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DEVELOPMENT OF SOLAR ENERGY IN POLAND IN THE CONTEXT OF EUROPEAN COUNTRIES

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Purpose: The aim of the article is to analyse the development of solar energy in Poland against the background of other European countries.
Design/methodology/approach: The research was conducted on data for 22 countries between 2012 and 2020 using dynamic analysis and multivariate analysis in the form of cluster analysis.
Findings: Between 2012 and 2020, intensive development of solar energy sources was observed in the 22 countries studied. Although Poland invests very intensively – compared to other countries – in solar technologies (especially in photovoltaics), it does not yet belong to the cluster of high-performing countries in this respect.
Originality/value: The article's value is to view the development of solar thermal systems in Poland and Europe from the perspective of a multidimensional analysis, which we conducted in two separate time units. This allowed us to draw conclusions about the development of solar systems in Poland also with regard to time.

Keywords: solar energy, collectors, photovoltaic, renewable energy, Poland in the context of Europe.

Category of the paper: research paper.

Introduction

Energy is a vital issue for the development of the modern economy. The current method of obtaining it from fossil fuels generates huge environmental problems such as air pollution and carbon dioxide emissions. Renewable energy sources (RES) include solar, wind, geothermal, flowing water, wave, tidal, and biomass energy. Renewable energy sources are considered inexhaustible in the very long term, and their resources are not depleted as they are used. Hence, in recent years, there has been a shift towards renewable energy sources to overcome existing environmental problems. In addition, in 2021, the European Commission published the "Fit for 55" package (Fit for 55, 2021), which contains many changes to the existing regulations and which is to serve the new target of reducing carbon emissions by 55% in 2030. The package includes, among others, a proposal to increase the share of renewable energy in gross final energy consumption to 40% in 2030. Adoption of an increased RES target will accelerate investments in new, non-emission sources in the generation sector. This article is dedicated to solar energy. The development of solar energy technology is currently being intensively explored in research. Technological opportunities and innovations in this area are being explored (Ge et al., 2018). Factors delaying the implementation of solar technologies are analysed (Budin et al., 2021; Zarębski et al., 2021; Szultka et. al., 2021; Jasiński et al., 2021). Factors influencing public acceptance of solar technologies are also investigated (Parzonko et al., 2021; Graziano and Gillingham, 2015; Müller and Trutnevyte, 2020; Zdonek et al., 2022).

In view of the long-standing interest in solar energy, the development of solar energy in Poland is interesting compared to European countries. It has already been explored research-wise, but usually, the analyses were dedicated to a specific technology, e.g. photovoltaics (Olczak et al., 2020, 2021; Wolniak and Skotnicka-Zasadzień, 2022) or the analyses lacked multidimensionality and international context (Mularczyk and Hysa 2015; Mularczyk, 2016). Therefore, the main objective of this article is to analyse the development of solar energy in Poland in comparison with other European countries. Consequently, we posed the following research questions:

Research question 1: How have the variables describing the development of the solar systems evolved in particular European countries over the period 2012-2020, and how does Poland compare?

Research question 2: Which group of countries did Poland belong to in terms of developing solar systems in 2012 and 2020?

To address the research questions posed, dynamics analysis and cluster analysis were carried out on data from 2012-2020 for 22 European countries downloaded from Eurostat. Accordingly, the article is organised as follows: section one presents the literature background of the study, section two discusses the methodological aspects of the study, section three presents the results, and the final fourth section presents a discussion of the results obtained.

1. Literature review – characteristics of solar systems

Solar systems can be divided into two main groups: with photothermal conversion (solar collectors) and with photovoltaic conversion (photovoltaic panels). Solar collectors enable the direct conversion of solar energy into heat. At the same time, photovoltaic technology directly converts solar energy into electricity (Górzyński, 2020; Ge et al., 2018). Solar water heating is one of the most widely used water heating systems in the world, as collectors efficiently convert solar energy into heat with relatively low life cycle costs (Ge et al., 2018). Therefore, the collectors are used for heating domestic and process water, supporting the central heating system, heating water in swimming pools and cooling buildings. According to (Tokarczyk et al., 2020), collectors are a technology that, together with heat pumps and, temporarily, biomass boilers, will allow Poland's heating sector to decarbonise. However, it should be added that insolation conditions in Poland do not allow collectors to become the only source of heating in single-family houses, although they are an important auxiliary source (Fordrowksa, 2021). Even though the collector market in Poland has been developing at its best since 2010, mainly due to subsidised loans provided by the National Fund for Environmental Protection and Water Management, it has started to shrink with the development of PV panels. The collector and PV market is currently stimulated by anti-smog programmes and the Clean Air Programme.

Photovoltaic (PV) systems, which directly convert solar energy into electricity, have recently become increasingly popular. Both photovoltaic farms and prosumer micro-installations are developing intensively in Poland. Numerous studies on PV microgrids show that many factors influence public acceptance of these systems. These primarily include economic factors (Parzonko et al., 2021; Briguglio and Formosa, 2017; Müller and Trutnevyte, 2020), where the income of those investing in PV systems and the costs of these systems, as well as subsidies provided by the state to cover part of the installation costs, play a decisive role. Therefore, the development of PV systems is dependent on GDP per capita, as shown in a study (Wolniak and Skotnicka-Zasadzień, 2022). Besides, the emphasis on PV systems are supported by environmental factors, i.e. environmental awareness (Zhang et al., 2011), the share of hybrid or electric cars in total cars purchased (Davidson et al., 2014) and the level of pollution in a region (Balta-Ozkan et al., 2015). Furthermore, investment in PV systems depends on the characteristics of households and their environment, i.e. household size, the background of its members, population density, building type and the influence of friends and family (Balta-Ozkan et al., 2021; Graziano and Gillingham, 2015). In Poland, according to a study (Zdonek et al., 2022), investments in PV microgrids were most influenced by economic factors. This is why introducing the discount system, and the Mój Prąd (My Current) programme has contributed to the high interest of Poles in-home photovoltaics. Typically, electricity from domestic photovoltaics is used to power household appliances and lighting, but with the development and promotion of heat pumps, domestic photovoltaics will make an important contribution to the greening of district heating in Poland. Photovoltaic panels, like collectors, are regarded as environmentally friendly technology. Still, the issue of their disposal in a nature-friendly manner has not yet been resolved.

To summarise solar thermal systems, it should also be added that, in economic terms, both systems feature low running costs when using free renewable energy, yet high initial costs. The payback period for such systems is in the range of 3-15 years, which is strongly dependent on the type of components, geographical location and subsidies from different governments (Ge et al., 2018). In terms of technical investment conditions, the installation of solar systems is quick (about 2 days), and the equipment on the roof can serve for at least 20 years with proper maintenance. These installations are generally viewed as easy and maintenance-free, which further promotes their acceptance in the market (Zdonek et al., 2022).

2. Materials and methods

Collecting data

Data for the analysis were extracted from the online Eurostat database (Eurostat) and supplemented based on the results of the EuroObserver portal report (Solar Thermal and..., 2022). In this way, data was obtained from 22 European countries from 2012 and 2020 on the level of advancement of renewable energy sources (countries with missing data were not taken into the analysis). The following variables were extracted from the databases in question: 1) consumption of solar thermal, 2) solar thermal collectors' surface area, 3) gross electricity production from solar photovoltaic and 4) share of renewable energy in gross final energy consumption. These variables are summarised in table 1.

Table 1
Variables used for the study

Variable	Description	Unit
ConsOfRen_solTherm _perCapita	Consumption of Solar thermal	GJ/capita
SolarThermalColSurf _perCapita	Solar thermal collectors' surface	sqm/capita
GrossProdElecPV _perCapita	Gross electricity production from Solar photovoltaic	MWh/capita
Share_of_ren_en	Share of renewable energy in gross final energy consumption	Percentage

The first two variables are related to the topic of thermal energy. The consumption of energy from solar collectors is presented in GJ/capita. Solar collector area refers to all sectors with solar collectors in a country. Solar collector area data includes solar thermal (not photovoltaic). The unit, in this case, is sqm/capita. The third variable relates to issues of PV advancement in the country. It measures the gross electricity generation from solar PV in MWh/capita. And the last variable: the renewable energy share in gross final energy consumption is the share of renewable energy consumption in gross final energy consumption (according to the Renewable Energy Directive). It refers to all renewable energy in a country. This variable, therefore, corresponds in some way to a country's commitment to RES. The value of this share is expressed as a percentage. To allow the comparison analysis, the data collected, presented in the appropriate units (variables 1 to 3), have been divided by the country's population, bringing information about the size of the 'per capita' variable.

Data analysis

During the exploratory data analysis, the dynamics of the four study variables were first examined. To do this, the total change was calculated for each variable, which was obtained by dividing the 2020 value by the 2012 value (whereby, when interpreting this figure, it is necessary to convert it into percentages after subtracting the singularity: and this is how it is presented in the table and charts). Later, the average pace of change (the geometric mean of the chain indices calculated from the values of the phenomenon in successive periods; that is, in this case, the eighth-degree root of the total change before subtracting the singularity – on which a similar transformation as above must be performed for interpretation) was calculated, denoted as average growth. This stage of analysis was performed in a spreadsheet, and the results obtained were additionally visualised in bar charts made in Tableau. A hierarchical *cluster analysis* of the 22 countries was then carried out using these four variables. Ward's method was employed as the agglomeration method during the cluster analysis, and Euclidean distance was taken as the distance measure. This time the calculations were made in the R environment, and the results were visualised on dendrograms. Accompanying analyses were additionally performed, mainly characterisation of clusters using measures of descriptive statistics.

The flowchart of the data collection and analysis stages is shown in the figure below.

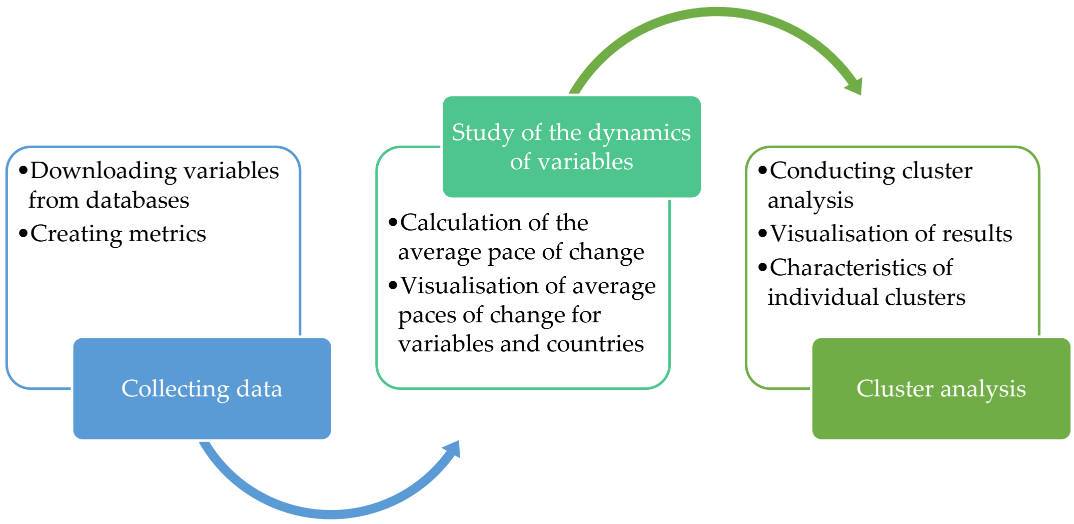

Figure 1. Flow chart for data collection and analysis. Source: own work.

3. Results

3.1. Evolution of variables describing the development of solar energy in European countries over the period 2012-2020

To address research question 1, i.e. to present the evolution of variables describing the development of solar thermal systems in Europe, table 2 was carried out. It shows the average values of all variables, the total change and the average pace of change over the period 2012-2020 over the whole area of the study countries combined (in this case, the indicators were calculated for the total area of the study countries). In addition, figure 2 and figure 3 were performed, which show how the average pace of change of the studied variables evolved between 2012 and 2020, separately in each country.

Table 2.
Average levels of variables combined in 2012 and 2020

	Solar thermal energy consumption [GJ/capita]	**Surface of solar collectors [sqm/capita]**	**Gross electricity production from solar photovoltaics [MWh/capita]**	**Share of renewable energy in gross final energy consumption [%]**
2012	0.3101	0.0906	0.1533	17.9643
2020	0.4171	0.1195	0.3149	24.1422
Total change	*35%*	*32%*	*105%*	*34%*
Average pace of change	***4%***	***4%***	***9%***	***4%***

Note: The results refer to the total surface area per capita of the surveyed countries.

Source: own work.

In the 22 countries' analysis area, the most significant change in the years under study was in the gross electricity generation from solar PV per capita. In 2020, it was as much as 105% higher than in 2012, representing an average year-on-year increase of 9%. Also, a significant increase in the solar thermal variables can be observed: 35% and 32%, with a constant year-on-year increase of around 4%. The values of the fourth variable, the share of renewable energy in gross final energy consumption, were at a similar level.

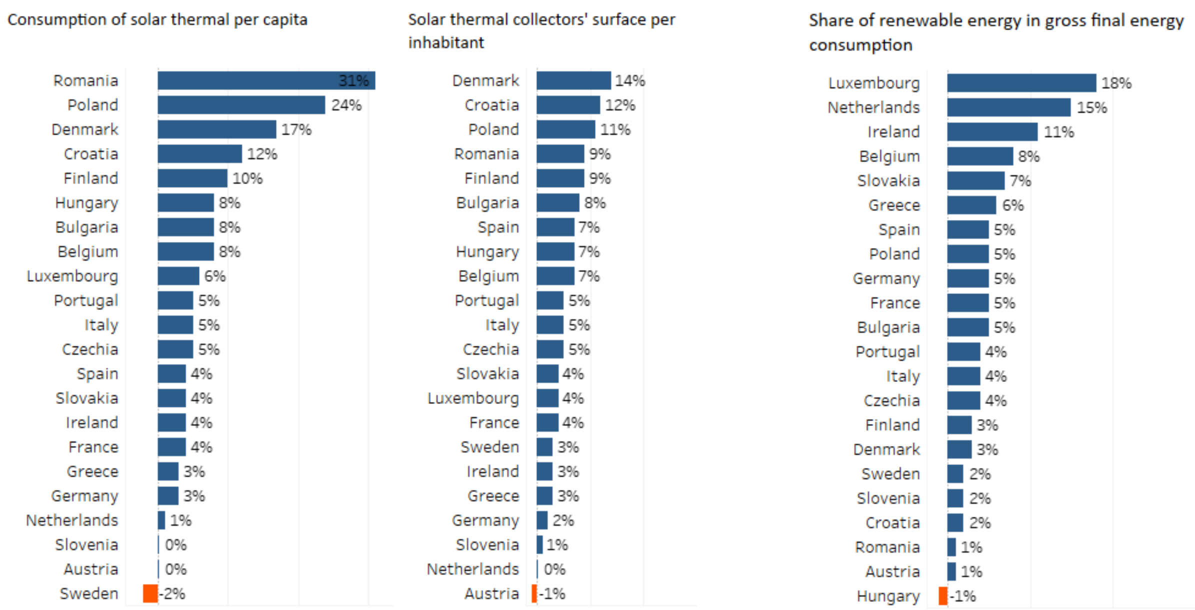

Figure 2. Average year-on-year growth of the study variables from 2012 to 2020, part 1. Source: own work.

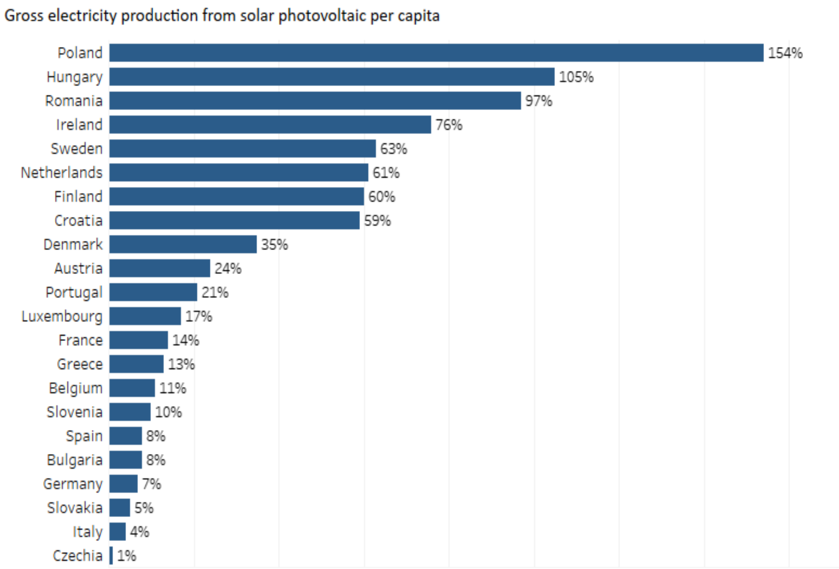

Figure 3. Average year-on-year growth of the study variables from 2012 to 2020, part 2. Source: own work.

In most of the countries analysed, different levels of an upward trend in the variables studied can be observed. Poland is a country where this development has been particularly evident during this period due to the only developing RES market. For variables describing the development of energy from solar collectors, Poland ranks second and third in terms of growth pace. The average year-on-year increase in solar collector area was 11% while moving up from 17th to 10th place compared to other countries (with the most significant increase for Denmark: 14%, which moved from 4th to 3rd place). The countries with the highest solar collector surface per capita were Austria, Greece, Germany (2012) and Denmark (2020). However, in the case of the variable describing the consumption of energy obtained from solar collectors, the increase amounted to 24% on average per year in Poland. It meant a change from 20th to 15th place (with the highest rise for Romania: 31%, which however remained in 22nd place).

In contrast, the countries with the highest energy consumption generated from solar panels were consistently: Spain, Greece and Austria. The rapid development of photovoltaics in recent years in Poland has probably contributed to its first place in terms of the pace of change in gross electricity generation from this source (on average, by as much as 154% per year). It means swapping place 22 for 19. The leading countries in this respect were Germany, Italy (2012), the Czech Republic (2012) and the Netherlands (2020) and Belgium (2020). Regarding changes in the share of renewable energy in gross final energy consumption, Poland ranks eighth, with an average year-on-year increase of 5%. However, this means swapping 17th place for 18th (with the most considerable increase for Luxembourg: 18%, which ranked 22nd in both periods). The countries with the highest share of renewable energy in gross energy consumption were Sweden, Finland and Austria. This points to other renewable energy sources used in the first two countries.

3.2. Development of solar energy systems in Poland compared to other European countries from the perspective of 2012 and 2020

To address research question 2, a cluster analysis of the countries studied was conducted in terms of the four variables analysed. Data from 2012 were explored first, followed by data from 2020.

Analysis for 2012

After performing the cluster analysis, the dendrogram shown in figure 4 was obtained. Its research established the division of the countries studied into four clusters. Poland is in cluster one along with Bulgaria, France, Hungary, Ireland, Luxembourg, the Netherlands and Slovakia. The individual mean values of the studied variables for each group are presented in table 3. This table is complemented by figure 5. It presents box plots for the study variables in isolated clusters, showing their differences.

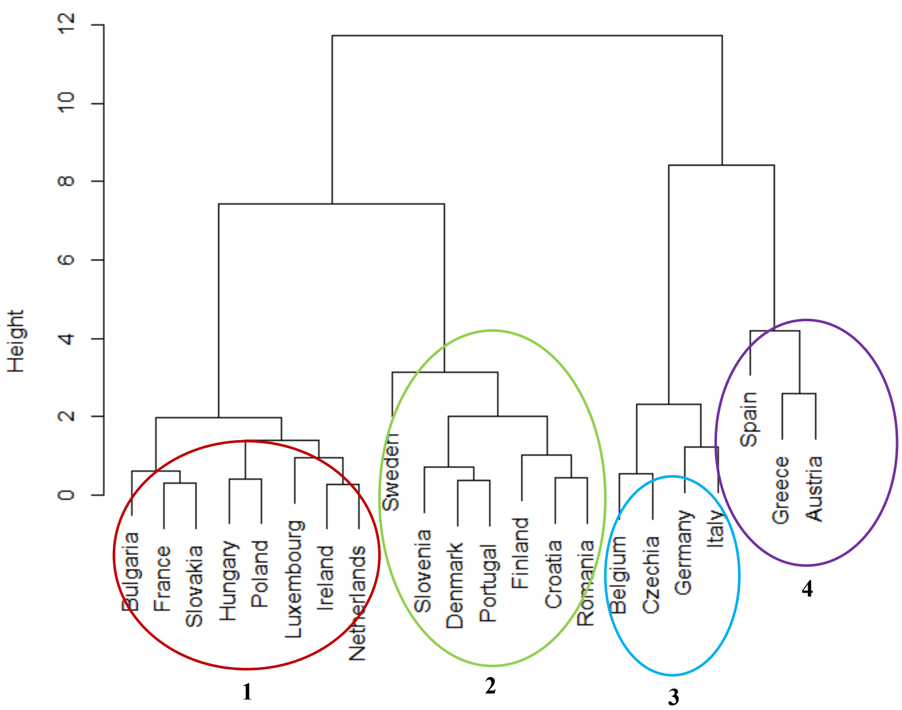

Figure 4. Dendrogram for 2012. Source: own work.

Table 3.
National average variables for countries in each cluster in 2012

Cluster	Solar thermal energy consumption [GJ/capita].	Solar collector area [sqm/capita].	Gross electricity production from solar photovoltaics [MWh/capita]	Share of renewable energy in gross final energy consumption [%]
1	0.0658	0.0415	0.0428	10.10
2	0.1075	0.0539	0.0199	**29.26**
3	0.1280	0.0825	**0.2611**	12.22
4	**1.1017**	**0.3378**	0.1226	20.24

Source: own work.

Countries that are in cluster one together with Poland are those whose average values rank fourth in three cases and third for the variable on energy production from photovoltaics. Countries in the second cluster have the highest shares of renewable energy in gross final energy consumption. Still, as other variables have lower values for them, this energy probably comes from sources other than solar. Countries belonging to cluster three are characterised by the highest electricity generation from photovoltaic panels. These include Germany, the Czech Republic, Belgium and Italy. Countries belonging to cluster four have the most developed solar collector infrastructure. These are Spain, Austria and Greece. The box plots illustrate the above analysis.

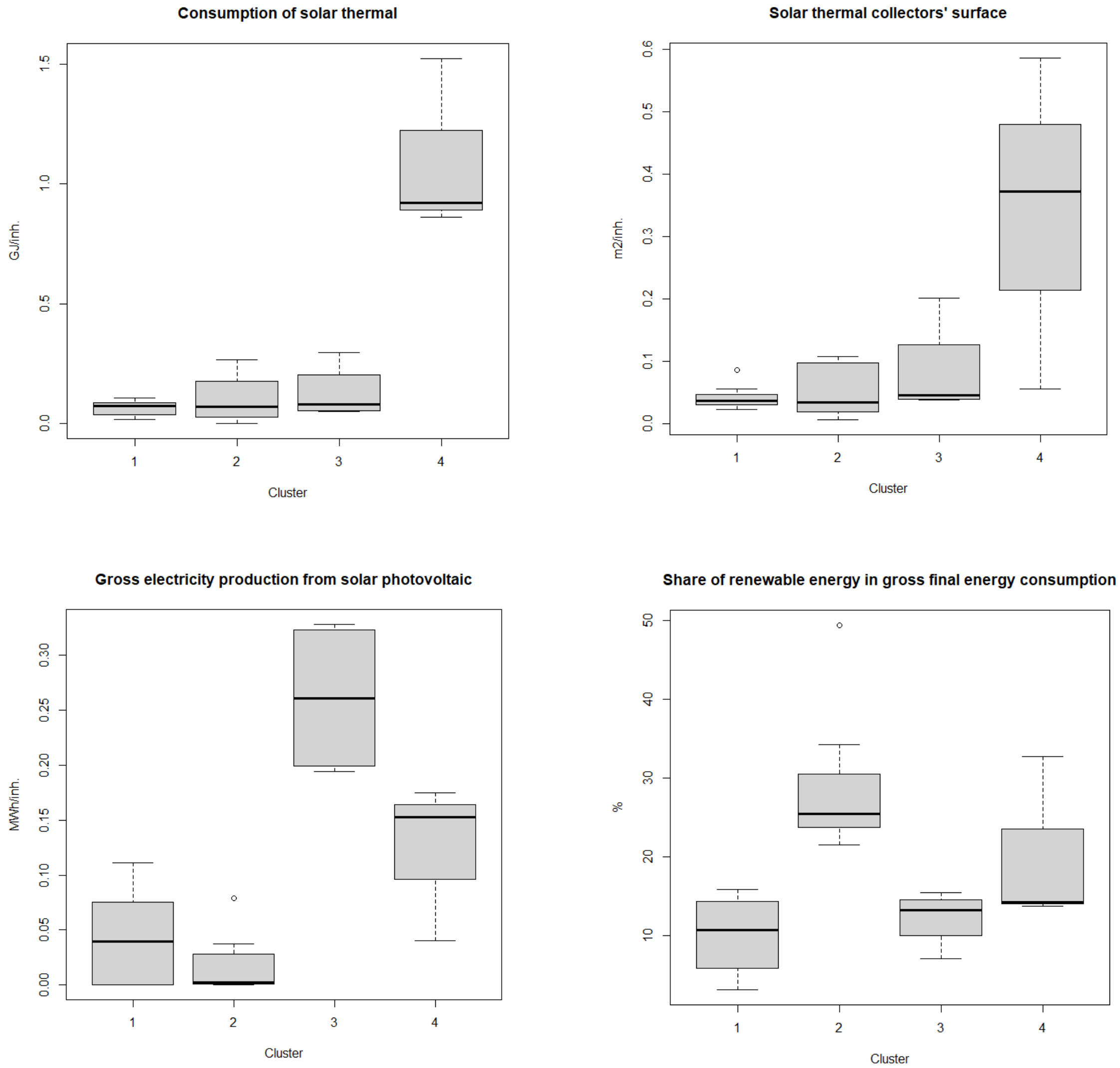

Figure 5. Study of differences in individual clusters in 2012. Source: own work.

Analysis for 2020

The analysis presented in this article includes changes over time, so similar calculations have been made for 2020. The results of the cluster analysis are shown in figure 6. As in 2012, 4 clusters can be distinguished. Poland is in the largest second cluster, together with Bulgaria, the Czech Republic, Ireland, France, Croatia, Luxembourg, Hungary, Portugal, Romania, Slovakia and Slovenia. In turn, the mean values of the variables for each cluster are shown in table 4. This table is complemented by figure 8. It presents box plots for the study variables in each group, showing the differences between clusters. To better visualise the clusters found in the context of the variables studied, a biplot (figure 7) was performed.

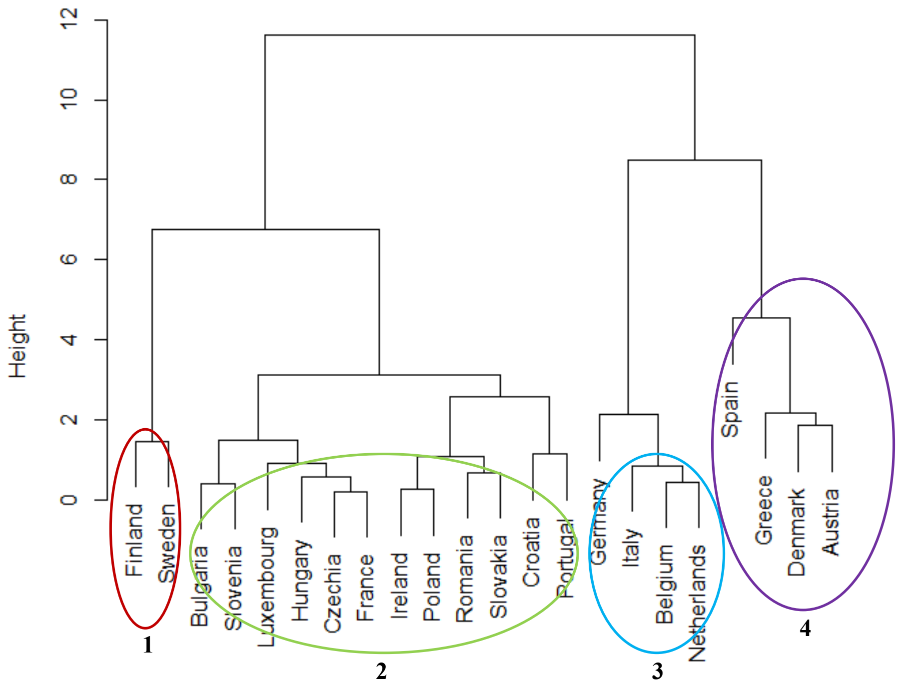

Figure 6. Dendrogram for 2020. Source: own work.

Table 4.

National average variables for countries in each cluster in 2020

Cluster	Solar thermal energy consumption [GJ/capita]	Surface of solar collectors [sqm/capita]	Gross electricity production from solar photovoltaics [MWh/capita]	Share of renewable energy in gross final energy consumption [%]
1	0.0302	0.0285	0.0740	**51.96**
2	0.1372	0.0696	0.1480	20.78
3	0.1771	0.1038	**0.4874**	16.67
4	**1.1469**	**0.3560**	0.2946	27.79

Source: own work.

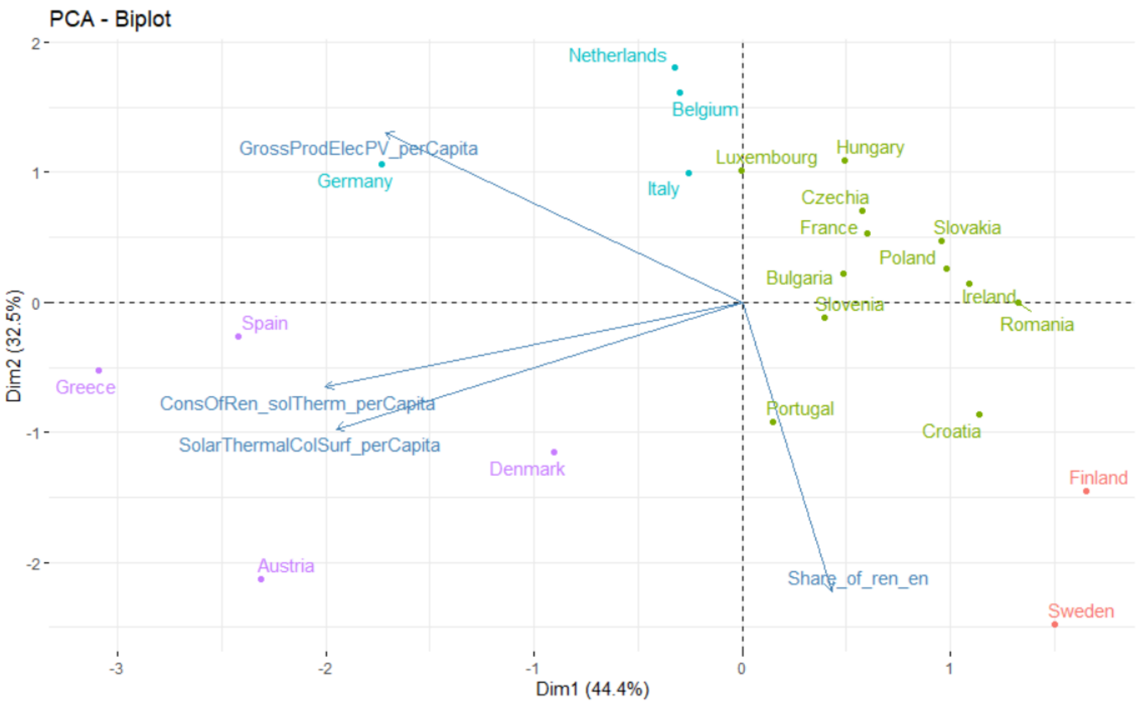

Figure 7. Biplot: country clusters in the context of the study variables in 2020. Source: own work.

The countries classified in the first cluster (Finland and Sweden) have the highest shares of renewable energy in gross final energy consumption. The biplot, therefore, shows the closest neighbourhood of these countries with the variable Share_of_ren_en. The other variables examined for cluster 1 take small values. This means that renewable energy in these countries comes from sources other than solar (typically hydroelectric, wind, biofuels). The low share of solar sources can be explained by the unfavourable insolation conditions due to the northern location of these countries.

Countries in cluster two together with Poland are the former Eastern Bloc countries and countries such as France, Portugal, Ireland, and Luxembourg. Their average values for the variables studied ranked third in each case. Therefore, this cluster is far from the vectors presenting the variables under study on the biplot. Exceptions are Portugal and Croatia, which are close to the variable Share_of_ren_en and Luxembourg, close to the variable GrossProdElecPV_perCapita. The analysis of Poland's situation showed an increase in the average values of the metrics (in relation to cluster one of 2012, in which Poland was located).

Countries belonging to cluster three are characterised by the highest electricity generation from photovoltaic panels. Therefore, on the biplot, they are located close to the variable GrossProdElecPV_perCapita, and on the box plots, cluster 3 reaches the highest mean value for this variable. These include countries such as Germany, Belgium, the Netherlands and Italy.

Countries in cluster four have the most developed solar collector infrastructure and consume the most solar thermal energy. On the biplot, these countries are located close to variables such as ConsOfRen_solTherm_perCapita and SolarThermal ColSurf perCapita. These are countries such as Greece, Spain and Austria and Denmark. Analysis of box plots for cluster 4, on the other hand, for variables representing solar thermal energy consumption and solar collector area shows a difference between the mean values of clusters 1, 2 and 3 and cluster 4 with significantly higher mean values.

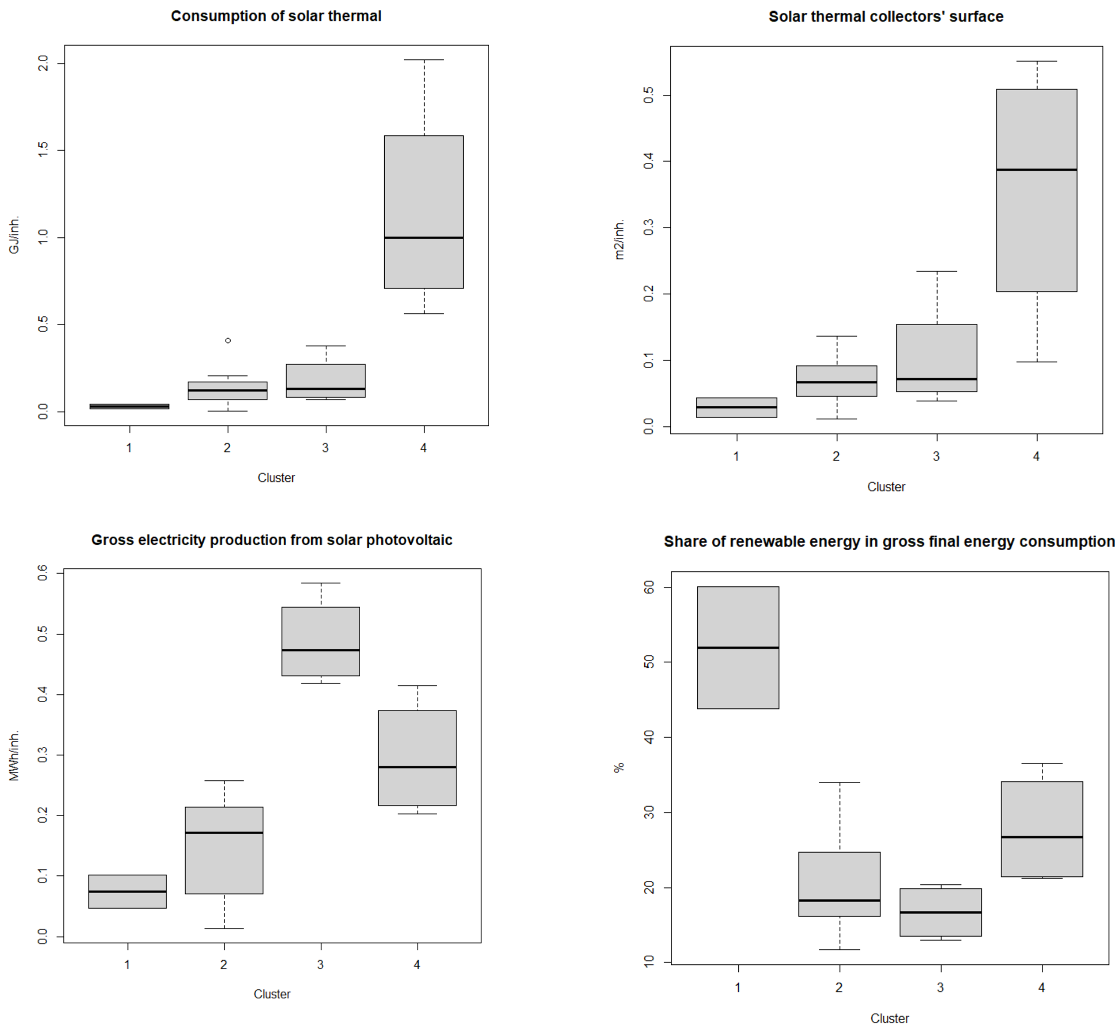

Figure 8. Study of differences in individual clusters in 2020. Source: own work.

4. Discussion and findings and conclusion

When analysing the development of solar systems, two aspects were taken into account: the change in the variables studied from 2012 to 2020 and the positioning of the values of these variables for each country in relation to each other. The first aspect was related to the first research question, related to the evolution of variables describing solar systems in individual European countries (including Poland) over the period 2012-2020. While the second aspect was related to the second research question concerning the search for a group of countries similar to Poland in terms of the development of solar systems in 2012 and 2020.

Summarising the first aspect, therefore, it is essential to recognise that, in total, the years under study have seen the most significant growth in photovoltaics. It was more than doubled by as much as 105%, giving an average annual increase of 9%. A considerable increase was also observed for collectors – by one-third and by an average of 4% per year. These results support the conclusions presented in the paper (Fordrowska, 2021). The share of renewable energy in final gross consumption increased by 34%, with an average annual increase of 4%. Among the 22 countries studied, Poland emerged as the country with the highest growth in gross electricity generation from solar PV (which averaged 154% per year) between 2012 and 2020. This is due to the subsidy system to support the development of prosumer photovoltaics proposed in Poland. It can therefore be concluded that the conclusions of the studies have been confirmed (Parzonko et al., 2021; Ge et al., 2018; Briguglio and Formosa, 2017; Müller and Trutnevyte, 2020). As far as energy from solar collectors is concerned, Poland ranked in the top three (solar thermal energy consumption and the area of solar collectors – per capita – increased on average year by year by 24% and 11% respectively, which gave Poland 2nd and 3rd place). In turn, the eighth place in terms of growth of the share of renewable energy in energy consumption (annual average increase of 5%; also in the top ten) testifies to the dominant share of solar energy in our country's renewable energy sources. All of these increases are higher than the average increases calculated for all countries surveyed combined. They, therefore, indicate a great deal of dynamism and change in attitudes towards renewable energy sources.

However, it is worth noting that the large values of the relative increases are mainly due to the small initial sizes of this variable (in 2012 - which is especially true for photovoltaics). It should be borne in mind during the analysis that countries with high initial values of the analysed variables, such as Germany, do not show such great dynamics due to probable market saturation (this development had already taken place there, which can be explained by the correlation with GDP presented in (Wolniak and Skotnicka-Zasadzień, 2022). This is supported by the fact that in 2020, Poland ranked in the second cluster, achieving results in the third place, in terms of the size of the examined variables. In contrast, in 2012, its cluster (No. 1) was in last place in terms of most variables. In the context of the intensive development that accompanied the years 2012 - 2020, this confirms the growing trend of solar energy use in Poland. With reference to the study (Zdonek et al. 2022), this can be explained by the influence of economic factors, particularly the subsidy system promoting solar technologies in Poland.

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