

## Article

# The Consumption of Renewable Energy Sources (RES) by the European Union Households between 2004 and 2019

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**Abstract:** The paper provides the analysis of fuel and energy transition in households sector and its sustainable development in the period 2004–2019. The main purpose of the paper is to determine the development trends in the use of renewable energy sources (RES) in the EU countries household sector in 2004–2019, to recognize the state of development and functioning of the studied area as well as to indicate their successes and shortcomings in observed reality. The article employs the results of Energy balance sheets from Eurostat. The research entity were households from 28 European Union countries, with particular emphasis on households from Poland and selected neighboring countries. The research subjects there were different sources of renewable energy used by households, i.e., solar thermal system, geothermal technologies, primary solid biofuels, charcoal, biogases, blended biogasoline, blended biodiesels, ambient heat (heat pumps). To achieve the research objective a number of statistical measures and methods, including cluster analysis and linear trend indicator applied. In the analyzed 16 years, an absolute and relative increase in the use of RES in the household sector was noticed. Taking into account the specificity of using RES in households, 6 clusters of countries were distinguished. In Poland, it was noted that there was a significant increase in the use of RES in households, with stagnation in the use of non-renewable energy sources, such as, for example, hard coal.

**Keywords:** renewable energy sources; household; primary solid biofuels; solar thermal system; ambient pumps



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## 1. Introduction

For several decades, strong processes of globalization of economies, intensive interconnections between countries have influenced the interaction between consumption patterns [1,2]. It seems clear that as fossil fuel resources are depleted, greater use of renewable energy sources (RES) will become necessary. [3,4]. In the last decades of the 20th century, the cost of household investment in renewable energy sources was extremely high and, thus, out of reach for many consumers. The progress in research and development activities resulting in creation numerous innovative solutions [5,6], as well as financial support from EU funds led to the situation that RES began to play more and more increasing role as energy carriers in households.

Renewable energy sources are the basis for sustainable economic development. Between 2004 and 2019, in the EU-28 countries, the usage of renewable energy sources by all sectors of the economy in final energy consumption increased from 5.1% in 2004 to 10.2% in 2019, while in the household sector from 10.8% to 18.2% [7].

Sustainable development is a basic and main objective of the European Union. The EU sustainable development strategy aims for the continuous improvement of quality of life for society [8]. Sustainable production and consumption patterns are important elements in tackling climate change. Reduction in energy consumption and changes in the fuel mix, by switching to less carbon-intensive energy sources, is linked to lower CO<sub>2</sub> emissions. Transition to a low carbon economy would be an important stage towards meeting this demand for climate stability.

The use of energy from renewables brings numerous advantages: decrease in the cost of energy supply, reducing both environmental pollution and the pressure on fossil fuel energy production, and also more convenient form of energy production and supply [9,10]. It can also contribute to energy poverty alleviation [11,12]. Replacing fossil fuels with renewable energy sources also reduces particular countries need for energy imports and their dependence on countries exporting non-renewable fuels [13].

The paper covers the issue of renewable energy sources (RES) consumed by European Union households. It considers the use of RES as a whole and also its different type categories in the household sector from 2004 to 2019, and (in some parts of the analysis) the time range also includes 1990.

The main purpose of the paper is to determine the development trends in the use of RES in the EU countries household sector in 2004–2019, to recognize the state of development and functioning of the studied area as well as to indicate their successes and shortcomings in observed reality.

In view of the research goals the following research questions were formulated:

**Research Question 1.** What changes have occurred in the use of renewable energy between 2004 and 2019?

**Research Question 2.** What groups of countries can be distinguished according to the category of renewable energy sources used in the household sector?

**Research Question 3.** How is the use of renewable and non-renewable energy sources changing in the household sector from selected EU-28 countries?

The undertaken research topic is important for several reasons. Households are one of the important sectors consuming energy. In 2019, households accounted for 26.9% of final energy consumption [7] in the EU-28 countries. Thus, from a practical point of view, involving them in the process of improving environmental quality can contribute towards climate improvement by reducing emissions of harmful substances into the atmosphere. Observing the changes in the household sector in terms of RES consumption gives an overview of the situation of individual EU members and can be a wake-up call for those who have accomplished little in the period under study to involve citizens in initiatives to install new technological solutions based on cleaner energy. From a theoretical point of view, the diagnosis of the situation of RES use in households is cognitively interesting, since analyses of RES use, as a rule, appear only for their overall use in the economy or in relation to transport. Moreover, the use of energy commodities in households can also be associated with responsible consumption. The problem addressed is also important from the point of view of the 17 Goals of Sustainable Development [14,15] formulated by the United Nations.

The originality of the presented article in comparison to the existing literature data lies in the emphasis on the important role of households in energy consumption and related problems. The novelty is also the presentation of the author's types of households observed in the EU-28 countries, according to the patterns of RES categories.

## 2. Literature Review

### 2.1. EU Policy for RES

The European Union, by developing numerous binding policies, is the biggest promoter of renewable energy investments. Within the European Union policies, RES and its support are strongly anchored in the form of strategies, development goals, priorities and current legislation [16]. The principal initiative to promote renewable energy at the European Union level was launched in 1997, when the European Council and the European Parliament adopted the "White Paper for a Community Strategy and Action Plan", aiming to increase the share of renewable energy, which at that time accounted only 6% of gross energy consumption [17].

EU policy standards for the use of RES have been acquired especially in the last two decades. Firstly, the EU Sustainable Development Strategy [18] stipulated that 12% of energy consumption and 21% of electricity consumption should be covered by RES by

2010, with an increase to 15% by 2015. The Europe 2020 Strategy [19], on the other hand, has indicated policy standards towards increase of the RES usage and to promote energy efficiency and greater energy security.

Directive 2009/28/EC of the European Parliament and of the Council (2009) [20] set a mandatory target by 2020 at the level of a 20% RES energy share. The Directive also sets out various mechanisms that Member States can implement to achieve their goals (joint projects, support schemes, cooperation between Member States and other countries). Moreover, it also defined national renewable energy targets for each country, taking into account its starting point and overall renewable energy potential. These goals range from a low of 10% in Malta to a high of 49% in Sweden. The EU countries define how they plan to meet these objectives and all their renewable energy policies in their National Plans. The results in achieving the national goals are measured every two years when EU countries publish national renewable energy progress reports [21].

The Article 3 of Directive 2018/2001 (2018) [22] on the promotion of the use of energy from renewable sources established a new and binding overall EU target for the total share of energy from renewable sources in the Union's gross final energy consumption for 2030 of at least 32%.

The Green Deal for Europe, proposed at the end of 2019, creates new conditions for a very ambitious climate protection agenda. The vision is for Europe to become the world's first climate-neutral continent by 2050. The package of measures in the European Green Deal should enable European citizens and businesses to reap the benefits of a sustainable green transition. The measures, together with an initial 'roadmap' of key policies, cover tasks such as reducing emissions, investing in cutting-edge research and innovation, together with protecting Europe's environment [23]. The implementation of the Green Deal for Europe idea will let EU countries achieve energy independence, which may have a significant impact on the energy market as well as on their regional policies. It is also assumed that the achieved climate neutrality will contribute to the dynamic development of the economy and improve its competitiveness [24].

The support accompanying implementation the abovementioned policies in EU countries resulted in increased the renewable energy use throughout the Community. In the EU-28 final energy consumption, renewable energy sources accounted for 3.8% in 1990, 5.1%, while in 2019 this percentage increased by a further 5.1 p.p. to 10.2%. A relatively high share of RES consumption is characterized by the household sector, where the share of RES in household final energy consumption in 1990 was 8.5%, in 2004—10.8%, and 16 years later by 7.4 p.p. more. [7].

The construction sector in Europe accounts for 40% of energy consumption and 36% of CO<sub>2</sub> emissions [25]. Due to the estimated, high energy saving potential of the housing construction sector, the European Union has established a policy framework focused on reducing energy consumption in buildings, consisting of different policy actions, i.e., Energy Performance of Buildings Directive (EPBD) [26], Energy Efficiency Directive (EED) [27], Ecodesign Directive [28], Energy Labelling Regulation [29] and the mentioned Renewable Energy Directive (RED) [20].

In summary, the EU countries' policies, since the 1990s, have systematically increased the importance and role of RES in the energy sector structure s [30]. All plans for the presumed targets are presented in the National renewable energy action plans 2020 [31]. National RES energy targets for individual countries are established at various levels and the process of reaching them is different depending on the country [24], which also affects the use of RES in the household sector.

## 2.2. The Role of Authorities in Promoting New Energy Solutions

The EU countries are trying to influence and propose different solutions to improve the situation regarding energy consumption. One of the more effective ways is to exploit renewable energy obtained from natural resources such as wind, sunlight, geothermal heat, etc. instead of non-renewable energy [32].

The consumption of renewable energy is growing in importance and there is an increasing need to encourage households to cooperate. For the development of renewable energy, it is important to ensure an active role of government and other authorities at all levels of general interest. It is even suggested [33] that public institutions, both state and municipal, should be legally obliged to install solar systems on the roofs of the buildings where they hold office. Also, electricity buyers can have an important influence on the way energy is generated in public procurement, where RES energy should be given priority.

However, not all countries have a good appreciation of government policies to promote RES. For example, in Croatia it is found that citizens are not actively encouraged to participate in investments that would largely benefit the environment [33]. A study in Malta [34] concluded that future programs promoted by the government should consider the role of pro-(and anti-)government sentiment in predicting their adoption in the initial stages. Strong pro-government sentiment can strengthen citizen initiatives to install new RES technologies. Delegating RES promotion to municipalities or even commercial entities may also result in increased citizen interest in such installations. The financial constraints faced by low-income households are also pointed out [34]. RES technologies are often expensive and the way in which support schemes are implemented require upfront investment, leaving households unable to afford to pay (in cash) for any investments. It is suggested that subsidies and programs offered by the government, should offer staggered payments for the initial investment in order to provide an incentive. Furthermore, the experience in Malta [34] emerged that requiring consumers to pay for net rather than gross value would enable more households to benefit from the program. Support schemes should also pay attention to vulnerable groups of society. Helping elderly households (for example, through preferential feed-in tariffs or targeted communication) could unlock further potential by encouraging older people to engage in investment. Similarly, significant scope appears to encourage investment in rental housing. Some programs can be designed to promote investment agreements between landowners and tenants [34].

Local authorities should assume a central role and responsibility in the task of solarizing their territories. They have the autonomy to regulate the situation on-the-spot, in particular through their well-known water and wastewater utilities, which can also provide other RES for local energy production (biogas from bio-waste and sewage sludge, energy stored in water). Such companies would therefore integrate power generation into their regular activities and could provide installation and maintenance services for power generation systems installed in their area of competence [33].

### *2.3. Willingness to Involving in the RES Use by the Household Sector*

Energy resources have always played a key role in human life. Sufficient energy resources influence economic and social development. A kind of interdependence is observed between technological development, energy consumption and world population growth [35]. Providing adequate energy resources for entities such as households is also about meeting basic social needs. Energy is one of the main categories of consumer expenditure in households [36]. Maintaining adequate thermal comfort affects the consumer life quality [37,38]. On the other hand, improving this kind of comfort is associated with an increase in the consumption of fossil energy carriers, which in turn is associated with an increase in environmental pollution [39,40]. Thus, in order to reconcile social and environmental objectives, it is important to widely involve households in initiatives for the use of energy from renewable energy sources.

An important issue is the problem of consumers' attitude and propensity to make decisions on the use of renewable energy technologies. As indicated by Ropuszyńska-Surma and Węglarz [41], social acceptance of RES technologies is important for their development and should be taken into account when shaping policies for sustainable development in the region.

The results of research by A. Jacksohn, P. Grösche, K. Rehdanz and C. Schröder [42] suggest that households tend to act fairly rationally in the sense that investors consider the

costs and benefits of their decision. Since economic factors influence the decision to invest in a renewable energy system, policy makers can provide reasonable financial incentives to steer households in the desired direction.

A number of studies show that financial incentives become a strong motivation for households to switch to renewables. A study of Italian and Austrian households investing in solar PV found that higher financial support was more likely to attract younger and less educated people, as well as those with an anthropocentric attitude towards nature [43].

In contrast, Wasi and Carson [44] investigated how households' decisions to switch to more environmentally friendly water heaters changed with the introduction of a rebate scheme for hot water systems. They concluded that the likelihood of households choosing to use the aforementioned renewable system for hot water, or a heat pump, increased significantly after the introduction of a scheme to financially support these initiatives. Furthermore, the impact of this rebate policy varied with household income, education, access to the gas grid, hot water consumption and expectations of future electricity prices.

In Germany, research on household investment in RES found that the propensity to adopt them was influenced by housing characteristics, household energy consumption and geographical factors, while most socio-demographic variables were found to be insignificant [45]. Other studies [46,47] have considered the motives for adopting an innovative residential heating system based on renewable energy. It was revealed [46] that the influence of socio-demographic, housing and spatial characteristics was more significant for households replacing a heating system in an existing house than for households choosing a heating system for a newly built house.

The likelihood of investing in RES also increases with environmental concern, income, number of children and solar radiation intensity [48]. Men and well-educated people were more willing to engage in RES installations than older people.

In Poland, social acceptance of RES varies, and depends on age, gender, education, income and type of building inhabited. The groups that showed the highest acceptance for RES installation were men, people aged 30–49 years, having secondary technical education, low income and people living in a single-family house. The rationale for installing RES was the expected long-term savings, while the biggest barrier was the lack of financial resources. The financial aspect is crucial for the installation of RES in Polish households. In the case of prosumers, besides the financial aspect, were also pointed out technical possibilities, unclear regulations, complicated grid connection process and lack of knowledge. Thus, besides financial support, additional support in the form of consumer education, promotion of RES development, technical and legal support of potential prosumers seems to be necessary [49].

D. Štreimikienė and A. Baležentis [50] studying households in Lithuania paid attention to employment status and income level that have a significant impact on the willingness to purchase renewable energy sources in households of this country. The self-employed showed the highest willingness to purchase RES. Private sector employees and, surprisingly, pensioners also showed more willingness to invest in RES compared to other social groups. In terms of education level, only respondents with higher education showed a higher willingness to buy RES than the rest. Thus, the willingness to pay for RES in Lithuanian households was determined by factors such as awareness of their existence, education level and income. Other studies showed that the willingness to pay for RES was influenced by age, gender, education, income, price, geographical place of residence. In contrast, membership in environmental organizations, race, political views and perceived health effects had less influence on household usage of renewable energy technologies [51].

A study conducted in Malta [32] revealed that factors associated with the use of RES energy (in this case, energy from photovoltaic devices) were the age of those forming households (the younger the individuals, the higher the involvement in RES) and unemployment (if present, there were fewer opportunities to invest in RES), both of which suggest that financial motives and constraints are crucial to household uptake of RES initiatives.

In contrast, a study by Luttenberger [33] for Croatia, showed that people support for RES projects increased together with knowledge about them. Positive attitudes towards



new clean technologies prevail in this country. However, there is a general lack of solid information and understanding of the concepts that are necessary for the possible benefits for end-users in a household. There is also a lack of professional and trained human resources for renewable energy issues, there are no relevant courses at universities and colleges, no systematic research, a lack of experience of local companies in organizing projects and the volume of theoretical knowledge about RES and practical capabilities involved is limited [52]. Even though household purchasing power is modest, their owners are at least declaratively putting aside more money for RES, but only after sufficient additional information has been provided. Croatians also mention obstacles such as national solar quotas, administrative barriers and complexity of the procedure [53].

Summarizing the abovementioned studies, it can be pointed out that the financial motive is an essential motive for household members to undertake RES installations. On the other hand, educational level and age are indicated among the important socio-economic characteristics of those willing to accept RES. Providing consumers with extensive information and educating them on new technologies for the overall social and environmental good is also an important determinant of consumers' commitment to RES application. So, the impacts of socioeconomic factors provide substantial policy implications for the design of green electricity programs [54].

#### *2.4. Application of Cluster Analysis in Comparative Research on RES Use in Different Countries*

Cluster analysis was first introduced in the work of R.C. Tryon [55]. It is a useful tool for exploratory data analysis that aims to arrange individual objects into groups so as to acquire objects within the same group most similar to each other and the objects between other groups most dissimilar to each other [56,57]. This analysis, using several different classification algorithms, detects the data structures without explaining why they occur.

European Union member states vary in terms the exploited both of total energy sources [58] and also of RES. The cluster analysis method may be useful for searching the similarities between individual member states. This method is often represented by the simple hierarchical method. The common feature of the stepwise algorithms used in this method is the clustering by combining smaller clusters, created in the previous steps of the algorithm. The basis of all algorithms of this method is the appropriate determination of the measure for object dissimilarity [59].

Below are presented a few selected studies reporting on the results produced by cluster analysis performed for country classifications regarding RES market. Therefore, for example, the study by Bluszczyńska, Manowska [58] is applying the agglomeration procedure, which results in the division of European Union member states into clusters according to their similarity, with regard their energy markets. The research results constitute an interesting study that could potentially provide a model for the creation of so-called regional energy markets in the transitional integration phase. The above-mentioned authors chose the following diagnostic variables for the analysis: consumption of electric energy which is generated from renewables per capita (TWH per person), consumption of hard coal (million ton per person), emissions of greenhouse gas per capita, available for final consumption (Gigawatt-hour per person), final energy consumption (thousand ton of oil equivalent (TOE) per person), petroleum available for final consumption (Gigawatt-hour), natural gas (Terajoule gross calorific value—GCV) per person, energy intensity of GDP (kilograms of oil equivalent (KGOE) per thousand euro), import dependency (%). The paper distinguishes six clusters, consisting of countries with similar levels of energy system development. The cluster formed by Finland and Sweden presented renewable energy production at the highest level in the EU. Finland had slightly higher greenhouse gas emissions per capita in the energy mix and a higher energy consumption factor than Sweden, as solid fuel use accounted for 9%. Luxembourg formed a one-element cluster. This country had the highest level of electricity consumption per capita compared to other UE member states. Greenhouse gas (GHG) emissions per capita and energy dependency levels were also the highest there. Another cluster, comprising France, Slovenia, United

Kingdom, Latvia and Romania had levels of electricity consumption per capita below the EU average. Energy dependency levels were relatively low in this cluster, ranging from 50% in Slovenia to 24% in Romania. The countries grouped in the cluster comprising Greece, Lithuania, Croatia, Hungary, Spain, Portugal and Italy were characterized by high levels of energy dependency, ranging from 52% for Croatia and 58% for Hungary to over 70% for all other countries in this cluster. In these countries, the contribution of solid fuels to electricity production was significantly higher than in the first and second clusters. The cluster including countries such as the Czech Republic, Slovakia, Poland, Bulgaria and Estonia was characterized by a level of greenhouse gas emissions per capita close to the average and thus exceeded the desired GHG emission factors. For this cluster, renewable energy consumption per capita was one of the lowest in the EU. The level of energy dependency was low, less than 1% in Estonia, 36% in Bulgaria and Czech Republic and 44% in Poland (with the exception of Slovenia, at 63%, the highest in this cluster). The last cluster containing the following countries: Netherlands, Germany, Belgium, Ireland, Denmark and Austria had the lowest level of energy intensity, while the consumption of energy from renewable sources was high [58].

Other researchers [60] analyzed in their paper the renewable energy sector in European Union countries. The k-means clustering method was used for grouping of countries. This method is widely used in various areas of science for the data analysis. The advantage of this method is the intuitiveness and simplicity of the basic calculation idea. In the k-means method, the distances between objects are determined by the Euclidean distance or its square (the peculiarity of the algorithm makes the results in both cases the same). The k-means algorithm can be described in three points: 1. The starting point is the division of a given set of objects into k subsets (usually generated by assigning each element to the “closest” preselected representative of the k groups). 2. For each group, the centers of gravity in the space of diagnostic variables are determined. 3. Each element is assigned to the nearest center of gravity, and then it is necessary to return to step 2, if at least one element has been moved to another group [61]. The algorithm of the k-means method can be regarded as a kind of “inverse” of the analysis of variance. It is helpful in finding a division of the studied community into k groups, so as to maximize the intergroup variance and, consequently, the F-statistic [61,62].

In the abovementioned paper, Parobek and colleagues [60] created nine clusters and the following diagnostic variables were selected forest cover, roundwood production, primary energy consumption, primary production of energy from renewable resources, share of renewable in gross final energy consumption, greenhouse gas emissions, employment, gross value added, GDP growth rate, expenditures on R&D, price of electricity, energy dependence. The 1st cluster was formed by the leaders in the use of renewable energy sources and the average production of primary energy from biomass, i.e., Austria, Portugal, Sweden, Finland. However, these countries were below the EU average in terms of employment rate and energy dependence. The 2nd cluster, consisting of Hungary and Belgium, had the use of renewable energy sources below the average. The 3rd cluster that contained Greece and Romania had a utilisation of renewable energy sources slightly above the EU average. These countries had significant production of wind, solar and hydropower energy. The 4th cluster, consisting of Bulgaria, Lithuania, Czech Rep., Denmark, Ireland and Slovakia had a medium level of renewable energy use. The 5th cluster was formed by Cyprus, Estonia, Latvia, Slovenia, Luxembourg and Malta. In these countries the share of renewable energy sources remained above average, but on the other hand they their production of primary energy from renewable resources was insignificant. Germany formed a one-element cluster (the 6th cluster) with the highest production of primary energy from biomass and RES consumption below average. It was also noted that this country is one of the largest producers and users of wood. Another one-piece cluster formed France (the 8th cluster), which (just as Germany) was a leader in the production of energy from wood and had a relatively low level of greenhouse gas emissions compared to the countries in the other clusters. The 7th cluster included Netherlands, Poland and United Kingdom, i.e.,

the countries having lower primary energy production from renewable resources and the lowest share of use of renewable resources. Italy and Spain formed the last, the 9th cluster. Use of renewable energy resources in these countries was below the average, but primary energy production from renewable resources—above the average [60].

In turn, K. Chudy-Laskowska and co-authors [63] in their article distinguished clusters on the basis of similarity such EU countries regarding the current level of the wind energy development. The research applied Ward's analysis and Wroclaw taxonomic methods. The Wroclaw method was described and employed in the mentioned article and in other studies [64,65]. Seven clusters containing from 1 to 7 countries were obtained. Denmark, forming one-element cluster, turned out to be the wind energy leader in the EU. This country had not only very profitable use of wind energy but also the highest rates of wind turbine electricity generation, and also the share of wind energy in gross inland energy consumption. The following diagnostic variables were adopted: wind farms per 100 thous. people, number of turbines per one wind farm, renewable (wind offshore) electricity capacity (MW) per thous. people, renewable (wind onshore) electricity capacity (MW) per thous. people, wind cumulative capacity growth rate, renewable (wind) electricity generation (GWh) per thous. people, share of renewables in gross inland energy consumption of which: wind power. The cluster comprising Spain, Portugal, Ireland, Sweden and Germany also had excellent wind energy technologies. These countries have been leaders in the introduction and development of wind energy for many years and have had a significant number of wind farms (above the European average) and these farms were quite large. Finland is another one-element cluster. This country invests and develops the mentioned branch of renewable energy. The index on the number of wind farms was above the world average, so there were more these farms than the EU average, but they were not large. Three countries: the United Kingdom, the Netherlands and Belgium, forming another cluster, were relatively strong in terms of both wind energy potential and the level of its development. There was also an upward trend in wind energy resources in this group. In the countries forming cluster that included Cyprus, Romania, Greece, Italy and Estonia there were not many wind farms, but the existing were relatively large. In addition, all wind energy indices were below the EU average. Another cluster includes six countries: Austria, Luxembourg, Lithuania, Croatia, Poland and France. In these countries there was a chance to change their position for the better by possible investing in wind energy. However, during the analyzed period, the level of wind energy development was still below the world average there. The last and worst group in terms of both wind energy potential and development level was a cluster including seven countries: Slovakia, Slovenia, Malta, Czech Republic, Hungary, Latvia and Bulgaria. This cluster also included Malta, which did not have a single wind farm, and the other countries in this group had almost no wind farms. These countries invested in other renewable energy sources. Slovakia, Latvia, Hungary and Bulgaria invested mainly in hydropower energy, while Hungary and Malta in solar energy [63].

Overall, the methods k-means and Ward were the most frequently applied clustering techniques. Other studies using cluster analysis in research on the use of renewable energy are [66–69].

### 3. Sources and Research Methods

#### 3.1. Data Sources

The study was focused on European Union households. The research material was from Eurostat "Energy balance sheets" [7].

The energy balance is the most complete statistical data of energy products and their flow in the economy. The energy balance offers a complete view on the energy situation of a country and of individual sectors (e.g., households). The energy balance is a multi-purpose tool, is the natural starting point to study the energy sector [70].

The research entities were the countries of the European Union. The subject of the research were various sources of renewable energy used by households, i.e.,



- Solar thermal system,
- Geothermal technologies,
- Primary solid biofuels,
- Charcoal,
- Biogases,
- Blended biogasoline,
- Blended biodiesels,
- Ambient heat (heat pumps).

The data for the different products are expressed in a common energy unit: thousands of tons of oil equivalent (ktoe) [70].

### 3.2. Study Design

To achieve the research objective and carry out the tasks presented in this article, the researcher had to apply a number of statistical measures and methods. Subsequent research tasks were subordinated to research questions.

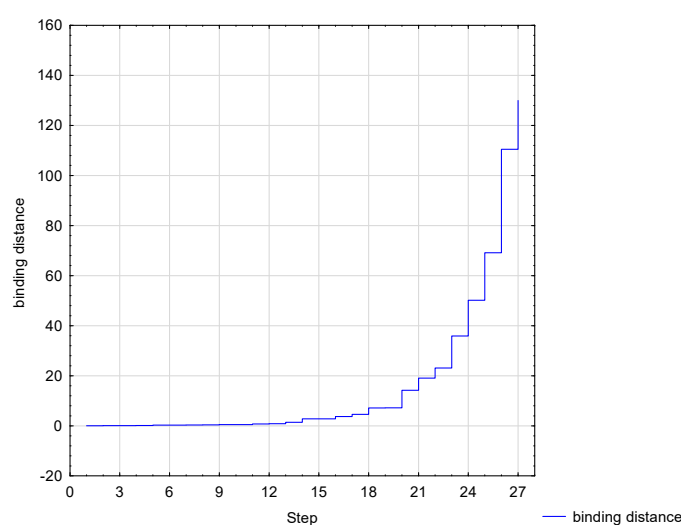
Step 1. Monitoring the evolution of RES consumption in European households required:

- aggregation of data from the Eurostat Energy balance sheets database for individual countries;
- calculating the structure of the RES energy carriers used in each country;
- generation of a ranking of countries in terms of the RES amount and its share in total household energy consumption.

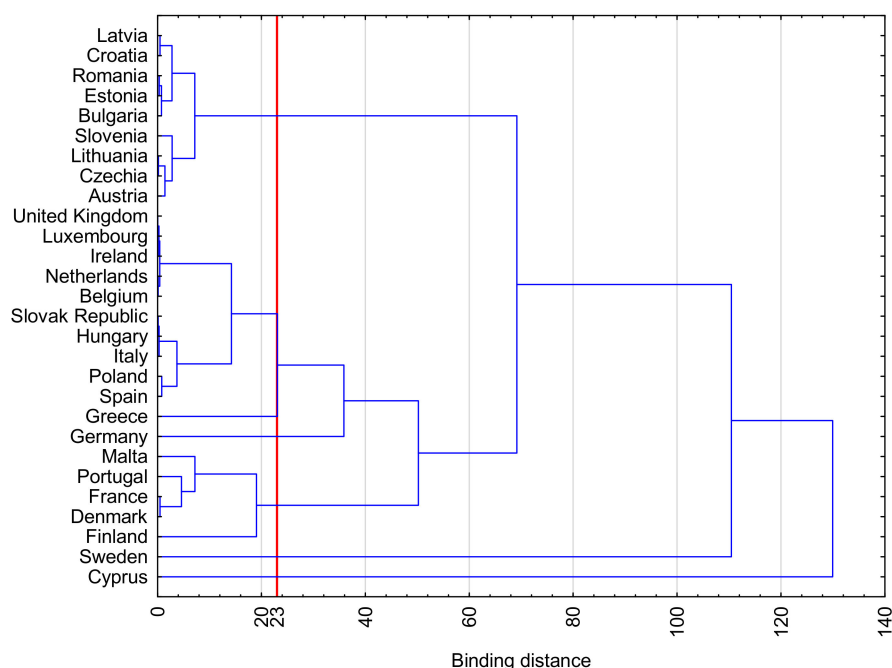
Step 2. Identification of European household types in terms of RES consumption. This task required:

- data standardization;
- Ward clustering method and establishing the optimal number of clusters;
- carrying out clustering with the k-means method;
- description and labelling of clusters.

The use of Ward's method cluster analysis provided an answer to the question about the optimal number of country (state) groups [71,72]. A plot of clustering distances by clustering step indicated that the first clear spike was at the level 23.45. The dendrogram was cut at this level, yielding six clusters of households (Figures 1 and 2). Ward's method for determining the optimal number of clusters is also used by other researchers [73].



**Figure 1.** Results binding distance according to binding steps. Source: own elaboration based on data from [7].



**Figure 2.** Results of the hierarchical grouping of similarities between the EU countries in final energy consumption from renewable energy sources in households' sector in 2019 using the Ward's method. Source: own elaboration based on data from [7].

Then, the k-means method was used to group countries. K-means cluster is widely described in the literature on the subject [74–77]. The algorithm for the k-means method is presented in Theorem 1.

**Theorem 1.** *The algorithm for the k-means method*

$$J = \sum_{i=1}^k \sum_{d \in D_i} sim(c_i, d_t) \quad (1)$$

The research algorithm of the k-means method consists of several stages, presented in the publication [78]. More about the k-means algorithm on the example of country grouping in the article [78,79].

Step 3. Examining trends of changes in RES use among households in Poland and neighboring countries. This task required the use of a directional trend indicator. A linear trend is a special case of linear regression, where the explanatory variable X is the time variable t [80]. A trend model belongs to a special class of econometric models in which the variability of the explained variable is described by a specific explanatory variable, namely time. In general, these models do not explain the mechanism of development of the considered explanatory variable but illustrate the development of this variable over time. In this case, therefore, a time series is considered, that is, data that are time-stratified.

**Theorem 2.** *A formula of linear trend function.*

$$Y = a \cdot t + b \quad (2)$$

where:  $a$ —trend slope:

$$a = \frac{\sum (t_i - \bar{t}) * (Y_i - \bar{Y})}{\sum (t_i - \bar{t})^2}$$

$b$ —trend intercept:

$$b = \bar{Y} - a * \bar{t}$$

$t_i, Y_i$  values of the variables  $t$  and  $Y$ .

$\bar{t}, \bar{Y}$ —means of variables  $t$  and  $Y$ .

When  $a > 0$  we are dealing with a growing trend. The greater the  $a$ , the faster the value of  $Y$  increases over time.

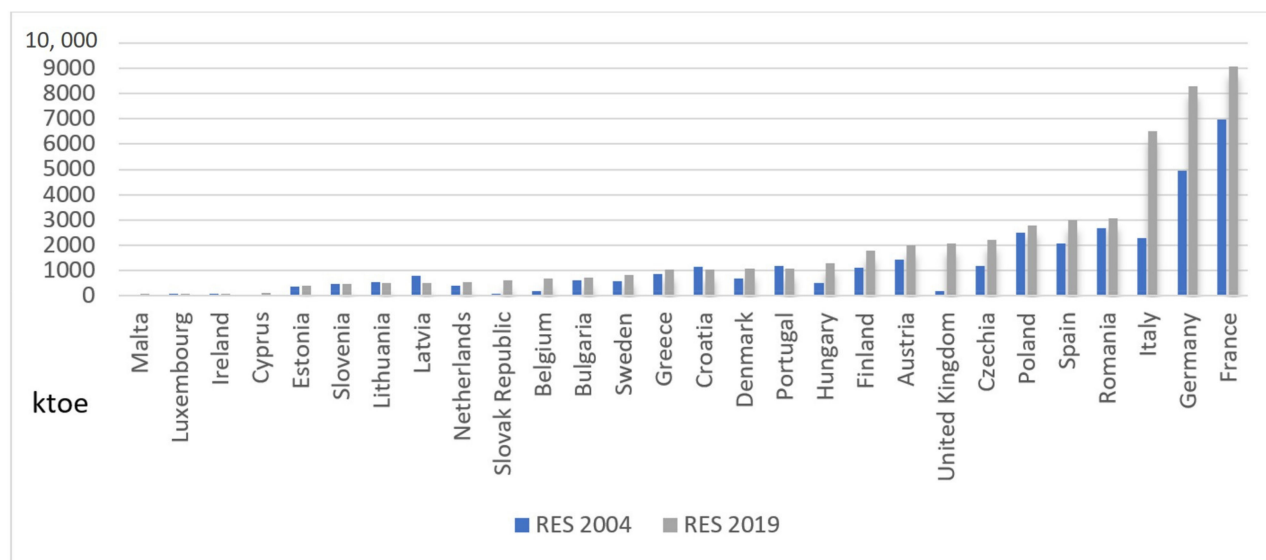
When  $a < 0$ , there is a downward trend. The smaller the  $a$ , the faster the  $Y$  value decreases over time.

#### 4. Results

##### 4.1. Changes in the Use of RES in European Households

The aim of this section is to analyze the changes in the use of renewable energy sources in EU-28 households between 2004 and 2019.

In absolute terms, the leaders in household sector RES consumption are the French, Germans and Italians. In 2019, RES energy in these households represented between 6508.6 thousands of tons of oil equivalent (ktoe) in Italy, 8293.3 ktoe in Germany and 9094.3 ktoe in France. The least RES energy consumed households in Malta (14.0 ktoe) and in Luxembourg (19.3 ktoe) (Figure 3). Between 2004 and 2019, the highest increase in energy in absolute units was observed precisely in the mentioned leader countries. In Italy the amount of energy used in the household sector increased by 4247.9 ktoe, in Germany by 3348.3 ktoe and in France by 2123.4 ktoe. Relatively large increases in RES consumption over the 16-year period were also observed in the UK (by 1897.8 ktoe) and the Czech Republic (by 1027.4 ktoe). Even though in the majority of EU countries an increase in household RES consumption was observed, there were also decreases, such as in Latvia (by 255.6 ktoe), Portugal (by 110.4 ktoe), Croatia (by 96.0 ktoe), Lithuania (by 57.1 ktoe) and Slovenia (by 2.1 ktoe).



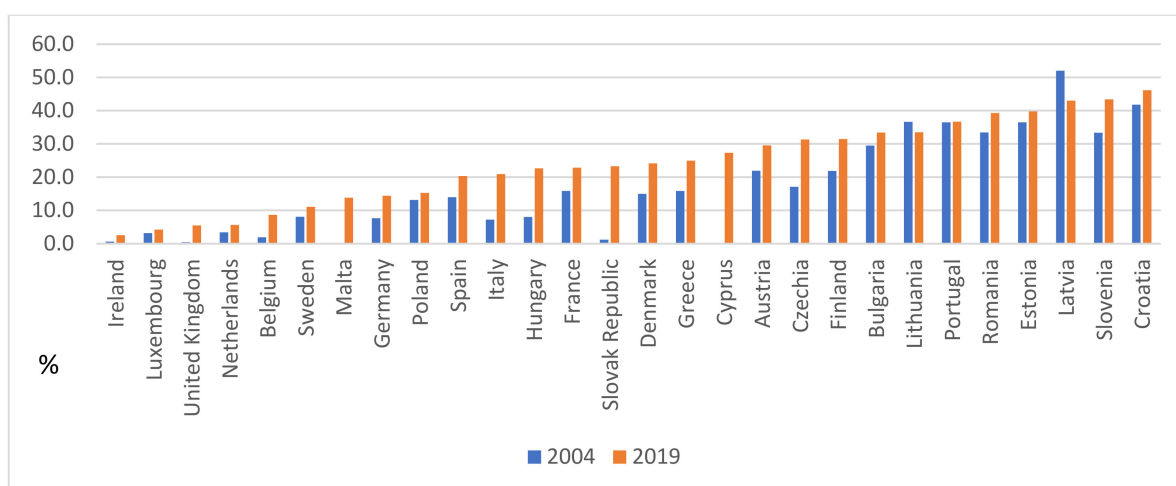
**Figure 3.** Energy from RES in EU households in 2004 and 2019, in thousands of tons of oil equivalent. Source: own elaboration based on data from [7].

In absolute terms, the consumption of RES by the household sector depends, among others, on the country size and the number of households in it. In the further section of this paper, the RES consumption in relative terms and the type structure of the energy used will be analyzed. Thus, in 2019—in relative terms—the first place in the ranking of renewables use by EU-28 households had Croatia, where RES accounted for more than

46% of household energy exploited. A high share of RES in the energy carriers used in households was also recorded in Slovenia and Latvia—more than 43% of final energy consumption each. In turn, Estonian, Romanian and Portuguese households had more than 36% share of RES in energy carriers used. At the other end of the scale were households of Ireland, Iceland, Luxembourg, the UK, the Netherlands and Belgium, where the share of RES in household final energy consumption did not exceed 9% (Figure 4).

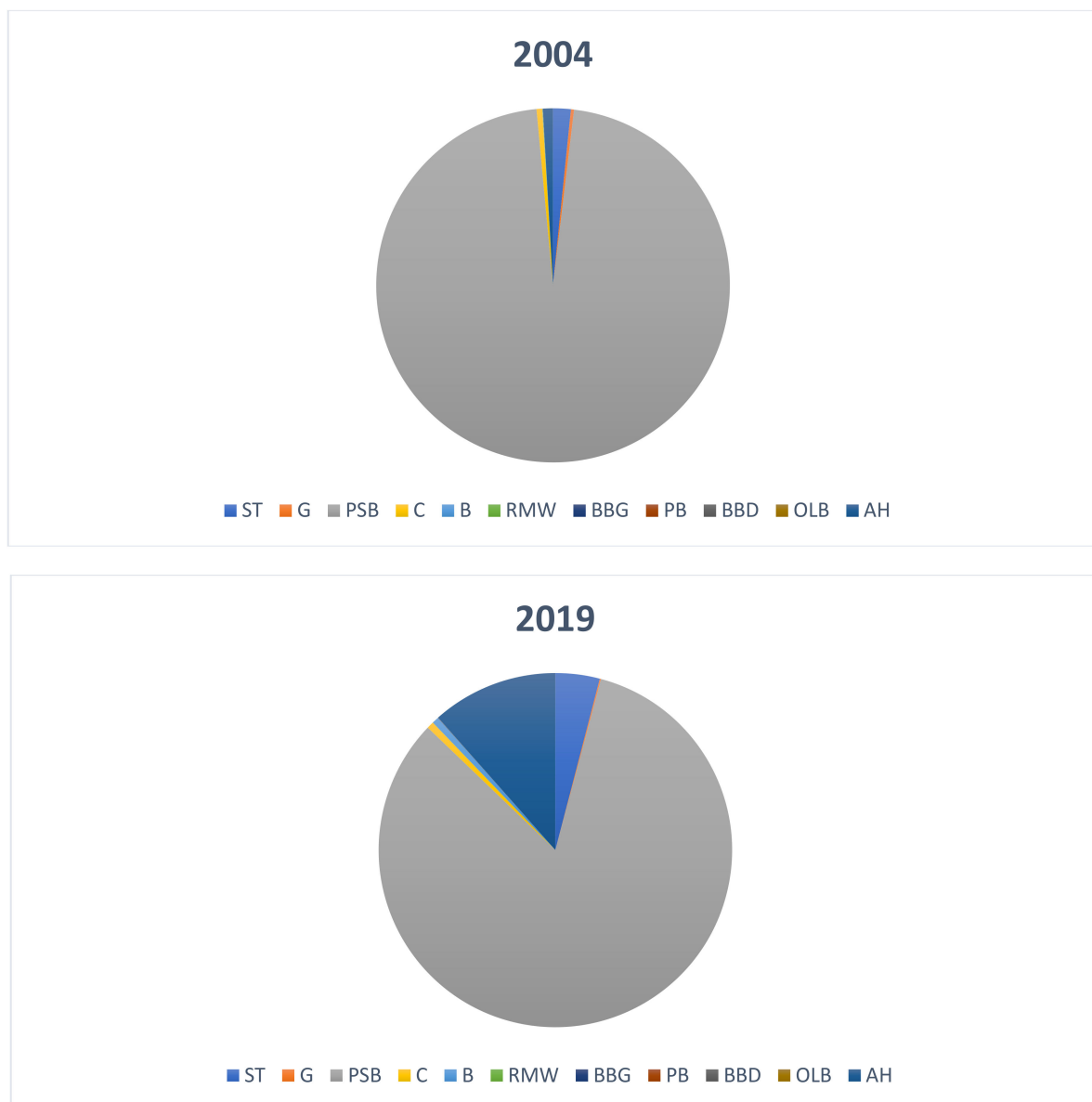
The greatest progress—in relative terms—in the use of RES in EU-28 households was observed in Cyprus. Over a period of 16 years, the increase in the percentage of RES used by these households was 27.3 p.p. However, it is worth mentioning that the first data for this country appeared in 2005, where 11.1 p.p. of RES in household final energy consumption was recorded and all of this energy came from solar thermal system. The next highest increase in RES use by households was in the Slovak Republic (increase by 22.1 p.p.). A relatively high progression was observed in the case of RES usage between 2004 and 2019 by households of Hungary, the Czech Republic, Malta, Italy, i.e., by about 14 p.p. Here it should also be noted that in the case of Malta—as well as the aforementioned Cyprus—no RES usage was recorded in households in 2004 at all. In 2010 Maltese households started using RES (6.2%), which came mainly from solar thermal technology (close to 83%), as well as from primary solid biofuels.

The largest decrease in RES consumption in the household sector was recorded Between 2004 and 2019 in Latvian and Lithuanian households, with a 9.0 p.p. and by 3.1 p.p., respectively, decrease in the share of energy used from RES by these households.



**Figure 4.** The share of energy from RES in the final energy consumption in European Union households in 2004 and 2019. Source: own elaboration based on data from [7].

The main renewable energy sources used in the EU-28 households are primary solid biofuels. In 2019, the share of primary solid biofuels in the total consumption of renewable energy sources in households was 83%, while in 2004—96.6%. This was followed by ambient heat at 11.6% (0.9% in 2004) and solar thermal technology at 4.0% (1.3%). Charcoal and biogases each accounted for 0.6% and geothermal heat for 0.1% (Figure 5).



**Figure 5.** Structure of RES used by the household sector in 2004 and 2019, percentage. Comment: ST—Solar thermal system, G—Geothermal system, PSB—Primary solid biofuels, C—Charcoal, B—Biogases, RMW—Renewable municipal waste, BBG—Blended biogasoline, PB—Pure biodiesels, BBD—Blended biodiesels, OLB—Other liquid biofuels, AH—Ambient heat. Source: own elaboration based on data from [7].

#### 4.2. Identification of Household Types in Terms of RES Consumption

The aim of this section is to identify the types of European households showing similarities in the structure of use of the different renewable energy sources. In the first step of the analysis, the EU countries were divided into similar groups, according to the total amount of energy used from RES in households and the structure of particular sources of this energy in 2019. The EU countries were divided into six clusters (k-means method), based on the assumed optimal number of groups (Ward's method). The adopted division was made on the basis of the first significant jump in the bonding distance related to the bonding stages (Figures 1 and 2, Table 1).



**Table 1.** Elements of clusters with distances from centers.

| Cluster 1 | Distances from<br>Centre of<br>Cluster 1 | Cluster 2       | Distances from<br>Centre of<br>Cluster 2 | Cluster 3 | Distances from<br>Centre of<br>Cluster 3 | Cluster 4      | Distances from<br>Centre of<br>Cluster 4 | Cluster 5 | Distances from<br>Centre of<br>Cluster 5 | Cluster 6 | Distances from<br>Centre of<br>Cluster 6 |
|-----------|------------------------------------------|-----------------|------------------------------------------|-----------|------------------------------------------|----------------|------------------------------------------|-----------|------------------------------------------|-----------|------------------------------------------|
| Sweden    | 0.00                                     | Slovak Republic | 0.373972                                 | Cyprus    | 0.00                                     | United Kingdom | 0.114460                                 | Latvia    | 0.242084                                 | Malta     | 0.635871                                 |
|           |                                          | Italy           | 0.321990                                 |           |                                          | Poland         | 0.455330                                 | Slovenia  | 0.375570                                 | Portugal  | 0.484746                                 |
|           |                                          | Hungary         | 0.413577                                 |           |                                          | Ireland        | 0.185776                                 | Romania   | 0.224730                                 | France    | 0.279430                                 |
|           |                                          | Spain           | 0.345554                                 |           |                                          | Netherlands    | 0.103627                                 | Lithuania | 0.217831                                 | Denmark   | 0.419897                                 |
|           |                                          | Greece          | 0.943778                                 |           |                                          | Luxembourg     | 0.139628                                 | Croatia   | 0.393219                                 | Finland   | 0.919940                                 |
|           |                                          | Germany         | 1.259942                                 |           |                                          | Belgium        | 0.103894                                 | Estonia   | 0.163824                                 |           |                                          |
|           |                                          | Austria         | 0.336421                                 |           |                                          |                |                                          | Czechia   | 0.336215                                 |           |                                          |
|           |                                          |                 |                                          |           |                                          |                |                                          | Bulgaria  | 0.231347                                 |           |                                          |

Source: own elaboration based on data from [7].

In accordance to the analyses performed, measures of intra- and inter-cluster variation and degrees of freedom (df) were determined. The obtained values of the F-statistic, which is the ratio of the variation between clusters to the variation within clusters, made possible to identify the most important clustering variables in terms of their discriminatory power. This means that the higher value of the F-statistic for a given variable, the more important the assignment of given countries to particular clusters.

The analysis of variance showed that blended biodiesel use played the greatest role in the assignment of EU countries to particular clusters. The value of the F statistic for this variable was the highest at 2995.72, followed by geothermal energy (47.05). Biogases, for which the value of the F statistic was 3.07, were the least significant factor in the assignment of EU countries according to the criterion adopted. However, it is worth remembering that each diagnostic variable, i.e., each renewable energy source, ultimately influenced the grouping of EU countries into homogeneous clusters both in terms of structure and volume of energy exploited from these sources.

As blended biodiesels and geothermal heat were important factors in assigning EU countries to particular clusters, countries using these sources formed single-element clusters. The compositions of the formed clusters and the distance from their centers (cluster centers) are presented in Table 2. The greater the distance of a given EU country from the center of the cluster in which this country was located, the greater its variability in relation to the countries whose distance from the cluster center was smaller.

**Table 2.** Analysis of variance for renewable energy consumption in households' sector.

| Specification             | Between SS | Specification | Between SS | Specification | Between SS | Specification |
|---------------------------|------------|---------------|------------|---------------|------------|---------------|
| Renewables and biofuels   | 22.47      | 5             | 4.53       | 22            | 21.85      | 0.0000        |
| Solar thermal             | 22.79      | 5             | 4.21       | 22            | 23.84      | 0.0000        |
| Geothermal                | 24.69      | 5             | 2.31       | 22            | 47.05      | 0.0000        |
| Primary solid biofuels    | 22.47      | 5             | 4.53       | 22            | 21.84      | 0.0000        |
| Charcoal                  | 18.99      | 5             | 8.00       | 22            | 10.44      | 0.0000        |
| Biogases                  | 11.10      | 5             | 15.90      | 22            | 3.07       | 0.0298        |
| Blended biogasoline       | 19.15      | 5             | 7.85       | 22            | 10.73      | 0.0000        |
| Blended biodiesels        | 26.96      | 5             | 0.04       | 22            | 2995.72    | 0.0000        |
| Ambient heat (heat pumps) | 22.10      | 5             | 4.90       | 22            | 19.86      | 0.0000        |

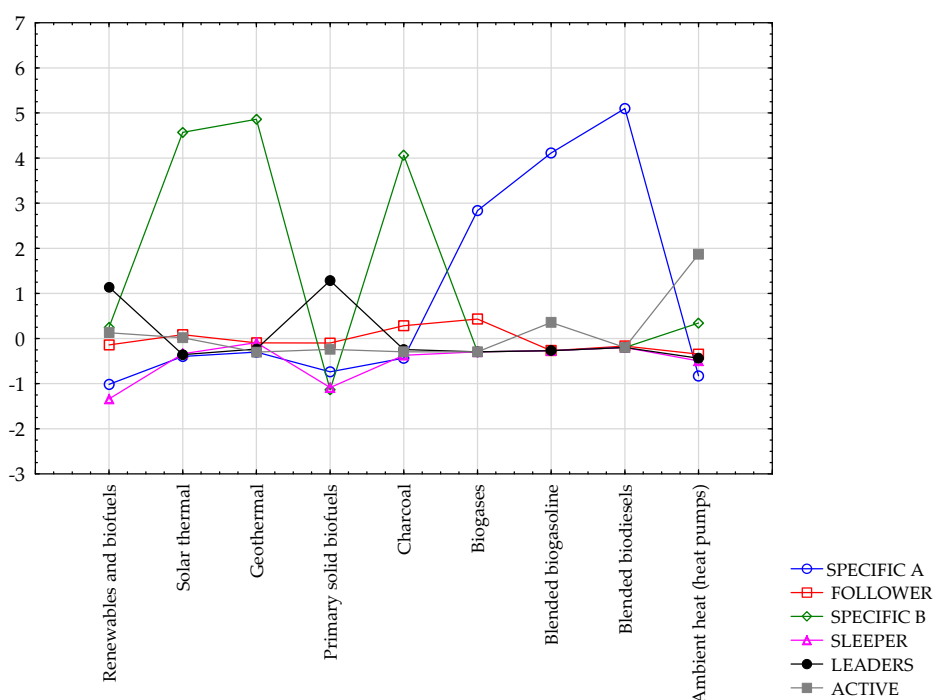
Source: own elaboration based on data from [7].

The results indicate the homogeneity of two clusters (the 1st and the 3rd clusters). Sweden (the 1st cluster—Specific A), as the only country using blended biogasoline and blended biodiesels, is located in the 1st cluster. No other country has reported the use of this renewable source in households. The Swedes were also ones of the few to use biogases (3.2%), while primary solid biofuels consumption accounted for nearly 94% (Figure 6, Table 3).

Cyprus (the 3rd cluster—Specific B), on the other hand, was one of the few countries with a relatively high geothermal energy consumption in households (1.6%). Cypriot households are also leaders in the use of solar thermal energy (62.5%) and also a relatively low use of primary solid biofuels compared to other countries (18.5% of total household RES consumption) is reported there. In addition, ambient heat (11.4%) and charcoal (6.0%) and geothermal heat (1.6%) appeared among the RES sources in households of this country. The overall use of RES by Cypriot households in final consumption energy was 27.3%.

The 2nd cluster (Follower) comprised seven countries with total RES use ranging from over 14% in Germany to 30% in Austria. These countries were characterized by relatively high use of primary solid biofuels, i.e., from nearly 62% in Greece to over 98% in Hungary. In almost all countries the RES categories observed in the renewable energy mix were solar thermal energy (from 1.0% in Hungary to 26.7% in Greece), charcoal (from 0.1% in Slovakia

to 4.4% in Greece, in Hungary this category was generally absent) and ambient heat (from 0.7% in Hungary to 13.9% in Germany).



**Figure 6.** Mean values of energy consumption from renewable energy sources for individual clusters (results of the non-hierarchical grouping of similarities between the EU countries in final energy consumption from renewable energy sources in households' sector in 2019 using the k-mean's method). Source: own elaboration based on data from [7].

The obtained results revealed that the six countries in the 4th cluster (Sleeper) acquired the lowest average value of energy obtained from RES, ranging from 2.5% in Ireland to over 15% in Poland. Primary solid biofuels in this cluster were the relevant source of RES for households ranging from nearly 35% in Ireland to over 93% in the UK. The second place was for heat pumps, i.e., its total household RES use was from 5% in the UK to 47% in Ireland. Luxembourg and Ireland had also relatively high use of solar thermal energy, i.e., 13% and 19% of household RES consumption, respectively.

The most numerous cluster was formed by 8 countries (the 5th cluster—Leaders). This cluster had the highest value of renewable energy used by households. It was found that in 2019 the use of renewable energy sources in final energy household consumption ranged from just over 31% in the Czech Republic to over 46% in Croatia. These households relied mainly on primary solid biofuels, ranging from over 89% in Slovenia to 100% in Estonia.

In the 6th cluster (Active), which includes five countries, there are countries with rather low total RES use, i.e., from 14% in Malta to 37% in Portugal. In these countries there was relatively less use of primary solid biofuels in the household sector (in total RES use ranging from 12% in Malta to 80% in Denmark) and more use of ambient heat (ranging from 19% in Denmark to 52% in Malta). In Malta, solar thermal was a relatively popular source of RES, with more than 36% of RES coming from this source. An overview of the average RES energy shares for each country, cluster by cluster, is presented in Table 3.

Between 2004 and 2019 a diversification of RES sources is observed. Even though primary solid biofuels still remain the dominant source of RES in households, other sources are emerging, notably ambient heat and solar thermal system. In 2004, a sector of households in nine EU-28 countries used ambient heat, while 16 years later this source appeared in 23 countries. In 2004, households in 16 countries used solar thermal energy, while in 2019—in 24 countries. Another RES source, charcoal appeared in households of six EU-28 countries in 2004, while in 2019—it extended to 12 countries.

**Table 3.** Groups of EU-28 countries due to the use of RES in the household sector in 2019, in percentages.

|                                               | Affiliation to Clusters | Renewables and Biofuels | Solar Thermal | Geothermal | Primary Solid Biofuels | Charcoal | Biogases | Blended Biogasoline | Blended Biodiesels | Ambient Heat (Heat Pumps) |
|-----------------------------------------------|-------------------------|-------------------------|---------------|------------|------------------------|----------|----------|---------------------|--------------------|---------------------------|
| 1                                             | 2                       | 3                       | 4             | 5          | 6                      | 7        | 8        | 9                   | 10                 | 11                        |
| % renewables and biofuels (100% = 3th column) |                         |                         |               |            |                        |          |          |                     |                    |                           |
| SPECIFIC A                                    |                         |                         |               |            |                        |          |          |                     |                    |                           |
| Sweden                                        | 1                       | 11.1                    | 1.3           | 0.0        | 93.7                   | 0.0      | 3.2      | 0.6                 | 1.0                | 0.0                       |
| FOLLOWER                                      |                         |                         |               |            |                        |          |          |                     |                    |                           |
| Slovak Republic                               | 3                       | 23.3                    | 1.1           | 0.0        | 94.2                   | 0.1      | 0.0      | 0.0                 | 0.0                | 4.6                       |
| Italy                                         | 3                       | 20.9                    | 2.6           | 0.0        | 95.2                   | 0.7      | 0.0      | 0.0                 | 0.0                | 1.5                       |
| Hungary                                       | 3                       | 22.6                    | 1.0           | 0.0        | 98.3                   | 0.0      | 0.0      | 0.0                 | 0.0                | 0.7                       |
| Spain                                         | 3                       | 20.3                    | 9.2           | 0.4        | 84.3                   | 0.9      | 0.0      | 0.0                 | 0.0                | 5.3                       |
| Greece                                        | 3                       | 24.9                    | 26.7          | 0.0        | 61.8                   | 4.4      | 0.0      | 0.0                 | 0.0                | 7.1                       |
| Germany                                       | 3                       | 14.4                    | 8.4           | 0.3        | 72.0                   | 2.0      | 3.4      | 0.0                 | 0.0                | 13.9                      |
| Austria                                       | 3                       | 29.5                    | 5.7           | 0.0        | 84.9                   | 0.3      | 0.3      | 0.0                 | 0.0                | 8.7                       |
| SPECIFIC B                                    |                         |                         |               |            |                        |          |          |                     |                    |                           |
| Cyprus                                        | 2                       | 27.3                    | 62.5          | 1.6        | 18.5                   | 6.0      | 0.0      | 0.0                 | 0.0                | 11.4                      |
| SLEEPER                                       |                         |                         |               |            |                        |          |          |                     |                    |                           |
| United Kingdom                                | 4                       | 5.5                     | 1.7           | 0.0        | 93.4                   | 0.0      | 0.0      | 0.0                 | 0.0                | 4.8                       |
| Poland                                        | 4                       | 15.2                    | 2.4           | 0.7        | 88.4                   | 0.0      | 0.0      | 0.0                 | 0.0                | 8.5                       |
| Ireland                                       | 4                       | 2.5                     | 18.6          | 0.0        | 34.6                   | 0.0      | 0.0      | 0.0                 | 0.0                | 46.8                      |
| Netherlands                                   | 4                       | 5.6                     | 4.4           | 0.0        | 73.6                   | 1.2      | 0.0      | 0.0                 | 0.0                | 20.8                      |
| Luxembourg                                    | 4                       | 4.2                     | 12.7          | 0.0        | 80.1                   | 0.0      | 0.0      | 0.0                 | 0.0                | 7.3                       |
| Belgium                                       | 4                       | 8.6                     | 3.8           | 0.0        | 82.8                   | 0.8      | 0.0      | 0.0                 | 0.0                | 12.5                      |
| LEADERS                                       |                         |                         |               |            |                        |          |          |                     |                    |                           |
| Latvia                                        | 5                       | 43.0                    | 0.0           | 0.0        | 99.5                   | 0.4      | 0.0      | 0.0                 | 0.0                | 0.0                       |
| Slovenia                                      | 5                       | 43.4                    | 2.3           | 0.0        | 89.1                   | 0.0      | 0.0      | 0.0                 | 0.0                | 8.6                       |

Table 3. Cont.

|           | Affiliation to Clusters | Renewables and Biofuels | Solar Thermal | Geothermal | Primary Solid Biofuels | Charcoal | Biogases | Blended Biogasoline | Blended Biodiesels | Ambient Heat (Heat Pumps) |
|-----------|-------------------------|-------------------------|---------------|------------|------------------------|----------|----------|---------------------|--------------------|---------------------------|
| Romania   | 5                       | 39.3                    | 0.0           | 0.1        | 99.9                   | 0.0      | 0.0      | 0.0                 | 0.0                | 0.0                       |
| Lithuania | 5                       | 33.5                    | 0.0           | 0.0        | 95.2                   | 0.0      | 0.0      | 0.0                 | 0.0                | 4.8                       |
| Croatia   | 5                       | 46.1                    | 1.0           | 0.0        | 96.7                   | 0.8      | 0.0      | 0.0                 | 0.0                | 1.4                       |
| Estonia   | 5                       | 39.8                    | 0.0           | 0.0        | 100.0                  | 0.0      | 0.0      | 0.0                 | 0.0                | 0.0                       |
| Czechia   | 5                       | 31.3                    | 0.7           | 0.0        | 92.0                   | 0.0      | 0.0      | 0.0                 | 0.0                | 7.4                       |
| Bulgaria  | 5                       | 33.4                    | 1.5           | 0.0        | 98.5                   | 0.0      | 0.0      | 0.0                 | 0.0                | 0.0                       |
| ACTIVE    |                         |                         |               |            |                        |          |          |                     |                    |                           |
| Malta     | 6                       | 13.8                    | 36.3          | 0.0        | 12.0                   | 0.0      | 0.0      | 0.0                 | 0.0                | 51.7                      |
| Portugal  | 6                       | 36.7                    | 5.4           | 0.0        | 71.1                   | 0.7      | 0.0      | 0.0                 | 0.0                | 22.8                      |
| France    | 6                       | 22.8                    | 1.9           | 0.0        | 70.9                   | 0.0      | 0.0      | 0.0                 | 0.0                | 27.2                      |
| Denmark   | 6                       | 24.1                    | 1.2           | 0.0        | 80.1                   | 0.0      | 0.0      | 0.0                 | 0.0                | 18.7                      |
| Finland   | 6                       | 31.4                    | 0.1           | 0.0        | 69.5                   | 0.0      | 0.0      | 0.2                 | 0.0                | 30.3                      |

Comment: the percentages for individual clusters are presented horizontally, i.e., the summed results in the rows should give 100%. Source: own calculation based on data from [7].

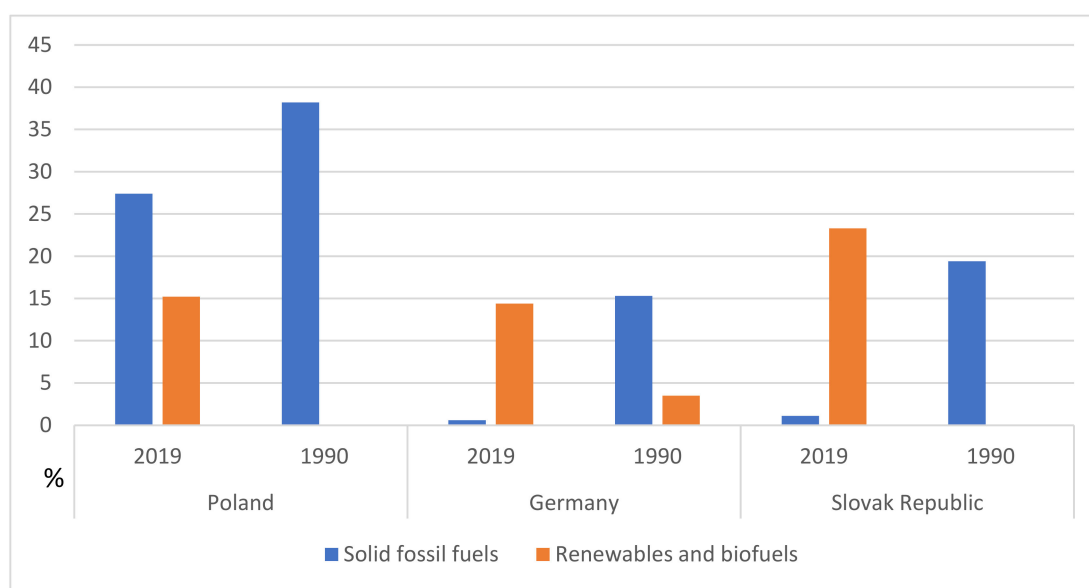
#### 4.3. Changes in the Use of RES in Households from Poland, Slovakia and Germany

The aim of this subsection is to analyze changes in the use of energy carriers in Polish households and selected neighboring countries, i.e., Slovakia and Germany. The case of Poland was chosen due to the fact of high use of hard coal in this country. Poland is the largest hard coal producer and the second largest brown coal producer in the EU, generating about 80% of electricity from coal. Resistance to limiting coal mining and consumption comes from various sides, namely coal corporations, trade unions, parts of civil society and the government—and their coalition partners. Their objection centers around the prospect of lost business, previous negative experiences of structural change, fears of rising energy prices and concerns about energy security, as well as potential unemployment in regions almost entirely dependent on coal [81].

Germany and Slovakia were chosen for comparison for the following reasons. Firstly, they are neighboring countries. The winter climate in these countries is quite cold, which makes it necessary to use heat energy in every sector, especially in households. Secondly, Germany is a country from the so-called ‘richer’ west of Europe, while Slovakia, similar to Poland, is a central and eastern European country with a similar history and socio-economic development. There are more than 20 countries in the world whose share of renewable energy sources in total energy consumption exceeds 20%, and Germany is among these countries. By 2050, Germany plans to achieve a 60% share of renewable energy in the country’s total energy balance and 80% in electricity production [82].

Raising the level of economic and human development has increased the demand for fossil fuels. Currently, conventional energy sources dominate in terms of resources used by economies, including some European households. Many countries in the world, facing the problem of energy and national security, have intensified their efforts to transition from conventional energy sources (primarily fossil fuels) to alternative energy sources [83]. However, these transitions differ from country to country.

Polish households are a kind of “coal island” on the map of Europe [84]. In 1990, the use of hard coal in total energy consumption in Polish households accounted for 38.2%, and for nearly three decades this percentage has been reduced by 10.8 p.p. In the same period the use of hard coal in German households decreased from 15.3% to 0.6% and in Slovak households from 19.4% to 1.1% (Figure 7). Thus, the progress in this respect—beneficial from the environmental point of view—was definitely better in the countries neighboring Poland.



**Figure 7.** Use of solid fuels and renewable energy sources in the Polish, German and Slovak household sector in 2019. Scheme 7.



Between 1990 and 2019, the use of RES in households in relative terms increased, most notably in Slovak households—by 23.3 p.p., while German (10.9 p.p.) and Polish (15.2 p.p.) households had smaller achievements in this respect. Even though looking at this aspect in absolute terms, between 1990 and 2019 the use of RES by the household sector in Poland increased by 1662.7 ktoe, in Germany by 5308.8 ktoe and in Slovakia by 615.5 ktoe. However, it is worth noting that in 1990 in Slovakia there was no RES consumption in the household sector at all.

In Poland, residential heating is mainly provided by hard coal. In the total consumption of energy carriers in Polish households, hard coal and other bituminous coal accounted for 54.5% in 2019. In the 16-year period, since 2004, coal consumption in the household sector has decreased slightly, i.e., by 2.6 p.p. [7]. The high share of coal in the total consumption of energy carriers is the cause of air pollution, among others in sulphur dioxide, nitrogen oxides and dusts. The household sector is responsible for total atmospheric emissions of sulphur dioxide in nearly 23%, nitrogen oxides in about 8% and dusts in nearly 36% [85].

Based on the directional coefficient of the trend, it can be concluded that the consumption of renewables in Polish households has statistically significantly increased between 2004 and 2019, on average by 31.1 thousands of tons of oil equivalent (ktoe). Similar to other European households, among renewable energy sources, primary solid biofuels are here in the lead, accounting for 88.4% of total RES consumption in these households. Ambient heat accounts for 8.5%, solar thermal system for 2.4% and geothermal energy for 0.7%. Thus, the hierarchy of RES consumption in Polish households is consistent with that observed in European ones. Regarding the different types of RES, a significant increase was recorded for solar thermal (by 4.47 ktoe on average per year), geothermal power (0.77 ktoe) and ambient heat (15.5 ktoe). In addition to the increase in renewable energy sources, Polish households enhanced the natural gas consumption, on average by 28.4 ktoe per year. Other energy sources showed a decrease (manufactured gases, gasworks gas, oil and petroleum gases, gas oil and diesel oil) or stabilization (solid fossil fuels, other bituminous coal, lignite, coke oven coke) (Table 4).

**Table 4.** Trends in the use of energy sources in Polish households in 2004–2019.

| Specification              | The Trend Slope Factor | <i>p</i> Value | R <sup>2</sup> |
|----------------------------|------------------------|----------------|----------------|
| Total                      | −33.10                 | 0.5164         | 0.0307         |
| Solid fossil fuels         | −23.10                 | 0.5484         | 0.0263         |
| Other bituminous coal      | −23.09                 | 0.5314         | 0.0285         |
| Lignite                    | 0.96                   | 0.3427         | 0.0644         |
| Coke oven coke             | −0.96                  | 0.6923         | 0.0115         |
| Manufactured gases         | −0.19                  | 0.0000         | 0.9550         |
| Gas works gas              | −0.19                  | 0.0000         | 0.9518         |
| Oil and petroleum products | −34.35                 | 0.0000         | 0.7717         |
| Liquefied petroleum gases  | −3.88                  | 0.0245         | 0.2626         |
| Gas oil and diesel oil     | −30.47                 | 0.0000         | 0.7577         |
| Natural gas                | 28.4                   | 0.0028         | 0.4453         |
| Renewables and biofuels    | 31.1                   | 0.0001         | 0.6327         |
| Solar thermal              | 4.47                   | 0.0000         | 0.8870         |
| Geothermal                 | 0.77                   | 0.0000         | 0.9262         |
| Primary solid biofuels     | 10.4                   | 0.1531         | 0.0787         |
| Ambient heat               | 15.5                   | 0.0000         | 0.9124         |

Comment: Tables 3–5 include the categories of energy sources that are used in a given country. The list of energy source categories in Tables 3–5 differs due to the differences (the absence of certain categories) in their use between countries. Source: own calculations based on data from [7].

Slovak households in 2019 were dominated by two energy carriers, natural gas and RES, which accounted for 42.4% and 23.3% of the total consumption of energy carriers,

respectively. Since 2004, natural gas consumption in the household sector has decreased by 13.4 p.p., instead of renewables and biofuels, which have increased by 22.1 p.p. In particular, between 2018 and 2019 consumption of renewables and biofuels in Slovak households increased markedly, due to the increase of primary solid biofuels in total consumption. The share of hard coal in the total consumption of energy carriers in Slovak households was 1.1% in 2019, while 16 years earlier it was 3.9% [7].

The directional coefficient of the trend demonstrates that the changes in consumption of renewable energy sources in Slovak households in 2004–2019 were not statistically significant. However, the analysis of particular types of renewable energy sources shows that the significant increase was recorded only in relation to solar thermal energy (by 0.52 ktoe on average per year) as well as other bituminous coal (average annual by 0.95 ktoe) and brown coal briquettes (average annual by 0.09 ktoe) (Table 5).

**Table 5.** Trends in the use of energy sources in Slovak households in 2004–2019.

| Specification              | The Trend Slope Factor | <i>p</i> Value | R <sup>2</sup> |
|----------------------------|------------------------|----------------|----------------|
| Total                      | −17.38                 | 0.1398         | 0.0723         |
| Solid fossil fuels         | −3.205                 | 0.0011         | 0.5107         |
| Other bituminous coal      | 0.95                   | 0.0000         | 0.7285         |
| Patent fuel                | 0.0197                 | 0.1148         | 0.1086         |
| Lignite                    | −4.073                 | 0.0001         | 0.6590         |
| Coke oven coke             | −0.1950                | 0.0024         | 0.4564         |
| Brown coal briquettes      | 0.089                  | 0.0189         | 0.2870         |
| Oil and petroleum products | −0.3894                | 0.1060         | 0.1169         |
| Liquefied petroleum gases  | −0.3894                | 0.1059         | 0.1169         |
| Natural gas                | −20.09                 | 0.0014         | 0.4973         |
| Renewables and biofuels    | 13.2                   | 0.0909         | 0.1327         |
| Solar thermal              | 0.52                   | 0.0000         | 0.8439         |
| Primary solid biofuels     | 12.0                   | 0.1060         | 0.1168         |
| Characoal                  | 0.098                  | 0.0929         | 0.1305         |
| Ambient heat               | 0.62                   | 0.1052         | 0.1765         |
| Heat                       | −10.82                 | 0.0002         | 0.5973         |

The same comment as in Table 3. Source: own calculations based on data from [7].

Regarding German households, three energy carriers dominate the overall consumption of energy carriers, i.e., oil and petroleum products, gas oil and diesel oil, renewables and biofuels, which accounted for 20.6%, 19.0% and 14.4%, respectively, in 2019. Since 2004, consumption of oil and petroleum products in the household sector has decreased by 6.7 p.p., gas oil and diesel oil by 6.6 p.p. and renewables and biofuels have increased by 6.7 p.p. The share of hard coal in the total consumption of energy carriers in German households in 2019 was—0.6% [7].

From the directional coefficient of the trend, it can be concluded that the consumption of renewable energy sources in German households increased statistically significantly between 2004 and 2019, on average by 198 ktoe. As for the individual types of renewable energy sources, significant increases were recorded for solar thermal technology (average annual increase of 34.7 ktoe), geothermal heat (1.81 ktoe), biogases (22.7 ktoe) and ambient heat (68 ktoe). In German households, apart from the increase in renewable energy sources, there was no significant increase in the consumption of other energy carriers (Table 6).

**Table 6.** Trends in the use of energy sources in German households in 2004–2019.

| Specification                                      | The Trend Slope Factor | <i>p</i> Value | R <sup>2</sup> |
|----------------------------------------------------|------------------------|----------------|----------------|
| Total                                              | −543                   | 0.0045         | 0.4104         |
| Solid fossil fuels                                 | −15.70                 | 0.0533         | 0.0487         |
| Anthracite                                         | −2.407                 | 0.0340         | 0.2313         |
| Other bituminous coal                              | −5.99                  | 0.0272         | 0.2530         |
| Patent fuel                                        | 4.04                   | 0.2815         | 0.0167         |
| Coke oven coke                                     | −2.590                 | 0.0002         | 0.5989         |
| Brown coal briquettes                              | −8.76                  | 0.0343         | 0.2310         |
| Oil and petroleum products                         | −432.7                 | 0.0002         | 0.6243         |
| Liquefied petroleum gases                          | −5.86                  | 0.3362         | 0.0661         |
| Motor gasoline (excluding biofuel portion)         | −1.085                 | 0.0000         | 0.7845         |
| Other kerosene                                     | −0.007                 | 0.9442         | 0.0004         |
| Gas oil and diesel oil (excluding biofuel portion) | −425.7                 | 0.0001         | 0.6366         |
| Natural gas                                        | −115.2                 | 0.11727        | 0.0663         |
| Renewables and biofuels                            | 198                    | 0.0004         | 0.5791         |
| Solar thermal                                      | 34.7                   | 0.0000         | 0.9714         |
| Geothermal                                         | 1.81                   | 0.0000         | 0.8675         |
| Primary solid biofuels                             | 67                     | 0.1296         | 0.0960         |
| Characoal                                          | 3.33                   | 0.0011         | 0.5137         |
| Biogases                                           | 22.7                   | 0.0000         | 0.9422         |
| Blended biodiesels                                 | 0.059                  | 0.1057         | 0.1176         |
| Other liquid biofuels                              | 0.0021                 | 0.9771         | 0.0000         |
| Ambient heat (heat pumps)                          | 68                     | 0.0000         | 0.9926         |
| Heat                                               | −79.6                  | 0.0044         | 0.4122         |

The same comment as in Table 3. Source: own calculations based on data from [7].

## 5. Discussion of the Findings

Investment in renewable energy technologies is essential to cut greenhouse gas emissions [86]. However, global CO<sub>2</sub> emissions are increasing, between 2004 and 2019 the increase was 28.6% [87]. In 2020, the COVID-19 pandemic reduced energy demand and reduced global CO<sub>2</sub> emissions by 8% compared to the previous year. This reduction resulted in a return to the CO<sub>2</sub> emissions of a decade ago [88]. It is conjectured [88] that, as after previous crises, the rebound in emissions may nevertheless be greater than the decline, unless the wave of investment to restart the economy will be allocated more widely to cleaner energy infrastructure. Nevertheless, there is an urgent need for policy action to curb the upward trend in CO<sub>2</sub> emissions. On the positive side, there has been an increase in the use of energy from renewable sources—the only one at the time of the COVID-19 pandemic. It should also be noted that, despite the global increase in CO<sub>2</sub> emissions, Europe has seen a fall in these emissions, thanks precisely to investment in solutions that promote renewable energy sources.

The transition to low-emission energy sources is occurring at different speeds in individual Member States of the Community. This is due to the divergent energy security interests of these countries and leads to dissonance in the energy union [89]. Achieving the objectives of the new EU energy strategy setting the goal of reaching 32% of the energy balance from RES in 2030 [90] requires reducing dependence on fossil fuels. The unbalanced perception of this issue and the different security priorities among the EU Member States result in a new west-east division of the Community, thus perpetuating the division that

has existed since the former Union of Soviet Socialist Republics (USSR) satellite countries joined the EU organization [91]. The own study shows that with regard to the household sector, a higher share of RES energy—in relative terms—in final energy consumption occurs in the so-called “poorer” part of Europe, while in countries with higher living standards [92] (Ireland, Luxembourg, UK, the Netherlands, Belgium, Sweden, Germany) RES use remains at a lower level. This may be due to the fact that improvements in the quality of life manifested by an increase in the area and standard of furnishings of dwellings and the possibility of obtaining an optimal indoor microclimate [93,94] result in significant energy consumption, which consequently diminishes the relative increase of RES in final energy consumption. In EU countries, the share of expenditure on energy consumed by households has an increasing trend [95]. Income growth is a strong determinant of increase in household energy expenditure [37,96,97]. Income is also a key determinant of investment spending on RES energy extraction. Thus, when considered as a whole, the reason for the smaller improvement in overall RES use is the higher living standards and changing lifestyles (more household appliances and larger dwellings) of today’s consumers. Even though the share of RES energy is increasing, the overall increase in consumer energy use diminishes these achievements.

It is worth mentioning that the leaders in absolute terms in the use of RES by sector households are the French, Germans and Italians. According to own research, these countries also saw the highest growth in RES use by sector households between 2004 and 2019. It is noted that Western European countries, but also Scandinavian countries, have for many years been taking and supporting measures to increase the share of RES in total energy production. This includes tax incentives and educational measures as well as public support programs in subsidies for investments in renewable energy [98–100]. At the same time, the energy transition is more manageable in these countries because these economies are not based on fossil fuels (coal) [101]. The leadership role in the use of RES by Western European and Nordic countries is emphasized in many publications [60]. It is worth mentioning that Germany is the largest energy producer in the EU, i.e., 19.7% in total energy production in the whole European Union. Germany is followed by France, with an energy production of 17.6% and the United Kingdom with 10.6%. Italy 8.8%, Spain 8.7%, Poland 5.0% and Sweden 4.8% are also responsible for  $\frac{3}{4}$  of total energy production in the EU [102].

The self-analysis grouped the EU-28 countries into 6 groups according to the size and structure of household RES used. This classification indicates that the countries with the highest use of RES in households are the countries of Central, Eastern and Southern Europe. In these countries the dominant RES category is primary solid biofuels. It can be expected that in these countries, due to lower living standards [92], citizens cannot afford to invest in more expensive RES technologies. Deciding to use primary solid biofuels is a cheaper RES alternative than, for example, heat pump installations. Primary solid biofuels include, among others, wood pellets. In Poland, for example, the introduction of the “Clean Air” program (EU support) has widely promoted the replacement of old boilers using non-renewable solid fuels with boilers using biomass. Of all heat source applications, 1/5 requested subsidies for biomass boilers [103]. Some countries have even committed to increasing the use of wood pellets. Croatia, Slovenia and Slovakia by signing the Kyoto Protocol (The Kyoto Protocol) have committed to reduce GHG emissions precisely by promoting the use of wood biomass, primarily wood pellets [104].

In countries in the richer part of Europe, the use of primary solid biofuels in the RES use structure is usually at a lower level. In Western and Northern Europe (e.g., Ireland, The Netherlands, Finland, France) a relatively high use of heat pumps in households is observed. Heat pump technology is regarded as one of the environmentally friendly solutions for increasing energy efficiency and reducing harmful gas emissions into the atmosphere. As indicated, the use of heat pumps is economically beneficial in the Baltic region and the market share of these systems is increasing [105].

Solar thermal technology is also popular in richer European countries such as Ireland and Luxembourg. It is submitted that the interest in solar thermal energy may continue to grow due to the COVID-19 epidemic, which has changed the balance of energy consumption across countries. In particular, household energy consumption increased as people were encouraged to stay indoors [106]. This fact may lead to an increase in solar PV investments in residential buildings [107].

For climatic reasons, it is obvious that solar thermal technologies are most popular in households in the south of Europe (Cyprus, Malta, Greece). Cyprus, which formed a single-element cluster, records the highest use of RES in households. Cyprus is the world champion in terms of solar energy applications [108]. Already in the first decade of the 21st century, it was estimated that about 90% of residences in this country had a solar water heater installed. This record in thermal applications was mainly attributed to favorable weather conditions, a pioneering solar energy industry and a strong coordinated effort by all the concerned [109]. In Malta, on the other hand, the use of solar thermal energy, although dominant among household sources used, is generally in a smaller proportion of households. Solar water heaters in the first decade of the 21st century were present in several percent of all dwellings. It is surprising as the Maltese islands have the highest insolation in Europe [110]. The wider uptake of RES in Maltese households occurred in the second decade of the 21st century. As indicated [111], driven by the need to meet mandatory European Union (EU) renewable energy targets and facing the constraints of a limited territory, Malta was one of the first countries to rely almost exclusively on households to meet its clean energy targets. In 2009, a subsidy scheme was launched to encourage households to install photovoltaic systems on their own properties to feed into the energy network [111].

The results of our own research indicated that the leaders in EU-households respecting the RES share in final energy consumption (in relative terms) are Croatia, Slovenia and Latvia, among others. Croatia has the technical and economic potential of renewable energy sources necessary to achieve 100% RES in energy consumption [33]. The solar energy potential in Croatia far exceeds both existing and future, energy needs. The sunniest parts of Croatia, receive about 40% more solar energy than Central Europe and 60% more than Northern Europe. In winter, the continental part of Croatia receives twice as much solar energy as Northern Europe, with the central and southern coastal parts receiving 3–5 times more than Northern Europe, or twice as much as Central Europe [33]. Croatia is also rich in biomass and waste, hence the high use of solid biofuels. It is worth noting that in the late 1970s this country was one of the few regions in the world to initiate a solar energy program in response to the 1973 oil crisis [34,112].

From our own research we found that in Polish households, although there is a significant statistical increase in RES, the share of solid fossil fuels still remains at a relatively high level. Between 2004 and 2019, the increase in the amount of renewable energy used was at the level of the EU-28 average. As indicated [113], there is potential for development of RES technologies in Poland. Solar energy, wind power and solid biomass processing have the greatest chances for development.

Yang and Zhao [114] analyzing the financial aspect of fossil resource use for shorter periods found that fossil energy generally has lower financial costs compared to renewable energy but based on the conditions of sustainable development and then long-term projections, renewable energy is the only way to achieve sustainable living in the world. The energy system must provide energy services that are socially acceptable, economically sustainable and environmentally friendly [114].

In comparison, in countries neighboring Poland, i.e., Germany and Slovakia, the process of transition of households from fossil energy sources to renewable energy sources has been more favorable. Currently, household sector uses only a small percentage of fossil fuels in these countries. In general, solid fuels in Poland constitute the largest part of the energy mix on the EU scale, which significantly complicates the achievement of environmental goals, especially with the emphasis on decarbonization [84,115]. The



transformation of the energy market in Poland depends on the financial situation of all energy producers (mainly coal companies in Poland) and power generators, whose activity is exposed to high financial risks [116,117]. The evolution of the Polish energy system is mainly influenced by the necessity to integrate energy markets in the EU. Despite the difficult conditions of the energy system in Poland, structural changes towards meeting the adopted environmental requirements are taking place. Therefore, the energy policy of the Polish country focuses on the energy supply security. In addition, competitive costs, minimal environmental impact and increase in energy efficiency are taken into account [58].

In conclusion, it can be stated, following Bąk and co-authors [101], that there are many factors influencing the disproportions between EU countries in the use of RES. Each EU Member State should look for the reasons why these disproportions become in order to answer the question how to improve its position in terms of RES use and how to change its policy to be more effective [101]. However, it is indispensable to include the household sector in the transition process from non-renewable to renewable energy sources.

It is impossible to compare the results presented in this paper with the results of similar studies because they have not been conducted so far. To date, taxonomic studies have been carried out on renewable energy in a broad sense, but not only on household consumption of renewable energy. The country classifications obtained in the studies quoted in the second part of the article do not coincide with the classification presented in this paper. It is not surprising that diverse cluster analysis results have been found, since they refer to a variety of aspects in the renewable energy sector and take into account multiple variables for the study. For this reason, the results presented in the paper contributes further to the issue of renewable energy sector in EU countries.

## 6. Conclusions

The household sector is an important contributor to overall energy consumption in the economy and should therefore be actively involved in measures to improve environmental quality. For a common future, it is necessary to include renewable energy in the long-term planning process of the energy sector. The use of renewable energy has numerous benefits, but investment in new RES technologies often proves costly, so many countries rely on the cheapest solutions using, for example, primary solid biofuels. Nevertheless, every year there is an increase in the use of RES in EU households, with diversification of the sources of this energy.

As in other aspects of life, there is a certain polarization among EU countries regarding the use of RES in the household sector. In central and eastern European countries there is a greater use of energy sources such as primary solid biofuels, while households in western European countries are more likely to install ambient heat, solar thermal systems or use biogases.

Many factors influence the disproportion between EU countries in the use of RES. Each EU Member State should look for optimal and efficient solutions to develop RES in the household sector in order to improve its position in terms of their use. The literature review shows that an important factor is an active State policy and extensive education of citizens on RES. Raising citizens' awareness of the opportunities and benefits of installing RES-based solutions with parallel taking care of the energy efficiency in residential building should bring tangible benefits in the long term.

The conducted analyzes gave answers to the research questions posed in the introduction to the study. Based on the analyses carried out, the following conclusions can be drawn:

- RES consumption in households is increasing, with the diversification of renewable energy sources. In some countries the growth of RES use by individual consumers is accelerating, while in other countries there is a kind of stabilization or even regression, which should prompt public authorities to become more involved in promoting the use of RES in households, which is the answer to 1 research question;

- The leaders in terms of absolute use of RES by the household sector are France, Germany and Italy. These countries also have the highest growth in household RES consumption. On the other hand, in relative terms, the CEE and SEE household sectors perform better than the households of the other EU members. The share of RES in final energy consumption in the CEE and SEE countries is the highest. It can be assumed that there is potential for development of RES technologies in the EU countries. Properly created mechanisms can further push forward investments from national budgets to develop renewable energy sectors, which is the answer to 1 and 3 research questions;
- EU-28 countries can be divided into six groups according to household RES use, with—in relative terms—poorer European countries (e.g., Croatia, Romania, Bulgaria) having higher household RES use than richer Western countries (e.g., Luxembourg, Belgium, the Netherlands). However, these poorer countries rely primarily on primary solid biofuels, while in the richer parts of Europe there is a wider use of ambient heat, solar thermal technology and even biogases. The use of primary solid biofuels is a cheaper solution in RES use and this enables the poorer countries to meet the energy policy targets set at EU level, which is the answer to 2 research question;
- In Poland the use of RES by the household sector is increasing year by year, in particular the use of solar thermal or geothermal technology, and ambient heat. However, the RES consumption is still at a relatively low level, which demonstrates the need to make household members aware of the advantages of investing in modern RES technologies for households. At present, Poland dependence on fossil fuels cannot be denied; on the other hand, the development of RES in Poland should be looked upon positively, which is the answer to 3 research question.

Some limitations in this research should be considered. Identifying the situation of RES use by the household sector at the country level gives only a general issues characterizing the discussed subject understanding of the topic under study is a considerable limitation for this study. The household sector is diversified in terms of demographic and socio-economic characteristics. Thus, a number of studies could be usefully developed basing on these results. Subsequent research should take into account the RES use by specific types of households, for example, by demographic, social, economic and culture characteristics.

The research could be extended with the analysis of specific categories of renewable energy sources and could also include other countries, outside Europe. This can be helpful in an assessment of the influence of various factors (e.g., social, economic, legislative, environmental, political, etc.) on the cluster structure. Similar future studies will also give a guidance to determine if there are any changes in the structures of separate clusters.

For energy policy makers and managers offering modern RES technologies, the information that the country remains low in RES consumption by household sector is a signal to deepen the work to raise public awareness about the advantages of introduction this modern and environmentally friendly technology into households.

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