Evaluation of the Level of Electricity Generation from Renewable Energy Sources in European Union Countries

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Abstract: Changes in recent years have resulted in an increase in the ways in which renewable energy is used and shared in total electricity generation. Each type of renewable energy is characterised by its uniqueness of the physical specificity and, therefore, differences in technological solutions. In this study, one of the methods of multidimensional comparative analysis (WAP)—Hellwig’s taxonomic measure of development—was used to assess the level of development of electricity production from renewable sources. Twenty-eight countries were surveyed, including 27 countries of the current European Union and the United Kingdom. Panel models were used to describe the relationship between the share of electricity production from RES in total electricity production and GDP per capita, public spending by countries on energy as a percentage of GDP as well as electricity production from water, wind, solar, and biogas per capita. The presented synthetic measures confirmed the more favourable situation of the rich northern EU countries in the production of electricity from renewable sources (solar, wind, hydro, and bio), at the same time highlighting problems with the greening of electricity production in a large group of the new EU member states. The panel study confirmed the importance of differences in economic potential and wealth between EU countries for the development of the use of RES for electricity production.

Keywords: renewable energy sources (RES); power generation; taxonomic measure of development (TMR); panel model

1. Introduction

The supply of energy from renewable sources (i.e., hydro, solar, photovoltaic, wind, geothermal, biomass, and others) is a fundamental element of any country’s energy strategy and is driven by the concern for the local and global environment, as well as for energy security and sustainable development. Changes in recent years have resulted in an increase in the ways in which renewable energy is used and shared in total electricity generation. This change has been facilitated by environmental investments, market trends, appropriate policies (support for technology development), changes in legal regulations as well as business opportunities.

Renewable energy helps secure national resources, mitigate pollution and climate change, and provides cost-effective services [1].

Each type of renewable energy is characterised by its uniqueness of the physical specificity and, therefore, differences in technological solutions.

When describing renewable energy sources (RES), the authors focus primarily on electricity: ways of obtaining it and meeting the country’s energy needs.

Hydropower storage is a well-established and commercially acceptable technology for industrial-scale electricity storage and has been used since the 1890s. Hydropower is not only a renewable and sustainable source of energy, but its flexibility and storage capacity...
also enable it to improve grid stability and support the deployment of other intermittent renewable energy sources such as wind and solar [2].

Wind energy is one of the cheapest renewable energy sources. The cost of producing it using wind in regions with good wind resources is comparable with producing electricity from fossil fuels. In most cases, the cost is lower or almost the same [3].

Photovoltaics, in turn, is a relatively young technology within the renewables group. Therefore, it is rather difficult to assess its environmental impacts and related costs due to uncertainties in assessing the causal impact of photovoltaic technologies on the environment and human health at each stage of the technology’s life cycle [4].

Biomass, or more precisely its availability for energy purposes, is a result of the adopted forestry and agricultural model and the rate of introduction of more efficient energy crop plantation [5]. In Poland, biofuels are primarily used to produce thermal energy.

The aim of this paper is to present the use of renewable sources in electricity production in Poland and compare it with other European Union countries in selected years.

In order to achieve the aim, one of the methods of multidimensional comparative analysis—the taxonomic development measure (which allows for the ranking of countries according to the level of RES use for electricity production) was applied along with other panel models.

The paper sets out the following research hypothesis:

H: The level of RES use for electricity production in European Union countries depends on the level of development of these countries, measured by GDP per capita.

2. Literature Review

The use of renewable energy sources has been determined by legal regulations. They relate to legal conditions on the global and European Union (taking the form of Directives) levels and to individual solutions introduced by the Polish regulator. Let us mention some of them:

1. At the UN Summit in Poznań in December 2008, the ‘Climate Package’, which was developed by the European Commission, was adopted. Its approval obliges Poland to develop renewable energy and increase energy efficiency in accordance with the 3 × 20 Programme [6].
2. On 24 November 2010, Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions (IED) was adopted, under which permissible standards for dust, sulphur oxide, and nitrogen oxide emissions must be lowered. It came into force in 2016 [7].
3. At the beginning of March 2011, the European Commission presented a document entitled ‘A roadmap for moving to a competitive low-carbon economy’, which includes a long-term plan for reducing carbon dioxide emissions after 2020 [8]. According to this plan, greenhouse gas emissions should be cut by 80% by 2050. The EC, by its decision of 27 April 2011, allocated for Poland approximately 477 million emission allowances for the period 2013–2020.
4. On 6 December 2012, at the UN COP 18 summit in Doha, Qatar, with participants from 194 countries, the first Kyoto Protocol was extended to 2020. At this conference, a nuclear power expert—Alan McDonald—presented the IAEA agency’s report ‘Climate Change and Nuclear Power 2012’, which classified nuclear power as a clean source [9].
5. The document entitled ‘A roadmap for moving to a competitive low-carbon economy’ contains provisions according to which the reform may be carried out in the event of low prices of pollution allowances, occurring since the beginning of 2013, when the price dropped to 4 euros per tonne. On 14 March 2013, the European Parliament voted on and approved this reform, which in practice means the withdrawal of 900 million allowances and a loss of around one billion euros in budget revenues for Poland.
6. On 28 March 2014 the Government approved the draft of the Renewable Energy Sources Act [10], which sets out how their development will be supported in the country.
Renewable energy sources have been governed by legal regulations for many years. At the European Union level, these include:

- Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003, establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC (Text with EEA relevance) (OJ L 275, 25 December 2003) [11].
- Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance) (OJ L 22 November 2008) [12].
- Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) [7].
- Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources [13].

Furthermore, it is worth noting the proposed changes in the regulations. The current Renewable Energy Directive was published in the EU Official Journal only at the end of 2018. The European Commission has now signalled that changes are needed to it to bring it in line with the European Union’s new, more ambitious CO$_2$ reduction targets. The provisions that appeared in it were supposed to lead to a 40% reduction in CO$_2$ emissions by 2030 compared with 1990 emissions. However, now, according to the EU, emissions reductions should be increased by 55%. This means adapting EU legislation. Moreover, EU officials stress the need to introduce additional criteria for the use of forest biomass.

The ongoing consultation will contribute to a regulatory change, which will undoubtedly be linked to EU countries’ actions, aimed at further developing and increasing the use of renewable energy sources. Renewable electricity is a pillar of the transition to sustainable development, implemented through climate and energy policy strategies, and the European Green Deal provides a potential investment blueprint for this new phase of development [14]. Halkos and Gkampoura [15] analysed fossil fuel and renewable electricity generation and examined their links to CO$_2$ emissions and economic growth in 119 countries around the world with different income levels. The publications by Szopik-Depczyńska et al. [16] and Szopik-Depczyńska et al. [17] are the examples of articles dealing with broader aspects of the implementation of the sustainable development goals, taking into account the role of RES. The problems of energy transformation, including the development of the use for electricity production, were studied by Pao and Fu [18] on the example of Brazil, by Lin, Liou, and Chou [19], who compared Taiwan and Japan, and by Pietrzak, Igliński, Kujawski, and Iwański [20] in relation to Poland.

Recently, there have been a number of publications relating to various aspects of renewable energy generation and consumption in European Union countries, as well as the question of energy self-sufficiency in these countries.

A wide spectrum of motivations to switch to environment friendly green energy was described by Grosse [21] and Pietrzak, Igliński, Kujawski, and Iwański [20] in relation to Poland, by Chovancová and Tej [22] from the point of view of four countries of the Visegrad Group, by Zielenkiewicz [23] and the Institute for European Environmental Policy [24] in the context of all the EU countries. The use of RES in the EU countries from the perspective of fuel and energy consumption data was presented by Piekut [25]. The share of renewables in power generation in EU countries was analysed by Yu et al. [26], in the context of both investment, production, and consumption aspects of power generation. The authors highlight the significant progress in the penetration of renewables in Western Europe against the background of Eastern Europe making progress, but much less within the EU. At the same time, they point to the significant, as yet untapped potential for renewable development across the EU [26]. Markandya, Arto, Eguino, and Román [27] examined the impact of low-carbon technologies on the employment in the EU countries Kacperska, Łukasiewicz, and Pietrzak [28] used the clustering method to assess the use of renewable energy sources in EU countries with a focus on the Visegrad Group, i.e., the Czech Republic, Hungary, Poland, and Slovakia.
Simoes et al. [29] produced six climate projections to calculate indicators of future wind, solar, and hydro power generation capacity, as well as temperature impacts on electricity demand for heating and cooling for each EU Member State. The projected indicators for climate-dependent renewable energy sources showed relative stability in the ability to meet renewable energy production and emission reduction targets across the EU, but at the same time, significant variation at the level of individual member states, especially for wind and solar energy.

Mehedintu et al. [30] investigated the evolution and forecasting of renewable energy consumption in EU countries with a special focus on Romania, also estimating the development of renewable energy use in the energy sector. Incentives and barriers to renewable energy consumption in twelve net energy importing EU countries were presented by Marra and Colantonio [31] using panel vector autoregression, focusing on socio-technological rather than economic aspects. Chakraborty and Mazzanti [14] in a panel analysis of OECD countries showed the existence of a moderately significant positive long-run relationship between renewable electricity consumption and economic growth. According to them, economic growth per capita is a causal factor for total electricity consumption as well as for fossil electricity consumption. The links between energy transition and economic growth were addressed in their articles by Marinas, Dinu, Socol, and Socol [32], who examined Central and Eastern European countries, by Belke, Dreger, and Dobnik [33], who examined OECD countries, and Overland [34] in the broader context of globalisation processes.

Remeikiene et al. [35] evaluated the progress in the development of the use of renewable energy sources in European Union countries for construction purposes by grouping countries according to a set of characteristics. They showed that the more developed EU countries use renewable energy sources to a greater extent than the others. Aklin [36] pointed out the danger of EU households associating the impact of renewables aggressively promoted by policymakers with the rising cost of purchasing electricity, resulting in declining public support for renewables.

The relationship between generation and consumption of electricity leads to a surplus of electricity for export or a shortage of electricity that has to be imported. The relationship between dependence on energy imports and carbon emissions in EU countries was investigated by Percebois and Pommeret [37], who showed that the best combination of low-carbon electricity production and independence from electricity imports is achieved by countries with a significant share of hydro and nuclear generation.

Much space in current publications is devoted to the proper functioning of power grids, which is necessary for the storage of electricity and the management of its surpluses and shortages. The issue of the cost of managing the stock of renewable energy produced is often raised.

Schreiner and Madlener [38] made a macroeconomic assessment of planned investments in electricity grid infrastructure in Germany. By conducting a static input–output analysis, they showed how the multiplier effects of grid investments affect macroeconomic outcomes—in terms of output, value added, employment, and fiscal revenues. They highlighted the importance of the planned significant increase in investments in electricity grid infrastructure as an important element of a sustainable energy transition in Germany. These investments are intended to ensure the flexibility of the electricity system, which is increasingly based on renewable energy sources.

Hiesl, Ajanovic, and Haas [39] highlighted the problems of long- and short-term storage of solar and hydropower and energy from other renewable sources in the countries of the European Union. According to the authors, managing surplus energy from a wide range of renewable sources requires a flexible and case-by-case approach to choosing the form of energy storage. This, however, implies potentially higher storage costs, limiting the profitability of production and encouraging the search for a mix of renewable energy sources that is optimal mainly from an economic rather than an environmental point of view.

The problem of managing surplus energy from renewable sources, in this case solar and wind, in the UK was studied by Cardenas et al. [40], concluding that providing
adequate energy storage capacity from these two sources would require an investment equivalent to 7% of the country’s GDP. Aqachmar et al. [41] performed an in-depth analysis of solar power generation technology options taking into account the environmental and financial performance of each option, creating global rankings of solar power generation. An important conclusion of their analysis is that many countries are not using their solar power production potential due to technological limitations, especially if the solar technology applied is accompanied by too high water consumption [41].

The prospects and cost effectiveness of combining biomass liquefaction with photovoltaics for energy storage and electricity production were presented by Perkins [42]. He concluded that the levelized cost of electricity (LCOE) of such production can be competitive with solar production combined with lithium-ion batteries in certain situations. This is another example of technical solutions to increase the economic viability of renewable power generation [42]. Based on the numerical data on solar modules, De Negri, Pezzutto, Gantioler, Moser, and Sparber [43] indicate a significant relationship between technological progress, the development of electricity generation devices, and their ever lower price, which translates into the universality of use and the amount of energy obtained.

3. Material and Methods

The article presents variables (indicators) that describe the level of use of renewable energy sources (RES) for electricity generation. Twenty-eight countries were surveyed, including 27 countries of the current European Union and the United Kingdom, which was still formally a member of the EU until the end of 2020. The following years were selected for the study: 2004, 2009, 2014, and 2019. The years 2004, 2009, 2014, and 2019 were selected to show the changes in the studied quantities at equal time intervals of five years, counting backwards to 2019, from which the most recent complete data are derived. At the same time, 2004 is the year of enlargement of the European Union by 10 new member states. According to the authors, data from a greater number of years would limit the transparency of the presentation of the problem and not increase the accuracy of the WAP method used. The data from all the years 2004–2019 were used in the panel model. The data come from the Eurostat database [44].

In this study, one of the methods of multidimensional comparative analysis (WAP)—Hellwig’s taxonomic measure of development—was used to assess the level of development of electricity production from renewable sources. It is one of the methods of linear ordering, which allows for the ranking of objects in order from the best to the worst according to the level of a complex phenomenon. Multidimensional comparative analyses are a willingly used research method, as evidenced by the works of Cheba and Szopik-Depczyńska [45], Rollnik-Sadowska and Dąbrowska [46], and Ginevičius [47].

The concept of a complex phenomenon is closely related to the concept of a diagnostic variable and a synthetic (aggregate) variable. Diagnostic variables are the variables describing the examined complex phenomenon, whereas a synthetic variable is ‘a variable which, based on a set of normalized diagnostic variables, determines quantitatively the level (degree of development) of the considered phenomenon in the studied objects’ [48]. The synthetic measure is unitless.

The selection of diagnostic variables is based on substantive and formal criteria [48,49]. The basic substantive criterion is the importance of a given variable in the description of a complex phenomenon under study (e.g., according to expert opinion). Formal criteria include a high degree of variability and weak correlation of diagnostic features. The variables that qualify to the set of diagnostic variables, apart from having a significant impact on the studied complex phenomenon, should also be characterized by an appropriate degree of variation and should be weakly correlated among themselves (then, they do not duplicate the information transmitted by other variables).

In the next step, the diagnostic variables are identified, i.e., the nature of the impact of particular variables on a complex phenomenon is determined. In practice, it means a
division of the set of diagnostic variables into two subsets: variables—stimulants (S) and variables—destimulants (D).

Next, the diagnostic variables are normalised. Normalisation aims to bring the values of individual variables to comparability (by being rid of denominators and standardising the ranges of values taken by diagnostic characteristics) [50]. In this article, the standardisation method was used to normalise the values of individual diagnostic variables. Variables normalized by this method are characterized by an arithmetic mean equal to zero and a standard deviation equal to unity.

In the next step, the so-called development pattern is determined, i.e., an ‘ideal’ object having the most favourable values of diagnostic variables (i.e., in the case of stimulants—the highest values, while in the case of destimulants—the lowest values).

Then Euclidean distances $d_i$ of particular objects from the so-called development pattern were calculated according to the following formula:

$$d_i = \sqrt{\sum_{j=1}^{k} (z_{ij} - z_{0j})^2},$$

(1)

where:

- $k$—number of diagnostic variables;
- $n$—number of objects (here: countries).

Subsequently, a synthetic measure was constructed, describing the level of use of renewable sources for electricity generation in each of the countries included in the study. The paper uses the following formula aggregating the normalized diagnostic variables:

$$z_i = 1 - \frac{d_i}{d_0},$$

(2)

where:

- $d_0 = \max d_i$.

The above formula is counted among model aggregating functions [48,49]. Formula (2) does not take into account weights, i.e., it assumes equal importance of all diagnostic features that describe the examined complex phenomenon. The synthetic measure takes values in the range [0; 1]. The level of development of renewable sources for electricity generation is the higher, the closer the synthetic measure is to one.

4. Results

The following variables were used to construct a taxonomic measure of development to describe the level of RES use in selected countries:

- $X_1$—share of electricity generation from renewable sources in total electricity generation (in %);
- $X_2$—electricity generation from water energy (in GWh per capita);
- $X_3$—electricity generation from wind energy (in GWh per capita);
- $X_4$—electricity generation from solar energy (in GWh per capita);
- $X_5$—electricity generation from biomass (in GWh per capita).

These variables were selected based on substantive criteria and constitute a set of potential diagnostic variables.

In the next step, formal (statistical) criteria were checked, i.e., potential diagnostic variables were analysed in terms of the degree of differentiation and correlation between particular variables. In order to assess the degree of variables’ diversity, the coefficient of variation ($V_j$) was calculated [13]. In this article, a limit value of coefficient of variation was assumed at the level of 10%. In the case when the condition is met:

$$0 \leq V_j \leq 10\% \ (j = 1, 2, \ldots, p),$$

...
where:

\( p \) — number of potential diagnostic variables.

The variable \( X_j \) is eliminated from the set of diagnostic variables. In this article, all proposed diagnostic variables were found to be sufficiently diverse.

Next, Pearson’s linear correlation coefficients were calculated between each pair of potential diagnostic variables.

Finally, all potential diagnostic variables were used to construct a taxonomic measure of development. The nature of these variables (i.e., the impact on the level of RES use for electricity generation) was then determined. All variables adopted for the study turned out to be stimulants, which means that the higher the values of these variables, the higher the level of development of RES for electricity generation in each country.

In the next step, the values of diagnostic variables were normalised using the standardisation method, and the so-called development pattern was determined, i.e., the object (here: country) with the best values of individual diagnostic variables. Then, the Euclidean distances of individual countries from the development pattern were calculated. The smaller the distance from the development pattern, the higher the level of renewable energy use in a given country.

The last stage consisted of calculating a synthetic measure (the so-called development measure), on the basis of which it is possible to rank the 28 countries surveyed in terms of the level of a composite phenomenon (i.e., the level of RES use for electricity generation). The values of the development indicator are standardised in the interval \([0; 1]\). The closer the value of this measure is to unity, the higher the level of the complex phenomenon (here: the level of development of renewable energy). Figures 1–4 show the values of the development ratio for the studied countries in selected years.

![Figure 1](image1.png)

**Figure 1.** Development taxonomic ratio values (TMR) for the examined countries in 2004. Source: author’s own elaboration.

![Figure 2](image2.png)

**Figure 2.** Development taxonomic ratio values (RMT) for the examined countries in 2009. Source: author’s own elaboration.
Table 1 presents the ranking of the surveyed countries by level of RES use for electricity production for four selected years (in five-year intervals). Table 1 and Figures 1–4 intentionally present the same data in two graphical forms, as they have varying usability for the reader.

Table 1. The ranking of countries by level of RES use for electricity production for four selected years (alphabetical order).

| Country     | Ranking Position in the Year: |
|-------------|------------------------------|
|             | 2004 | 2009 | 2014 | 2019 |
| Austria     | 4    | 2    | 2    | 3    |
| Belgium     | 22   | 14   | 11   | 10   |
| Bulgaria    | 20   | 25   | 23   | 22   |
| Croatia     | 8    | 11   | 13   | 14   |
| Cyprus      | 26   | 27   | 26   | 25   |
| Czechia     | 21   | 21   | 18   | 21   |
| Denmark     | 5    | 7    | 3    | 4    |
| Estonia     | 27   | 20   | 19   | 12   |
| Finland     | 2    | 5    | 4    | 2    |
Table 1. Cont.

| Country   | Ranking Position in the Year: |
|-----------|-------------------------------|
|           | 2004 | 2009 | 2014 | 2019 |
| France    | 17   | 17   | 22   | 20   |
| Germany   | 6    | 4    | 6    | 5    |
| Greece    | 15   | 16   | 12   | 13   |
| Hungary   | 24   | 23   | 27   | 27   |
| Ireland   | 16   | 13   | 16   | 15   |
| Italy     | 13   | 12   | 8    | 9    |
| Latvia    | 9    | 9    | 14   | 18   |
| Lithuania | 23   | 24   | 21   | 19   |
| Luxembourg| 3    | 8    | 9    | 6    |
| Malta     | 28   | 28   | 28   | 26   |
| Netherlands| 12  | 15   | 24   | 17   |
| Poland    | 25   | 26   | 25   | 28   |
| Portugal  | 10   | 6    | 5    | 7    |
| Romania   | 14   | 19   | 15   | 23   |
| Slovakia  | 18   | 18   | 20   | 24   |
| Slovenia  | 11   | 10   | 10   | 16   |
| Spain     | 7    | 3    | 7    | 11   |
| Sweden    | 1    | 1    | 1    | 1    |
| United Kingdom | 19 | 22 | 17 | 8 |

Source: author’s own elaboration.

In each of the years surveyed, Sweden topped the ranking in terms of the level of RES use for electricity generation. Malta was ranked last in 2004, 2009, and 2014, but Poland was ranked last in the last year examined.

A synthetic measure that takes into account both sources of electricity production directly dependent on climate (hydro, solar, and wind) and biocomponents (Table 2 column A) has identified an interesting group of seven countries at the top of the ranking for 2019. Table 2 should be viewed in conjunction with Table 3. When such a measure is reduced by energy production from biocomponents, the same countries appear in the top seven of the ranking, albeit in a different order (Table 2 column B). This shows a good diversification of renewable sources for electricity generation in those countries that (apart from Finland) are in the middle of the ranking in terms of the share of biocomponents in electricity generation from renewable sources. However, in the case of Estonia, the inclusion of biocomponents as a renewable source of electricity generation (the share of 60.6%) has resulted in the country moving up in the 2019 ranking from 25th to 12th place.

The group of countries that both measures present as the best performers in the development of renewable electricity sources includes Sweden, Finland, Austria, Denmark, Germany, Luxembourg, and Portugal. It should be noted that, apart from Portugal, the other six countries in this group are rich countries in northern Europe, and all of them belong to the group of the so-called old EU member states (adopted before 2004). This group includes both net electricity exporting countries (Sweden, Germany) and significant net importers (Finland and especially Luxembourg—Table 2 column C).
### Table 2. Taxonomic measures of development of renewable electricity generation in EU countries and net electricity exports—country rankings for 2019.

| Taxonomic Measures of Development * | C. Net Electricity Exports ** (as % of Electricity Production) |
|-------------------------------------|---------------------------------------------------------------|
| A. Ranking (with Bio)               | B. Ranking (without Bio)                                      |
| 1. O Sweden 0.4645                 | 1. O Sweden 0.4792                                           |
| 2. O Finland 0.3611                | 2. O Austria 0.4641                                          |
| 3. O Austria 0.3880                | 3. N Bulgaria 0.3293                                         |
| 4. O Denmark 0.3058                | 4. O France 0.3025                                           |
| 5. O Germany 0.2784                | 5. O Germany 0.2778                                          |
| 6. O Luxembourg 0.2186             | 6. O Belgium 0.2726                                          |
| 7. O Portugal 0.2030               | 7. N Slovenia 0.2482                                         |
| 8. O United Kingdom 0.1726         | 8. N Cyprus 0.2345                                           |
| 9. O Italy 0.1717                  | 9. O Netherlands 0.2269                                      |
| 10. O Belgium 0.1565               | 10. O Ireland 0.2257                                         |
| 11. O Spain 0.1474                 | 11. O Spain 0.1861                                           |
| 12. N Estonia 0.1312               | 12. N Romania 0.1836                                         |
| 13. O Greece 0.1312                | 13. O Austria 0.1645                                         |
| 14. N Croatia 0.1143               | 14. N Slovenia 0.1610                                        |
| 15. O Ireland 0.1021               | 15. O Portugal 0.1383                                        |
| 16. N Slovenia 0.1013               | 16. N Poland 0.1412                                          |
| 17. O Netherlands 0.1011           | 17. O United Kingdom 0.1393                                  |
| 18. N Latvia 0.0948                 | 18. O Italy 0.1305                                           |
| 19. N Lithuania 0.0899             | 19. N Latvia 0.1290                                          |
| 20. O France 0.0845                | 20. O Denmark 0.0852                                         |
| 21. N Czechia 0.0709                | 21. O Greece 0.0791                                          |
| 22. N Bulgaria 0.0688               | 22. N Estonia 0.0655                                         |
| 23. N Romania 0.0657                | 23. O Finland 0.0599                                         |
| 24. N Slovakia 0.0575               | 24. N Malta 0.0573                                           |
| 25. N Cyprus 0.0225                 | 25. N Hungary 0.0352                                         |
| 26. N Malta 0.0205                  | 26. N Croatia 0.0293                                         |
| 27. N Hungary 0.0143                | 27. N Lithuania 0.0168                                       |
| 28. N Poland 0.0000                 | 28. O Luxembourg 0.0000                                      |

Source: own elaboration based on Eurostat data. O = old EU countries (pre-2004). N = new EU countries (2004 and later). * Taxonomic measures of development of electricity generation from renewable sources: A.—solar, wind, hydro, and bio; B.—solar, wind, hydro only. ** C.—net electricity exports—as the difference between the percentage ratio of electricity exports to total generation (GWh) and the percentage ratio of electricity imports to total generation (GWh) regardless of source.

At the same time, in the case of both versions of the measure, the penultimate and last place goes to Hungary and Poland, respectively.

When interpreting the results, it has to be remembered that the sizes of electricity production (in GWh) from different renewable sources included in the synthetic measures were calculated per capita, and nominal production volumes are not used here. As a result, the construction of the measure does not directly reflect the size of the population and the size of the economic potential of the countries studied.

Interestingly, five countries out of the seven identified by the synthetic measure are also among the top seven EU countries for 2019 in terms of the percentage of renewable electricity production in total electricity production (Luxembourg, Denmark, Austria, Sweden, and Portugal—Table 3 column A) and in terms of the percentage ratio of renewable electricity production to final consumption (Austria, Sweden, Denmark, Portugal, and Germany—Table 3 column B).

It is characteristic that the last places in the ranking according to synthetic measures (Table 2 column A and column B) are occupied by a compact group of the so-called new Member States (admitted to the EU in 2004 and later). The countries, whose capacity utilisation of electricity generation from renewable energy sources is considered the weakest by the synthetic measures, besides the already mentioned Hungary and Poland, are also the Czech Republic, Cyprus, Malta, Romania, Bulgaria, and Lithuania.
Table 3. Share of renewable sources in electricity production and consumption and total energy consumption (in %) in European Union countries—country rankings for 2019.

| Share of Renewable Sources (in %) | A. Electricity Production * | B. Electricity Consumption ** | C. Energy Consumption *** |
|-----------------------------------|-----------------------------|-------------------------------|--------------------------|
| 1. O Luxembourg                    | 85.9                        | 1. O Austria                  | 87.5                     |
| 2. N Lithuania                    | 81.9                        | 2. O Sweden                   | 77.7                     |
| 3. O Denmark                      | 78.2                        | 3. O Denmark                  | 71.2                     |
| 4. O Austria                      | 77.8                        | 4. O Portugal                 | 59.1                     |
| 5. N Croatia                      | 66.2                        | 5. N Croatia                  | 51.0                     |
| 6. O Sweden                       | 58.7                        | 6. N Romania                  | 50.5                     |
| 7. O Portugal                     | 54.2                        | 7. O Germany                  | 48.6                     |
| 8. N Latvia                       | 49.6                        | 8. N Latvia                   | 48.0                     |
| 9. O Finland                      | 46.6                        | 9. O Spain                    | 42.6                     |
| 10. N Romania                     | 42.0                        | 10. O Ireland                 | 42.1                     |
| 11. O Germany                     | 40.9                        | 11. O United Kingdom          | 40.5                     |
| 12. O Italy                       | 40.1                        | 12. O Italy                   | 39.0                     |
| 13. O Ireland                     | 38.9                        | 13. O Finland                 | 38.4                     |
| 14. O United Kingdom              | 37.8                        | 14. O Slovenia                | 38.1                     |
| 15. O Spain                       | 37.8                        | 15. O Greece                  | 31.2                     |
| 16. O Greece                      | 33.2                        | 16. N Estonia                 | 27.5                     |
| 17. N Slovenia                    | 32.6                        | 17. N Lithuania               | 26.9                     |
| 18. N Estonia                     | 28.1                        | 18. O France                  | 26.7                     |
| 19. N Slovakia                    | 24.2                        | 19. N Slovakia                | 26.4                     |
| 20. O Belgium                     | 21.9                        | 20. O Luxembourg              | 25.6                     |
| 21. O France                      | 20.7                        | 21. N Bulgaria                | 25.2                     |
| 22. O Netherlands                 | 18.9                        | 22. O Belgium                 | 24.4                     |
| 23. N Bulgaria                    | 18.0                        | 23. O Netherlands             | 19.7                     |
| 24. N Poland                      | 16.0                        | 24. N Czechia                 | 18.7                     |
| 25. N Hungary                     | 13.8                        | 25. N Poland                  | 17.2                     |
| 26. N Czechia                     | 12.9                        | 26. N Hungary                 | 11.3                     |
| 27. N Malta                       | 10.5                        | 27. N Cyprus                  | 10.9                     |
| 28. N Cyprus                      | 10.0                        | 28. N Malta                   | 8.7                      |

Source: own elaboration based on Eurostat data. O = old EU countries (pre-2004). N = new EU countries (2004 and onwards). * A.—Percentage share of renewable sources in electricity generation (GWh). ** B.—Percentage share of renewable sources in electricity consumption (GWh). *** C.—Percentage share of renewable sources in total energy consumption (GWh).

This dichotomy of ‘old versus new EU Member States’ is more strongly accentuated by the synthetic measures than is apparent from the percentage share of renewable electricity generation in total electricity generation (Table 3 column A) or in final consumption (Table 3 column B) in the countries under study.

The thesis on the influence of the wealth of the surveyed countries on their current development of the use of renewable energy sources for electricity production will be verified later in this article by means of a panel model.

Of note is the low ranking of France (the 16th and 20th position for 2019) and the Netherlands (the 17th and 17th position for 2019) according to both synthetic measures (Table 2 column A and column B).

An important issue is the growing number of EU countries dependent on electricity imports. In 2004, it was 13 countries, in 2009, already 16 countries, in 2014, the number increased to 17 countries, and in 2019, it was as high as 20 countries. This means that seven countries have lost their energy independence in this way. The calculation uses the difference between the percentage ratio of electricity exports to total electricity production and the percentage ratio of electricity imports to total electricity generation in individual countries (Table 2 column C).

Interestingly, the Czech Republic and Bulgaria, which are ranked low in synthetic measures, reflecting the possibility of using renewable energy sources to produce electricity, are also countries that have a positive balance of electricity exports and imports, i.e., produce more electricity than they need domestically. This indicates the generation of surplus electricity for export through intensive production of electricity from non-renewable sources.
In the following section of this article, a panel model defined by formula (3) is used to describe the relationship between the share of RES power generation in total power generation and per capita power generation from water, wind, solar, and biomass energy in all EU countries. Data were collected for all 28 EU countries and cover the 2004–2019 period. The source of data was the Eurostat database.

The theoretical model can be written as follows:

\[ Y_{jt} = \alpha_0 + \alpha_1 X_{1jt} + \alpha_2 X_{2jt} + v_{jt} \] (3)

\[ v_{jt} = \epsilon_t + u_j + \epsilon_{jt}, \] (4)

Table 4 presents a description of the individual variables.

| Variables       | Description                                                      |
|-----------------|------------------------------------------------------------------|
| \( Y_{1jt} \)   | Share of electricity production from RES in total electricity production (in %) |
| \( Y_{2jt} \)   | Electricity production from water per capita (in GWh)             |
| \( Y_{3jt} \)   | Electricity production from wind per capita (in GWh)              |
| \( Y_{4jt} \)   | Electricity production from solar per capita (in GWh)             |
| \( Y_{5jt} \)   | Electricity production from biogas per capita (in GWh)            |

| Explanatory Variables | Description                                                                 |
|-----------------------|-----------------------------------------------------------------------------|
| \( X_{1jt} \)         | GDP per capita                                                               |
| \( X_{2jt} \)         | Public spending by countries on energy as a percentage of GDP                |

The random error in the object \( j \), in the time period \( t \), which consists of the following components:

- \( \epsilon_t \) —impulses affecting all observations in the time period \( t \);
- \( u_j \) —impulses affecting all the observations in the object \( j \);
- \( \epsilon_{jt} \) —impulses affecting only observations in the object \( j \), in the time period \( t \).

Source: elaborated by the authors.

The level of GDP per capita was used as a potential factor influencing the level of electricity production from renewable sources, assuming that richer countries with a higher level of development care more about the environment than poorer ones and, thus, invest in renewable energy sources. There is no measure of a country’s wealth that is not questioned. The Stiglitz commission’s report to then-French President Nicolas Sarkozy is an example of an extensive discussion on the subject. Alternative measures such as ISEW or HDI use GDP or its derivatives (GNI) in their construction. However, perhaps had there been more awareness of the limitations of standard metrics, such as GDP, there would have been less euphoria over economic performance in the years prior to the crisis; metrics that incorporated assessments of sustainability (e.g., increasing indebtedness) would have provided a more cautious view of economic performance. However, many countries lack a timely and complete set of wealth accounts—the ‘balance sheets’ of the economy—that could give a comprehensive picture of assets, debts, and liabilities of the main actors in the economy [51].

Panel data models (1) were estimated using the GRETL software (GNU Regression Econometrics Time-Series Library). In turn, for the estimation of panel data models, the following were used:

- Classic least squares method (KMNK) estimator;
- Fixed effect (FE) estimator;
- Random effect (RE) estimator.

The KMNK estimator is used when all objects covered by the study are homogeneous, and the differences between the empirical and theoretical values of the explained variable \( Y \) result only from the random component [52].
The FE and RE estimators are used in the case of sample heterogeneity. Individual effects are the source of sample non-homogeneity. The FE estimator assumes that the individual effects are non-random and can be estimated. In the case of the RE estimator, it is assumed that the individual effects are random and that they are part of the random component. In this case, it is not possible to estimate the value of individual effects; it is only possible to estimate their dispersion [52].

When selecting the type of panel model (simple model, i.e., without individual-dual effects or models with unidirectional individual effects, i.e., FEM—fixed effect model or REM—random effect model) the following tests are used: Wald test, Breusch–Pagan test, and Hausman test. The aforementioned tests allow to assess the correctness of the estimated model. These tests are discussed in many studies in the field of econometrics [53–55]. The choice of the estimation method was based on the decision procedure presented in the econometrics literature [52–57]. First, a simple panel model (without individual effects) was estimated using the classical least squares method, and diagnostic tests of the model were conducted.

Table 5 presents the results of Wald, Breusch–Pagan, and Hausman tests, based on which a decision is made on the choice of an appropriate model. These tests allow for the verification of the assumptions about the correctness of panel model estimation.

| Test                      | Hypotheses                                                                 | Model   | Test Statistics | \( p \) Value | Decision *               |
|---------------------------|----------------------------------------------------------------------------|---------|-----------------|---------------|-------------------------|
| The Wald’s test           | **H1:** the homogeneous model constant terms, independent of the item and time (OLS estimator) | Y₁     | \( F₁ = 85.3686 \) | \( p ≈ 0.00 \) | Rejection of H₁         |
|                           | **H2:** the heterogeneous terms for individual items, but constant over time (FE estimator) | Y₂     | \( F₂ = 777.714 \) | \( p ≈ 0.00 \) | Rejection of H₁         |
|                           | **H3:** the variance of the random component of individual effects insignificantly differs from zero (OLS estimator) | Y₃     | \( F₃ = 52.1408 \) | \( p ≈ 0.00 \) | Rejection of H₁         |
|                           | **H4:** the variance of the random component of individual effects significantly differs from zero (RE estimator) | Y₄     | \( F₄ = 14.4418 \) | \( p ≈ 0.00 \) | Rejection of H₁         |
|                           | **H₅:** the variance of the random component of individual effects insignificantly differs from zero (RE estimator) | Y₅     | \( F₅ = 258.451 \) | \( p ≈ 0.00 \) | Rejection of H₁         |
| The Breusch–Pagan’s test  | **H₆:** the variance of the random component of individual effects insignificantly differs from zero (OLS estimator) | Y₁     | \( \chi^2₁ = 24.5178 \) | \( p ≈ 0.00 \) | Rejection of H₃         |
|                           | **H₇:** the variance of the random component of individual effects insignificantly differs from zero (RE estimator) | Y₂     | \( \chi^2₂ = 2.83383 \) | \( p ≈ 0.24246 \) | No grounds for rejection of H₅ |
|                           | **H₈:** the variance of the random component of individual effects insignificantly differs from zero (RE estimator) | Y₃     | \( \chi^2₃ = 35.5537 \) | \( p ≈ 0.00 \) | Rejection of H₅         |
|                           | **H₉:** the variance of the random component of individual effects insignificantly differs from zero (RE estimator) | Y₄     | \( \chi^2₄ = 39.4448 \) | \( p ≈ 0.00 \) | Rejection of H₅         |
|                           | **H₁₀:** the variance of the random component of individual effects insignificantly differs from zero (RE estimator) | Y₅     | \( \chi^2₅ = 2.96674 \) | \( p ≈ 0.22687 \) | No grounds for rejection of H₅ |

* The adopted level of significance is 0.05 (i.e., \( \alpha = 0.05 \)). Source: author’s own calculation.

Analysing the results of the Wald test, it can be stated that a fixed effects model (FEM) is the correct model in all cases for describing the relation of the share of RES production in total electricity production and of production from water, wind, solar, and biomass and GDP per capita and government expenditure on energy per capita.

The results of the Breusch–Pagan test in each case indicate the random effects model (REM) as the better model. Finally, the results of the Hausman test allow for the conclusion, with the risk of error at the level of 5% (\( \alpha = 0.05 \)), that in the case of power generation from water energy and biogas energy per capita, the model with random individual effects is appropriate for describing the examined relationship, while in the remaining cases, the model with fixed individual effects (FEM). However, further analysis confirmed the occurrence of heteroskedasticity of the random component in the models \( Y₁, Y₃, \) and \( Y₄ \). To address this shortcoming, the weighted least squares (WLS) method was used to estimate the parameters of share of electricity production from RES in a total electricity production model, electricity production from wind per capita, and electricity production from solar per capita. In other cases—electricity production from water per capita and electricity production from biogas per capita—the random effects models were estimated.

Table 6 presents the estimation results of the above models.
Table 6. Results of model estimation.

**Dependent Variable Y₁, Share of Electricity Production from RES in Total Electricity Production (%) (WLS)**

| Independent variables | Coefficient | St. Error | t-ratio | p-value | Significance |
|-----------------------|-------------|-----------|---------|---------|--------------|
| Constant              | 10.6331     | 1.18383   | 8.982   | <0.0001 | ***          |
| X₁jt                  | 0.000386    | 0.0000042 | 11.58   | <0.0001 | ***          |
| X₂jt                  | 10.7911     | 0.177197  | 6.090   | <0.0001 | ***          |

Observations 448
Standard error residuals 0.977433
R² 0.265472
F(2, 445) = 80.41575
p-value for test F < 0.0001

**Dependent Variable Y₂, Electricity Production from Water per Capita (in GWh) (Model REM)**

| Independent variables | Coefficient | St. Error | t-ratio | p-value | Significance |
|-----------------------|-------------|-----------|---------|---------|--------------|
| Constant              | 0.00103611  | 0.000302482 | 3.425  | 0.0006 | ***          |
| X₁jt                  | −0.00000000001099 | 0.00000000243479 | −0.004512 | 0.9964 | *            |
| X₂jt                  | 0.0000931543 | 0.0000502918  | 1.852  | 0.0640 | *            |

Observations 448
Standard error residuals 0.001577

**Dependent Variable Y₃, Electricity Production from Wind per Capita (in GWh) (WLS)**

| Independent variables | Coefficient | St. Error | t-ratio | p-value | Significance |
|-----------------------|-------------|-----------|---------|---------|--------------|
| Constant              | 0.00001506  | 0.0000166  | 0.9074  | 0.3647 |              |
| X₁jt                  | 0.00000001029 | 0.00000000079  | 12.95  | <0.0001 | ***          |
| X₂jt                  | −0.0000147311 | 0.0000212765  | −0.6924 | 0.4891 |              |

Observations 448
Standard error residuals 0.942170
R² 0.279467
F(2, 445) =86.29923
p-value for test F <0.00001

**Dependent Variable Y₄, Electricity Production from Solar per Capita (in GWh) (WLS)**

| Independent variables | Coefficient | St. Error | t-ratio | p-value | Significance |
|-----------------------|-------------|-----------|---------|---------|--------------|
| Constant              | −0.0000115383 | 0.00000506263  | −2.279 | 0.0231 | **           |
| X₁jt                  | 0.00000001475 | 0.00000000176  | 8.373  | <0.0001 | ***          |
| X₂jt                  | 0.0000103074  | 0.00000962641  | 10.71  | <0.0001 | ***          |

Observations 448
Standard error residuals 0.947601
R² 0.272744
F(2, 445) =83.44460
p-value for test F <0.00001

**Dependent Variable Y₅, Electricity Production from Biogas per Capita (in GWh) (Model REM)**

| Independent variables | Coefficient | St. Error | t-ratio | p-value | Significance |
|-----------------------|-------------|-----------|---------|---------|--------------|
| Constant              | −0.0000707669 | 0.0000780464  | −0.9067 | 0.3646 |              |
| X₁jt                  | 0.00000011876 | 0.000000104695  | 11.34  | <0.0001 | ***          |
| X₂jt                  | 0.0000169734  | 0.0000220063  | 7.713  | <0.0001 | ***          |

Observations 448
Standard error residuals 0.000399

Source: author’s own calculation. * *** The statistically significant variable at the level of 1%; ** at the level of 5%; * at the level of 10%.

In the case of the model describing the share of RES energy generation in total energy generation, the model describing solar power production per capita and the model describing biogas power production per capita, both potential explanatory variables proved to be statistically significant. In the case of the model describing electricity production
from wind, only GDP per capita was statistically significant. In the case of the model describing electricity production from water, only public spending by countries on energy as a percentage of GDP was statistically significant at the 0.1 significance level. This proves large public expenditure on the development of solar electricity production in EU countries, which is significantly greater than for other RES sources.

At the same time, it confirms the significance of economic potential and wealth of countries for better use of RES for electricity generation, which was initially indicated by the analysis of country rankings according to the taxonomic measure of development.

The results obtained allow us to state that in the case of the model describing the share of electricity generation from RES in total electricity generation, two explanatory variables, i.e., GDP per capita and public expenditure on energy as percent of GDP, positively influence the explained variable (i.e., the share of renewable energy generation in total energy generation). The evaluation of the parameter with the independent variable $X_{1j}$ (0.000486) should be interpreted as follows: if GDP per capita increases by one percentage point, the share of electricity generation from RES in total electricity generation will increase on this account by about 0.000486 on average, assuming constancy of the other variables. The interpretation of the evaluation of the parameter with the explanatory variable $X_{2j}$ (10.7911) should be as follows: if public expenditure on energy per capita increases by 1 percent point, then the share of renewable energy production in total energy production will increase for this reason by approximately 10.7911 on average, under the assumption of constancy of the other variables.

5. Conclusions

The use of renewable energy sources is an important element in the functioning of the global economy due to its impact on environmental pollution. Minimising climate change and reducing CO$_2$ emissions is of interest to society, energy producers, government authorities, and many non-governmental organisations. Despite the great diversity in the involvement of selected countries (included in the study) in the production of electricity from water, sun, wind, and biomass energy, it should be noted that an important element is the development of social awareness and support for the actions of the governments in individual countries to make greater use of these energy carriers, which will allow for the slowdown of climate change and care for ecology.

The challenge for individual countries is to support them in their joint activities related to the use of new technologies to protect the environment. Studies have shown that there is still a lot to be done in the field of implementation, support, and use of RES.

The analyses carried out by the authors confirmed the hypothesis that the level of RES use for electricity production in the European Union countries depends on the level of development of these countries, measured by GDP per capita.

The presented synthetic measures confirmed the more favourable situation of the rich northern EU countries in the production of electricity from renewable sources (solar, wind, hydro, and bio), at the same time highlighting problems with the greening of electricity production in a large group of the new EU member states.

The panel analysis also showed a positive impact of GDP per capita on the use of RES for electricity production. Only the production of electricity from water (hydro) is not affected by the level of GDP per capita. It is the only renewable source of energy more strongly influenced by natural conditions (geological, hydrological) than economic ones.

The study also shows an increase in the number of countries in the studied period 2004–2019 that have a negative balance of electricity exports and imports, i.e., a lack of self-sufficiency in the country’s electricity supply. It follows from the data analysed that there is no direct relationship between energy self-sufficiency and various measures of the use of renewable sources for electricity generation.
Limitations of the Study

The analyses carried out do not take into account the volumes of electricity generation from different sources in the countries studied, and thus, weights reflecting the variation in energy production potential between the countries studied as a derivative of differences in economic potential and wealth were not used. The latter two issues are taken into account in the panel study part of the article; however, the data on electricity production are calculated on a per capita basis. Further research is needed to find a model that would allow for extending the analysis to include aspects of differences in the volume of electricity generation potential between EU countries, which would provide a better background for considering the structure of sources used for electricity generation.

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