + 0,00006[0,00009].TEN00124

The fixed effect model has the greatest explanatory ability (R-square = 98.39) compared to the other two in this sector. It fits well the empirical data although only one of parameters, this one associated with air emission intensity from industry (SDG_09_70), and the intercept are statistically significant at a 5% significance level. The results of model estimation show that in the cooling and heating sector unobserved factors related to the country-specifics and to the time-period analyzed affect to a greater extent the SRE than the factors identified and included in the model as regressors. The impact of air emission intensity from industry on the SRE in the cooling and heating sector is negative and causes 9.93 percentage points decrease of SRE per 1 gram/euro increase of air emission intensity from industry.

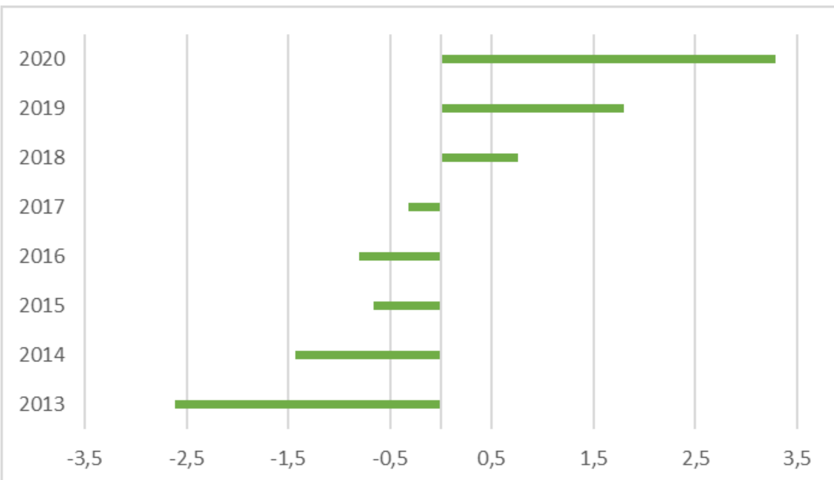
The effects of the unobserved factors related to the country-specifics and to the time-period considered in the cooling and heating sector are presented on figures 5 and 6 respectively. As can be seen the effects of unobserved factors related to the country-specifics are rather sound (figure 5). The most significant positive effect of unobserved factors on SRE in the sector is established for Sweden, Latvia, Finland and Estonia. The essential positive effect of specific country factors unobserved in this model is presented also for Denmark, Portugal and Lithuania. On the other hand, a notable negative effect is presented for Germany, the Netherlands, Ireland, Belgium, Luxembourg and Slovakia.



Source: Own elaborated

Figure 5: Effects of the unobserved factors on SRE in the cooling&heating sector related to the specifics of the EU countries

The time-effects of the unobserved factors change from significantly negative at the beginning of the period reviewed to significantly positive at its end (figure 6).



Source: Own elaborated

Figure 6: Effects of the unobserved factors on SRE in the cooling & heating sector related to the time-period reviewed

Conclusions

The results of the conducted analysis for the progress of SRE in the main sectors of the energy balance, electricity, transport and cooling & heating sectors in EU-27 countries and developed econometric models, estimated using panel data, for the factors influencing the SRE progress in each of the energy sectors mentioned can be summarized in the following conclusions.

- Multinomial classification of EU-27 countries in terms of the SRE in gross energy consumption using a 7-year in period from 2004 to 2022 as key variables in the clusterization procedure. Three clusters of countries are identified. The greatest cluster consists of 16 countries, which are with the lowest level of SRE in gross energy consumption.
- The greatest progress of SRE in gross energy consumption for the analyzed period is established for the 3rd cluster which consists of 3 EU members: Latvia, Finland, Sweden. The countries with average expressed dynamics of SRE in gross energy consumption in the studied period are included in the remaining cluster.
- The factors with significant positive effects on the SRE in gross energy consumption in the electricity sector, analyzed in the econometric models, when the effect of unobserved factors is identified and ignored, are: energy productivity, energy import dependency, expenditures for R&D by business and by government. Final energy consumption causes a negative effect on the SRE in this energy sector. The countries where specific factors have the most significant effects on SRE in the electricity sector are Luxemburg, Austria and Sweden.
- There is a small number of factors included in the models developed for the SRE in gross energy consumption in the transport sector. None of the factors in the fixed-effect model where the effect of unobserved factors is identified have a significant effect on the SRE in gross energy consumption. The effects of unobserved factors in the model that are related to the country-specifics are also quite negligible. Only 2 countries are identified with significant specific effects on SRE in this sector – Germany (with a lower effect than average) and Sweden (with a higher effect than average).
- In the model without unobserved factors effects identified and in the random-effect model for SRE in gross energy consumption in the cooling&heating sector the effects of most of the factors are proven to be statistically significant. The models, however, are with quite weak explanatory ability. The fixed-effect model for this sector is with a rather higher explanatory power but only one factor in it is proven to have a significant effect on the SRE – it is air emission intensity from industry. The effects of all other factors under consideration are statistically insignificant. The cross-section

effect of unobserved factors on SRE in this sector is significantly higher than the average one for most of the countries. The larger positive effect is established for Estonia, Latvia, Finland and Sweden and notably the larger negative – for Germany, Ireland, Luxemburg and the Netherlands.

- The time-period effects of unobserved factors on the SRE in all the studied energy sectors show a similar trend – from significantly negative at the beginning of the period reviewed to significantly positive at its end.

Clustering of EU-27 countries in terms of the SRE progress in gross energy consumption in 2004 – 2022 provide an opportunity for a glance on the renewable energy use in recent years and outlook for ecological transition in Europe. This also gives an opportunity to see where Bulgaria is in this process and to realize the necessity of appropriate policy and measures for intensifying renewable energy use in the economy as well as in the households.

The econometric models developed contribute to identifying and estimating the effects of important factors for encouraging renewable energy use in the main energy sectors. The results can also serve for effective further policy and measures for strengthening the greening at the European level as a whole and at the local one as well.

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