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Development of Wind Energy in EU Countries as an Alternative Resource to Fossil Fuels in the Years 2016–2022

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Abstract: The aim of this article is to present solutions related to wind energy in EU countries as an alternative to fossil fuels. This article is based on secondary information and statistical data regarding the development of wind power engineering in EU countries for the years 2016–2022. The main purpose of this paper is to analyze of the relations between the development of wind energy in European Union countries and GPD (gross domestic product) per capita and selected factors. The following hypotheses were formulated: H1—There is a statistically significant correlation between GDP per capita and the use of wind energy in European Union countries. H2—There is a relationship between the length of the coastline and the use of wind energy in European Union countries. H3—There is a statistically significant correlation between the attitude to uncertainty of the inhabitants of a given country and the use of wind energy in said country. The presented research results support all these hypotheses. The results of the research regarding H2 are as follows: in the case of northern European countries (Ireland and Finland) and the Iberian Peninsula (Spain and Portugal), the development of wind power engineering in the study period was faster than could be inferred from the length of the coastline in these countries. Regarding hypothesis H1, it was concluded on the basis of the analysis that the involvement of countries in the development of wind power engineering is correlated with their wealth. The novelty of this paper emerges from its innovative approach to analyzing wind power engineering, its incorporation of cultural factors, its quantitative assessment of correlations, and its actionable policy recommendations. These elements collectively contribute to a comprehensive and impactful study that advances our understanding of wind energy adoption in the European Union.

Keywords: wind energy; wind resources; energy transformation; EU countries; innovation

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Citation: Wolniak, R.; Skotnicka-Zasadzień, B. Development of Wind Energy in EU Countries as an Alternative Resource to Fossil Fuels in the Years 2016–2022. *Resources* **2023**, *12*, 96. https://doi.org/10.3390/resources12080096

Academic Editor: Elena Rada

Received: 13 July 2023
Revised: 7 August 2023
Accepted: 9 August 2023
Published: 17 August 2023

1. Introduction

Energy security in EU (European Union) countries has recently become a priority, especially after the outbreak of the war in Ukraine [1]. In addition to the EU becoming independent from oil and gas from Russia, another important factor influencing the development of alternative renewable energy sources is the increasingly visible climate change in the world and in Europe [2]. One of the key actions that EU countries should undertake is the transition to a low-emission economy and the associated use of various renewable energy systems and placing these energy sources wherever the production of clean energy does not significantly change the landscape and society [3]. Renewable energy sources offer significant advantages over fossil fuels, as they are abundant, sustainable, and produce little-to-no greenhouse gas emissions during operation [4]. By harnessing these clean and renewable sources, EU countries can substantially reduce their reliance on fossil fuels, thereby decreasing their carbon footprint, contributing to global efforts to limit global warming, and mitigating climate change impacts [5]. The strategic placement of renewable energy systems is a critical consideration in the transition to a low-emission economy. By locating these energy sources where they do not significantly alter the landscape or disrupt communities, the social acceptability and environmental sustainability of such projects are enhanced [6].

The societies of individual countries that are observing increasingly unfavorable weather phenomena related to the production of energy from fossil fuels have become very much involved in the development of innovative clean technology solutions [7]. Unfavorable weather phenomena, such as heatwaves, droughts, floods, hurricanes, and wildfires, have become more frequent and severe due to climate change driven by greenhouse gas emissions from burning fossil fuels [8]. These extreme events have devastating effects on communities, ecosystems, and economies. As a result, there is a growing recognition among EU societies that relying heavily on fossil fuels is unsustainable and poses significant risks to their wellbeing and prosperity [9]. All social strata of a given country participate in the energy transformation conducted in this way [10]. Achieving a successful energy transition involves not only the active involvement of governments and businesses but also the engagement of citizens, communities, and civil society as a whole [11]. This inclusive approach is crucial for driving the adoption of renewable energy and ensuring its sustainable development [12].

In recent years, very intensive work on the use of renewable energy sources (RESs) has been observed in European Union countries [11,13]. By involving all social strata in the energy transformation, EU countries can harness the collective efforts and ideas of their citizens, businesses, and communities to accelerate the adoption of renewable energy technologies and achieve their renewable energy targets [14]. This comprehensive approach ensures a more balanced and resilient energy system while fostering a sense of shared responsibility and ownership among all stakeholders in shaping a greener future [15,16]. Thanks to these works, the share of renewable energy sources in energy production in the EU in 2017 reached 29.9% [17,18]. Wind energy and its solutions are of great importance among renewable energy sources in the EU [19]. In 2018, wind energy achieved the largest share among renewable energy sources in the EU for the first time. In EU countries, the amount of electricity produced by wind turbines reached 362.4 TWh [20–22], which was a 37.2% increase in relation to 2007. In 2018, the total capacity of wind farms accounted for 24% of the total installed capacity of all RES installations [23]. In EU countries, the best conditions for the development of wind energy are in the North Sea and the Baltic Sea and off the Atlantic coast [24]. Apart from changeable wind conditions, the development of wind power engineering is also influenced by the internal conditions of a given country. Wind farms in the EU are installed both on land and at sea [25,26]. The number of offshore wind farms depends on the length of the coastline in a given country. According to the analysis conducted in this study, wind farms in the EU are located primarily on land. Offshore wind farms account for merely 4.1% of the total capacity produced by installations using wind energy [27]. Historically, onshore wind farms have been more cost-effective to develop and operate compared to their offshore counterparts [28]. The initial investment for offshore wind projects can be significantly higher due to the complexities of constructing and maintaining turbines in marine environments [29]. The development of onshore wind farms began earlier and gained traction in many EU countries before offshore wind technology was widely deployed [29]. As a result, onshore wind farms have had a head start and established a stronger presence in the energy landscape [30]. In 2021, the largest share of wind power in the European Union was generated by Denmark (44%), followed by Portugal (26%), Spain (24%), and Germany (23%). Countries where these values ranged from 20% to 10% include Sweden (19%), Greece (18%), the Netherlands (15%), Belgium (13%), Croatia, Austria and Romania (11%), and Lithuania (10%). Less than 10% generation from wind power was generated in countries such as Estonia (9%), Poland (9%), France (8%), Italy (7%), Bulgaria (4%), Latvia (2%), Hungary (1%), the Czech Republic (1%), and Slovakia (0.04%) [30–33].

This paper is related to resources in the context of exploring wind energy as an alternative resource to fossil fuels. It focuses on the development of wind power engineering in EU countries and investigates the use of wind resources as a renewable energy source.

This study also explores the solutions and technological advancements in the field of wind power engineering, highlighting the role of wind resources in generating clean energy. It discusses the conditions for wind energy development, including the length of coastlines and favorable wind conditions in specific regions, which are considered valuable resources for harnessing wind energy. This paper establishes the relevance of wind resources as an alternative to fossil fuels and investigates their utilization in EU countries, contributing to the understanding of wind energy as an innovative resource in the context of sustainable energy development.

The growing importance of wind power engineering in EU countries and solutions related to the use of wind energy provided inspiration for the research presented in this article. The choice of the topic was also influenced by the different conditions for the development of wind power engineering in individual EU countries. Social and economic factors influencing the development of wind power engineering were also taken into account in the conducted research.

The aim of the conducted research was to answer the following research questions:

1. How did the level of wind energy use in European Union countries change in 2016–2022?
2. Which EU countries are the most advanced in the use of wind energy?
3. Does the cultural orientation—the attitude to uncertainty—affect the use of wind energy in European Union countries?
4. Does the level of GDP (gross domestic product) per capita influence the use of wind energy in European Union countries?
5. Does the length of the coastline have an impact on the use of wind energy in European Union countries?

Three hypotheses were put forward in the research: H1: There is a statistically significant correlation between GDP per capita and the use of wind energy in European Union countries. H2: There is a correlation between the length of the coastline and the use of wind energy in European Union countries. H3: There is a statistically significant correlation between the attitude to uncertainty of the inhabitants of a given country and the use of wind energy in the countries of the European Union.

This article is divided into a theoretical part and a research part. The theoretical part is devoted to a review of the subject literature regarding the development of wind power engineering in EU countries as one of the main factors of renewable energy development. The research part presents the methods used, the research analysis, and a discussion.

2. Review of the Subject Literature Regarding Solutions Related to Wind Energy

In the last fifteen years, many legal acts regarding the promotion of renewable energy sources have been introduced in the EU [34,35]. In 2009, the EU leaders set targets, according to which by 2020 approximately 20% of the energy consumed in the European Union should come from renewable sources [36]. This directive obligated all the EU countries to reach a level of a 10% share of fuels from renewable sources in the transport sector. Based on this directive, all the EU countries defined how they intended to achieve individual targets and presented action plans regarding the policy of using energy from renewable sources. Every two years, each EU country is required to submit a report on progress in this area on the basis of relevant indicators [37].

In July 2021, in the European Green Deal package, the Commission presented the Renewable Energy Directive, aiming to increase renewable energy sources to 40% by 2023 [38,39]. In May 2022, after the Russian invasion of Ukraine, the European Commission decided to accelerate the transition to clean energy and reduce dependence on Russian oil (RED III) (RED—Renewable Energy Directive) as part of the REPowerEU plan. On 9 November 2022, it was decided that power plants using renewable energy sources would be considered an overriding public objective (RED IV) [40]. This decision represents a significant step forward in the European Union's commitment to advancing renewable energy and combating climate change [41]. The RED IV directive builds upon the existing

Renewable Energy Directive (RED) framework, which was first introduced in 2009 to set binding targets for renewable energy use across the EU member states [42]. The primary objective of RED IV is to further accelerate the transition towards a low-carbon and sustainable energy system by promoting the development and integration of renewable energy sources into the region's energy mix [43].

RED IV is expected to set even more ambitious targets for the share of renewable energy in the EU's overall energy consumption [44]. The directive is likely to call for higher percentages of renewable energy use by a specific timeline, encouraging member states to accelerate their renewable energy investments and deployments [45].

In July 2021, the European Commission published a legislative package entitled "Fit for 55: delivering the EU's 2030 climate target on the way to climate neutrality" [37]. The main targets included an increase in the use of renewable energy in buildings to 49% by 2023, a new benchmark of a 1.1 percentage point increase in the use of renewable energy in industry, an annual increase of 1.1 percentage points in the use of renewable energy sources for heating and cooling purposes in the member states, and an indicative annual increase of 2.1 percentage points in the use of renewable energy sources and waste-based heating and cooling processes [44,46]. After the EU decided to increase the use of renewable energy sources in individual EU countries, in September 2020, the European Commission established a mechanism for financing energy from renewable sources [47] based on Art. 33 of the Regulation [37] in the "Clean energy for all Europeans" package. This mechanism is still being implemented in EU countries [47]. Its main goal is to help the countries meet their individual and collective renewable energy targets. The energy generated owing to this financing mechanism will be included in the renewable energy targets of all the countries striving to achieve carbon neutrality by 2050 [42,48]. As part of the REPowerEU plan, the European Commission made important assumptions regarding the resources of individual types of renewable energy. The plan assumes that by 2025, the capacity of photovoltaic systems will have doubled to reach 320 GW, and by 2030, systems with a capacity of 600 GW will have been installed [40,49]. Regarding biomass and biofuels, the EU directive [50] assumes that by 2030, the share of advanced biofuels and biogas in the transport sector will have increased to 3.5% [49]. In the last three years, a very large development in wind power engineering, especially with regards to onshore wind energy, has been observed throughout Europe, including in the EU. In 2022, the most energy in the entire European Union was generated by wind and photovoltaic power plants. It is worth noting that for the first time in history, renewable energy sources outnumbered other power generation technologies [51,52]. Since 2020, the amount of wind energy in the European Union has been systematically increased in relation to the total amount of renewable energy produced in the EU. The European Parliament has been developing strategies and directives that assume an increase in the production of energy from wind farms [44]. Recognizing the urgent need to transition to renewable energy sources and combat climate change, the European Parliament has played a pivotal role in shaping the EU's energy policies and setting ambitious targets for the expansion of wind energy [53]. The European Parliament has consistently pushed for more ambitious renewable energy targets to be set at the EU level. These targets have provided a clear roadmap for member states to increase their share of renewable energy in their energy mix and have been a driving force behind the expansion of wind energy projects [54].

In November 2020, the Commission published a special EU strategy regarding offshore renewable energy [45]. According to this strategy, the production of electricity from offshore renewable sources is to reach 60 GW (gigawatts) by 2030 and 300 GW by 2050. In February 2022, the European Parliament adopted a resolution (2021/2012(INI)) (INI—own-initiative procedure) on the strategy for wind energy, which assumes that wind energy generation should range from 70 to 79 GW [55]. According to the report "Wind Energy in Europe: 2021 Statistics and the outlook for 2022–2026", onshore wind energy installations in EU countries generated 14 GW, whereas offshore installations generated merely 3.4 GW. This report assumes that in the years 2022–2026, 27 EU countries will build new wind farms with a capacity of ca. 18 GW. To achieve such a result, individual countries must provide 32 GW per year, which will result in a 40% share of wind energy in electricity generated by renewable sources in the EU. The increase in renewable energy resources is related to the economic efficiency of individual renewable energy generation technologies [56]. The economic efficiency of individual technologies in the EU countries has been specified in the document of the European Commission “Energy sources, production costs and operation of electricity generation technologies, heat production and transport” [57] as an attachment entitled “Second Strategic Energy Review”. This document compares the costs and efficiency of different technologies used to produce energy from renewable sources. The following parameters were taken into account: capital expenditure, operating costs, and the total cost of energy production [58].

Onshore wind energy is the cheapest form of electricity generated from renewable energy sources. The investment costs in this case range from EUR 1000 to EUR 1370/kW, whereas electricity from offshore farms is more expensive, reaching EUR 1750 to EUR 2750/kW. Wind energy is also unrivalled when it comes to operating costs, which for onshore farms amount to EUR 33–42/kW, and in the case of offshore farms, costs range from EUR 71 to EUR 105/kW. Also, production costs are lower, reaching €50–93/kW [59]. Based on the above-presented information, the European Commission has concluded that the costs of producing wind power, especially onshore energy, in the years to come will be the lowest of all electricity generation technologies [60]. The wind power sector has witnessed remarkable technological advancements and innovations over the years. Improved turbine designs, enhanced manufacturing processes, and better materials have led to increased efficiency and reduced production costs. As technology continues to evolve, the efficiency and performance of wind turbines are expected to improve further, driving down the overall cost of wind energy production [61].

The development of wind power engineering must comply with the principle of sustainable socio-economic development, taking into account an increase in the quality of life and natural environment improvements [2]. It is important that solutions related to the production of wind energy should have a positive impact on the natural environment and should reduce greenhouse gas emissions into the atmosphere [62]. The development of wind power engineering and its technologies results in a significant reduction in so-called environmental costs, i.e., the costs involved in the production of energy using conventional power generation technologies [63]. The advantages of wind energy also include the fact that wind is a source of renewable energy that will never run out. Another benefit is the partial independence from electricity suppliers, especially in places where power outages occur [64]. Wind energy also can be produced not only on wind farms—there are modern innovative wind turbines that can be installed on the roofs of residential houses, office buildings, and production halls. An innovative solution that is currently gaining popularity is placing wind turbines in the structures of bridge carriers and in movable boards or advertising billboards [52].

Wind power engineering as a source of energy encounters many obstacles related to the implementation of new solutions, which makes the development of this cost-effective technology difficult [65].

Barriers related to the development of wind power engineering that are mentioned in the subject literature can be divided into the following groups: legal and financial barriers, educational barriers, and technical and ecological barriers [66].

In the European Union, there are no regulations applying to visual and noise encumbrance related to wind farm operations, whereas individual countries have legal instruments that allow citizens and NGOs (non-governmental organizations) to block the establishment of wind farms and the installation of wind turbines. The legal instruments that can be used to block the development of wind power engineering include the environmental impact assessment procedure. The process of assessing the environmental impact is usually time-consuming as it must be conducted whilst consulting with the local community. Moreover, it may generate economic losses for the investor in the event that permission to build a new turbine is not granted. In accordance with legal requirements in the EU [67], investors of large wind farms are forced to follow the environmental impact assessment strategy. In addition to legal and economic barriers, large wind farm investors frequently encounter social resistance, i.e., reluctance or fear of local residents. Sometimes, despite the conducted and positively completed environmental impact assessment procedure, wind farms are not built due to the strong opposition from residents and non-governmental organizations [68]. An example of this could be the construction of a wind energy test center in north-western Jutland, which was to consist of five to seven wind turbines located on land [51]. The opposition of non-governmental organizations and the local community was so great that the investment was not completed. Another barrier hindering the development of wind farms and the introduction of new innovative solutions is the lack of legal regulations regarding protected areas of cultural heritage as well as the resistance of ecologists [67]. The EU is introducing many amendments that regulate these issues. Any legal changes deriving from community law must be applied in accordance with the provisions of the legislation of the country concerned. Currently, the EU is working on procedures regulating, among others, issues related to cultural heritage, protected areas, and local spatial development plans. All these regulations should be useful in the implementation of wind energy projects [67].

An important obstacle is also the information and education barrier; therefore, it is necessary to get through to local communities by launching information campaigns, in which people are informed in a clear and comprehensible way about investments related to the construction of wind farms and development of wind power engineering. Both the advantages and disadvantages should be presented in order to prevent future investments from being blocked by local residents, such as non-governmental organizations [69,70]. The lack of knowledge about the benefits of using wind energy among the society is a significant problem in EU countries and affects the development of wind farms. Education should be conducted for all renewable energy sources [67]. Significant obstacles include technical barriers connected with limited access to new technologies and devices used in wind power engineering as well as difficulties in the planning and forecasting of the available capacity and volume of energy produced at wind farms [1]. The European Union continues to implement technical solutions that support the infrastructure necessary for large-scale wind energy production. One of the solutions is to connect offshore wind farms directly to the mainland via a radial connection. This is related to the concept of so-called hybrid projects regarding islands where wind turbines and onshore power hubs are located [45]. Another example of an innovative solution used in wind power engineering involves vertical-axis wind turbines—an alternative to horizontal-axis wind turbines used so far [71]. Other innovative solutions are so-called mini power plants, i.e., home wind farms that can be used extensively in single-family housing [67]. Such solutions can be found in Scandinavian countries. It should be noted, however, that a home wind turbine does not cover the full demand for electrical energy, but merely ca. 25% [9].

The presented barriers affecting the development and use of wind power engineering in the EU are well known and frequently described in the context of RES use in EU countries. The subject literature does not mention any studies summarizing factors such as the correlation between the length of the coastline and the use of wind energy or the relationship between GDP per capita and the use of wind energy in European Union countries and the correlation between the attitude to the uncertainty of inhabitants of a given country and its use of wind energy. Such an analysis was conducted in the research part of this article.

In Table 1, a comparison between wind energy and common fossil fuels is presented.

Table 1. The comparison of wind energy and fossil fuels.

Factor	Wind Energy	Fossil Fuels
Energy source	Renewable—harnesses wind power	Non-renewable—derived from fossilized organic matter
Environmental impact	Low greenhouse gas emissions (GHGs)	High GHG emissions (CO_2, methane, etc.)
Fuel availability	Abundant and inexhaustible	Finite—will deplete over time
Fuel extraction	None required	Extensive mining/extraction
Energy production	Variable (dependent on wind)	Continuous (steady power generation)
Power generation cost	Initial setup costs can be high	Variable, depends on fuel prices
Operating costs	Low	Ongoing expenses for fuel and maintenance
Grid dependence	Requires backup or grid integration	Connected to existing power grids
Energy storage	May require additional storage	Not required
Land use	Requires larger land areas for setup	Smaller land areas for power plants
Water consumption	Negligible	Significant for cooling in power plants
Energy independence	Increases energy self-reliance	Reliance on imported fossil fuels
Reliability	Intermittent (subject to wind)	Stable and continuous
Climate change impact	Mitigates climate change effects	Contributes to climate change
Infrastructure	Turbines, transmission lines, etc.	Power plants, pipelines, and refineries
Decommissioning	Easily dismantled and recycled	Complex decommissioning process

Source: own analysis on the basis of [72–79].

3. Materials and Methods

This publication contains the results of an analysis of the wind energy market in European Union countries. The analysis was prepared based on data about the wind energy market in European Union countries that are annually published in the Wind Energy Barometer. This document is an annual report about the renewable energy market [80–85]. Reports prepared since 1998 measure the share and main data about the renewable energy market and bring data about progress made by the renewable energy sector. The data in the reports consist not only of wind energy data but also data about all sectors of renewable energy in all European Union countries. In this paper, we concentrated only on the data about the main topic, which is connected with wind energy.

The analysis took into account all 27 countries that currently belong to the European Union. Since some countries invest in wind energy to a very small extent (often due to their small size), they were excluded from the part of the analysis where correlations were calculated, as these countries could have distorted the results of the analysis. It was assumed that countries with a wind energy capacity of less than 200 MW are not taken into account in correlation analyses. Therefore, countries such as Latvia, Luxembourg, Malta, Slovakia, and Slovenia were not considered in these analyses. The analysis was conducted for the following countries: Germany, Italy, France, Spain, Belgium, Greece, the Netherlands, the Czech Republic, Romania, Austria, Bulgaria, Portugal, Denmark, Hungary, Slovakia, Sweden, Poland, and Finland.

In the research described in this publication, it was also decided to examine the relationship between the collected data and other country-specific indicators. The research conducted used data on GDP per capita calculated at purchasing power parity for 2021 as well as data on cultural indicators for each country. Data on GDP per capita were adopted from the International Monetary Fund's Economic Outlook databases [86].

To analyze the impact of cultural indicators, indicators of a country's culture were used—in particular, the uncertainty avoidance indicator. In the analysis, indicators based on research by Hofstede Insight—an international organization that collects data about cultural factors for most of the countries in the world—were used [87]. In particular, the uncertainty avoidance indicator was used. Uncertainty avoidance is an indicator that reflects the extent to which members of a society deal with uncertain situations and how their level of anxiety minimizes uncertainty. To estimate the uncertainty avoidance of a country, Hofstede and his team collected and analyzed data from surveys and questionnaires administered to individuals in various countries. The surveys contained a series of questions that aimed to capture people's attitudes and preferences regarding uncertainty, risk, and ambiguity in different aspects of life. The questions focused on topics such as the level of comfort with unpredictable situations, the desire for rules and regulations, the preference for clear and explicit instructions, and the tolerance for ambiguity. Respondents were asked to rate their level of agreement or disagreement with these statements on a scale. Hofstede and his team then aggregated and analyzed the survey responses to derive a numerical score for uncertainty avoidance for each country [88]. This score represents the average level of uncertainty avoidance exhibited by the respondents from that country [89]. Higher scores indicate a greater preference for stability, structure, and predictability, while lower scores indicate a higher tolerance for ambiguity and a willingness to take risks [90,91].

To calculate the wind capacity and installed wind capacity per capita ratios, population data for the analyzed European Union countries were used [92]. To analyze the relationship between wind capacity and shoreline length, data on shoreline length for the individual countries in the European Union were used [93].

4. Results

Table 2 presents data on the amount of energy produced by wind sources in 2016–2022. The data were compiled on the basis of the Wind Energy Barometer. They present the total volume of the production capacity in the case of wind energy in all European Union countries.

Table 2. Data on the amount of energy produced by wind sources in European Union countries (years 2016–2022).

	2022	2021	2020	2019	2018	2017	2016
Austria	3586	3300	3226	3159	3045	2844	2649
Belgium	5326.4	4740.9	4680.9	3826	3191	2848	2383
Bulgaria	708.2	707	702.8	698.9	698	699	699
Croatia	990.2	990	801.3	646.2	576	527	483
Cyprus	157.9	157.7	157.7	157.7	158	168	168
Czech Republic	339.4	339.4	339.4	337	310	282	282
Denmark	7100	6995.2	6259.5	6112.1	6131	5521	5246
Estonia	325	320	317	320	312	210	210
Finland	5677	3257	2586	2284	2041	2044	1532
France	20,698	17,484	18,548	16,494	15,108	13,559	11,761
Germany	66,206	63,865	62,188	60,840	58,908	55,602	49,592
Greece	4681.4	4649.1	4119.3	3607.4	2844	2541	2370
Hungary	331	329	321	329	329	329	329
Ireland	4527.3	4339	4306.7	4127	3564	3365	2827
Italy	11,700	11,100	10,870.6	10,512	10,300	9743	9384
Latavia	137	77.9	77.9	78.2	77	66	70
Lithuania	938	671	540	534	521	521	509
Luxembourg	165	160	152.7	127	120	116	117

Table 2. *Cont.*

	2022	2021	2020	2019	2018	2017	2016
Malta	0.1	0.1	0.1	0.1	0	0	0
Netherlands	8747	7800	6618.8	4463	4292	4270	4257
Poland	8129.5	7116.7	6298.3	5917	5864	6397	5747
Portugal	5671	5627	5122.3	5242.1	5380	5313	5313
Romania	3031	3029	3012.5	3032.3	3030	3029	3025
Slovakia	4	3	3	3	4	3	3
Slovenia	3.3	3.3	3.3	5.2	5	5	5
Spain	29,043	27,575.1	26,819.2	25,742	23,494	23,075	23,170
Sweden	14,585	12,080	9976	8984	7409	6721	6495
Total	202,807.7	186,716.4	178,048.3	167,578.2	157,711	149,798	138,626

Source: own analyses based on data [80–85,94].

An analysis of the data collected in Table 1 shows that in 2021, the top countries were Germany—63,965 MW, Spain—27,575.1 MW, France—175,484 MW, Sweden—12,080 MW, and Italy—11,100 MW. The value of wind capacity for all European Union countries in 2021 was 186,716.4 MW. In 2022, Germany had 66,206 MW of wind energy installed, Spain had 29,043 MW, France had 20,698 MW, Sweden had 14,585 MW, and Italy had 11,700 MW. The total installed capacity of wind energy in EU countries in 2022 was 202,807.7 MW.

The European top spot did not change throughout the entire period studied, starting in 2016. There were only slight shifts between the countries in the fourth and fifth places. Table 3 shows the top five places over the period 2016–2022. The only change occurred in 2021, when Sweden, which was previously consistently in fifth place, overtook Italy and moved up to fourth place. The situation was the same in 2022 as it was in 2021. The data about the wind energy capacity of EU countries is illustrated in Figure 1 in a map.

Table 3. European Union countries with maximum wind capacity in the years 2016–2022.

	2022	2021	2020	2019	2018	2017	2016
First place	Germany	Germany	Germany	Germany	Germany	Germany	Germany
Second place	Spain	Spain	Spain	Spain	Spain	Spain	Spain
Third place	France	France	France	France	France	France	France
Fourth place	Sweden	Sweden	Italy	Italy	Italy	Italy	Italy
Fifth place	Italy	Italy	Sweden	Sweden	Sweden	Sweden	Sweden

Source: authors own analysis.

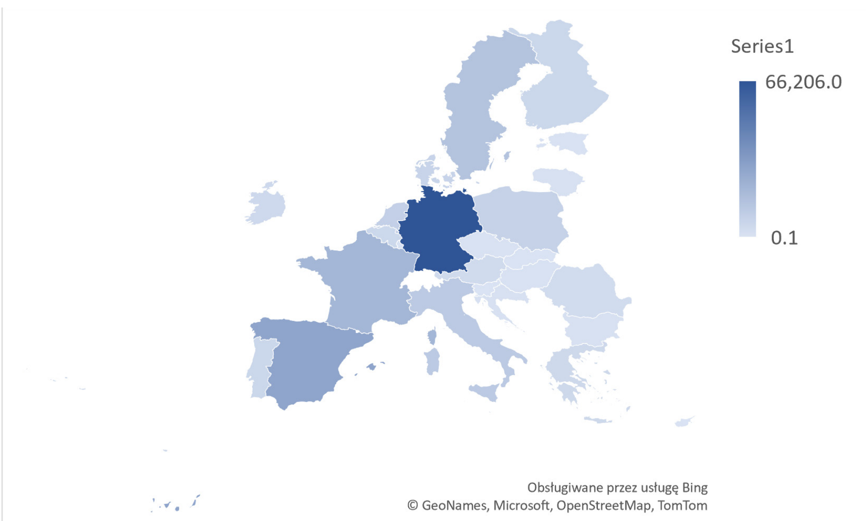

Figure 1. Installed wind capacity in European Union countries in the year 2022.

The dynamics of the changes in wind energy capacity varied across the countries analyzed. Table 4 presents the data on the changes in wind energy capacity in the countries studied from 2016 to 2022.

Table 4. Wind energy capacity inter-year change in European Union countries in the years 2017–2022 (MW).

Country	2022	2021	2020	2019	2018	2017
Austria	286	74	67	114	201	195
Belgium	585.5	60	854.9	635	343	465
Bulgaria	1.2	4.2	3.9	0.9	0	0
Croatia	0.2	188.7	155.1	70.2	49	44
Cyprus	0.2	0	0	0	0	0
Czech Republic	0	0	2.4	27	28	0
Denmark	104.8	735.7	147.4	0	610	275
Estonia	5	3	0	8	102	0
Finland	2420	671	302	243	0	512
France	3214	0	2054	1386	1549	1798
Germany	2341	1677	1348	1932	3306	6010
Greece	32.3	529.8	511.9	763.4	303	171
Hungary	2	8	0	0	0	0
Ireland	188.3	32.3	179.7	563	199	538
Italy	600	229.4	358.6	212	557	359
Latavia	59.1	0	0	1.2	11	0
Lithuania	267	131	6	13	0	12
Luxembourg	5	7.3	25.7	7	4	0
Malta	0	0	0	0.1	0	0
Netherlands	947	1181.2	2155.8	171	22	13
Poland	1012.8	818.4	381.3	53	0	650
Portugal	44	504.7	0	0	67	0
Romania	2	16.5	0	2.3	1	4
Slovakia	1	0	0	0	1	0
Slovenia	0	0	0	0.2	0	0
Spain	1467.9	755.9	1077.2	2248	419	0
Sweden	2505	2104	992	1575	688	226
Total	16,091.3	9732.1	10,622.9	10,025.3	8460	11,272

Source: own analyses based on data [80–85,94].

Significant differences between the countries in terms of the dynamics of installing wind capacity were found in the analysis of the data year by year. It is worth noting that countries in some years very actively invested in wind capacity, ranging from installing more and more of this type of installation to almost not investing in this area in other years. In 2017–2020, there was a continuous increase in the dynamics of wind capacity development, and the total amount of wind capacity in European Union countries increased. In contrast, in 2021, there was a crisis in this regard. While the countries installed 9870.8 MW of wind capacity in 2019 and 10,622.9 MW of wind capacity in 2020, in 2021, the number dropped to 9732.1 MW, the lowest in several years. The data shows that wind energy development in the European Union has been developing more or less steadily over the past few years (2018–2021). This is negative, as given the decarbonization policy introduced and the concept of increasing wind energy in the energy mix, wind energy development should proceed faster. Certainly, legal solutions and greater incentives are needed to accelerate the development of wind energy in European Union countries. In the year 2022, a big increase in the installed wind capacity was observed. The total amount of installed wind capacity in EU countries was 16,091.3 MW, and this was the biggest among the analyzed years.

Considering individual countries, significant fluctuations can be observed from one year to the next. For example, the Netherlands had invested very strongly in wind energy in recent years with an increase in wind capacity of 2155.8 MW in 2020 and 1181.2 in 2021, while in 2017–2019, the amount of wind capacity commissioned in the country was minimal. In Spain, investments were mainly handed over in 2019–2021. In 2022, a surge in installed wind energy capacity was observed. France was in first place in 2022 with 3214 MW of wind energy installed. The next were Sweden—2505 MW; Finland—2420 MW; Germany—2341 MW; and Spain—1467.9 MW.

The situation is different for Germany. In this country, even though it has been ranked in first place in terms of total wind capacity since 2017, one can observe a decreasing number of new wind power investment handovers. In 2017, Germany handed over 6010 MW of new energy capacity, in 2018 the figure was 3306 MW, and in the following years the number never exceeded 2000 MW.

Due to the significant differences year on year contrary to the total wind capacity in this case for the subsequent years, there were significant shifts in the first places in terms of installed wind capacity. The top five places in this regard are summarized in Table 5.

Table 5. European Union countries with maximum installed wind capacity in the years 2015–2019.

	2022	**2021**	**2020**	**2019**	**2018**	**2017**
First place	France	Sweden	Netherlands	Spain	Germany	Germany
Second place	Sweden	Germany	France	Germany	France	Poland
Third place	Finland	Netherlands	Germany	Sweden	Sweden	Ireland
Fourth place	Germany	Poland	Spain	France	Denmark	Finland
Fifth place	Spain	Spain	Sweden	Belgium	Spain	Belgium

Source: authors own analysis.

Figure 2 shows the changes that occurred in terms of wind capacity in the countries studied over the period 2016–2022. The largest number of wind farms during this period were installed in Germany, producing 14,273 MW. France was next with 5723 MW, followed by Sweden with 5585 MW. The next four places were occupied by countries that increased their wind energy capacity by 2000–5000 MW during the period under study; these were: Spain—4405.1 MW, the Netherlands—3543 MW, Belgium—2357.9 MW, and Greece—2279.1 MW, respectively.

The analyses presented so far were conducted in absolute numbers. The problem with this kind of analysis stems from the fact that individual countries vary greatly in population. For this reason, it is worthwhile to see how wind capacity develops concerning population. For this purpose, it is possible to propose an indicator of generation capacity per capita, which is expressed in units of W/inhabitant in this study. The indicator values for 2017–2022 are summarized in Table 6.

Table 6. Wind capacity in European Union countries per inhabitant in the years 2016–2022 (W/inhabitant).

	2022	**2021**	**2020**	**2019**	**2018**	**2017**	**2016**
Austria	404.8	372.5	364.2	356.6	343.8	321.1	299.1
Belgium	464.5	413.4	408.2	333.7	278.3	248.4	207.8
Bulgaria	101.2	101.0	100.4	99.8	99.7	99.9	99.9
Croatia	242.9	242.9	196.6	158.5	141.3	129.3	118.5
Cyprus	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Czech Republic	31.8	31.8	31.8	31.5	29.0	26.4	26.4
Denmark	1222.9	1204.8	1078.1	1052.7	1056.0	950.9	903.5
Estonia	245.5	241.7	239.4	241.7	235.6	158.6	158.6
Finland	1029.0	590.4	468.7	414.0	369.9	370.5	277.7
France	308.8	260.8	276.7	246.1	225.4	202.3	175.5
Germany	797.5	769.3	749.1	732.8	709.6	669.8	597.4
Greece	436.6	433.6	384.2	336.4	265.2	237.0	221.0
Hungary	33.9	33.7	32.8	33.7	33.7	33.7	33.7
Ireland	923.2	884.8	878.2	841.6	726.8	686.2	576.5
Italy	193.8	183.9	180.1	174.2	170.6	161.4	155.5
Latavia	71.4	40.6	40.6	40.8	40.1	34.4	36.5

Table 6. *Cont.*

	2022	2021	2020	2019	2018	2017	2016
Lithuania	335.7	240.2	193.3	191.1	186.5	186.5	182.2
Luxembourg	269.2	261.0	249.1	207.2	195.8	189.2	190.9
Malta	0.2	0.2	0.2	0.2	0.0	0.0	0.0
Netherlands	506.1	451.3	383.0	258.2	248.4	247.1	246.3
Poland	214.1	187.4	165.9	155.8	154.4	168.5	151.3
Portugal	551.9	547.6	498.5	510.1	523.6	517.0	517.0
Romania	156.2	156.1	155.3	156.3	156.2	156.1	155.9
Slovakia	0.7	0.6	0.6	0.6	0.7	0.6	0.6
Slovenia	1.6	1.6	1.6	2.5	2.4	2.4	2.4
Spain	618.8	587.5	571.4	548.5	500.6	491.6	493.7
Sweden	1425.7	1180.8	975.2	878.2	724.2	657.0	634.9
UE average	153.4	141.3	134.7	126.8	119.3	113.3	104.9

Source: own analyses based on data [80–85,94].

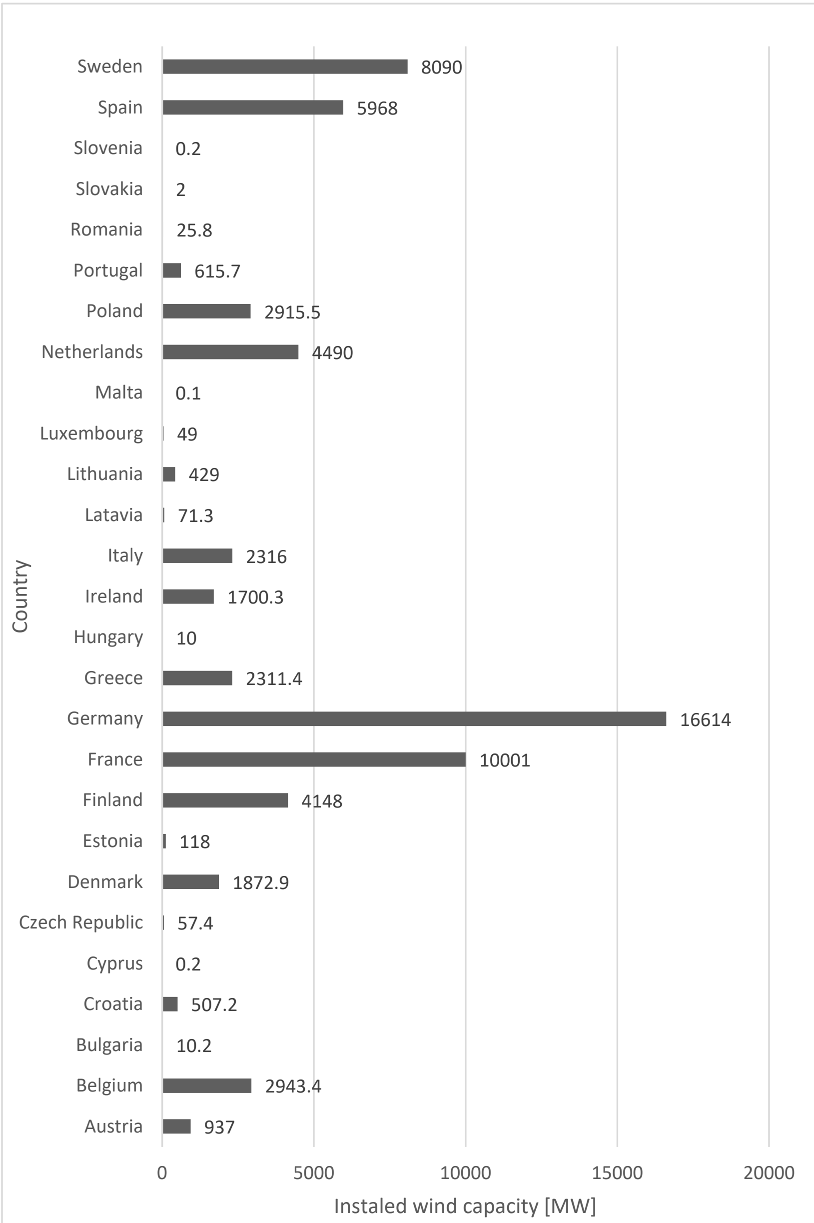

Figure 2. Installed wind capacity in the years 2016–2022 in European Union countries.

For wind capacity per capita in 2021, Denmark had the highest level with 1204.8 W/inhabitant, followed by Sweden with 1180.8 W/inhabitant and Ireland with 884.8 W/inhabitant. In fourth place was Germany with 769.3 W/inhabitant and Finland with 590.1 W/inhabitant. For the European Union as a whole, the average was 141.3.5 W/inhabitant per capita.

In the year 2022 the EU average installed wind capacity per capita was 153.4 W/inhabitant. The highest level was in Sweden with 1425 W/inhabitant, followed by Denmark with 1222.9 W/inhabitant, Finland with 1029 W/inhabitant, Ireland with 923.2 W/inhabitant, and Germany with 797.5 W/inhabitant. The first five places in 2022 were the same as in 2021, but it can be observed that Sweden surpassed Denmark, which was in first place in the last years of the analyzed time period. Also, Finland moved into third place, and Ireland surpassed Germany.

Table 7 summarizes the top five countries in terms of wind capacity per inhabitant for 2016–2022. Compared to the results of wind capacity calculated in absolute numbers (Tables 1 and 2), significant differences can be seen. The situation of wind energy implementation in the studied European Union countries in absolute numbers and per capita looks quite different. Germany, which was always in first place in absolute numbers, was only in fourth place (in 2016 it was in third place) counting in units of W/inhabitant. Spain, which was in second place in absolute numbers, was in fifth place in terms of generation capacity per capita (in 2020–2017).

Table 7. European Union countries with maximum wind capacity per inhabitant in the years 2016–2021.

	2022	**2021**	**2020**	**2019**	**2018**	**2017**	**2016**
First place	Sweden	Denmark	Denmark	Denmark	Denmark	Denmark	Denmark
Second place	Denmark	Sweden	Sweden	Sweden	Sweden	Sweden	Sweden
Third place	Finland	Ireland	Ireland	Ireland	Ireland	Ireland	Germany
Fourth place	Ireland	Germany	Germany	Germany	Germany	Germany	Ireland
Fifth place	Germany	Finland	Spain	Spain	Spain	Spain	Portugal

Source: authors own analysis.

In the case of per capita analysis, there was a clear advantage for Scandinavian countries. In terms of the Scandinavian countries in the European Union, Denmark and Sweden were in the top two places per capita for all the years studied. Germany and Ireland—both countries located in northern Europe—also ranked high. In addition, Spain and Portugal, countries in the Iberian Peninsula, can still be found, which were in fifth position in 2016–2020. In general, it can be seen that countries located in northern Europe are characterized by significantly higher levels of wind energy capacity compared to the rest of the European Union.

In the Figure 3, a map of the wind capacity per capita in European Union countries in the year 2022 is presented. Figure 4 shows a summary of the wind capacity per inhabitant for 2022.

In Table 8, data about the yearly changes in wind capacity in the studied European Union countries in the years 2017–2022 are presented. In Table 8, a juxtaposition of the five best countries in the case of increases in wind capacity in a particular year is presented.

In 2021, the largest increase in wind capacity per person occurred in the case of Sweden with 205.7 W/inhabitants. In second place was Denmark with 126.7 W/inhabitant. Third place goes to Finland with 121.86 W/inhabitants, fourth to the Netherlands with 68.3 W/inhabitants, and fifth to Greece with 49.5 W/inhabitants. The average for the studied European Union countries was 7.4 W/inhabitants. Analyzing the average value, a crisis in the installation of new wind farms within the European Union can also be observed. The year 2021 was the second worst year since 2016; the only worse result was in 2017. It is also worrying that the best year was 2016 in terms of new wind energy installations, where 8.5 W/inhabitant was installed in the European Union. Since then, the results have been worse every year. To increase the share of wind energy in the energy mix in European Union countries, it is undoubtedly necessary to rethink the causes of this crisis, because if the current unfavorable situation does not change, it will be difficult to achieve the climate targets set by the European Union.

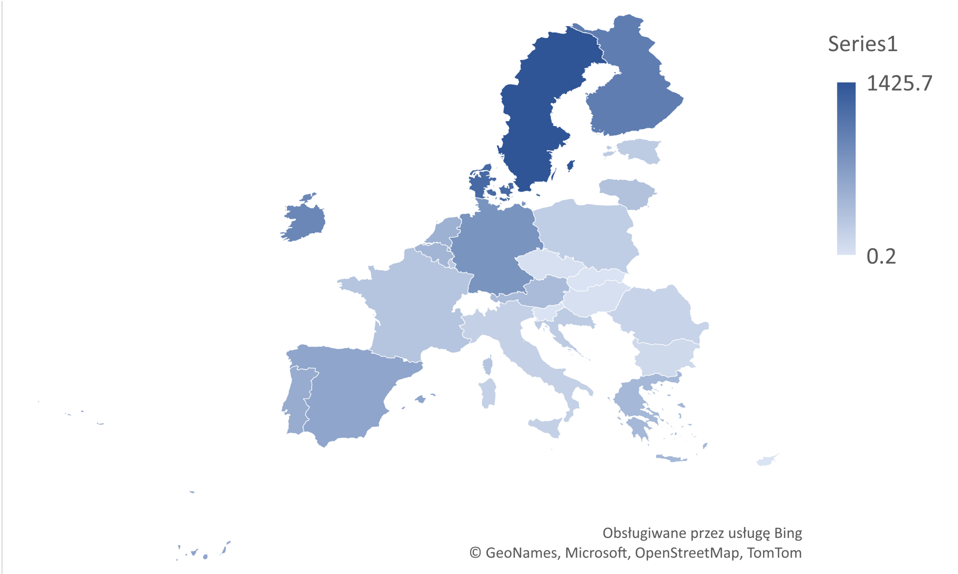

Figure 3. Wind energy capacity per inhabitant in European Union countries in the year 2022.

Table 8. Wind capacity installed in European Union countries in the years 2017–2022 per inhabitant (W/inhabitant).

	2022	2021	2020	2019	2018	2017
Austria	32.3	8.4	7.6	12.9	22.7	22.0
Belgium	51.1	5.2	74.6	55.4	29.9	40.6
Bulgaria	0.2	0.6	0.6	0.1	0.0	0.0
Croatia	0.0	46.3	38.1	17.2	12.0	10.8
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0
Czech Republic	0.0	0.0	0.2	2.5	2.6	0.0
Denmark	18.1	126.7	25.4	0.0	105.1	47.4
Estonia	3.8	2.3	0.0	6.0	77.0	0.0
Finland	438.6	121.6	54.7	44.0	0.0	92.8
France	48.0	0.0	30.6	20.7	23.1	26.8
Germany	28.2	20.2	16.2	23.3	39.8	72.4
Greece	3.0	49.4	47.7	71.2	28.3	15.9
Hungary	0.2	0.8	0.0	0.0	0.0	0.0
Ireland	38.4	6.6	36.6	114.8	40.6	109.7
Italy	9.9	3.8	5.9	3.5	9.2	5.9
Latavia	30.8	0.0	0.0	0.6	5.7	0.0
Lithuania	95.6	46.9	2.1	4.7	0.0	4.3
Luxembourg	8.2	11.9	41.9	11.4	6.5	0.0
Malta	0.0	0.0	0.0	0.2	0.0	0.0
Netherlands	54.8	68.3	124.7	9.9	1.3	0.8
Poland	26.7	21.6	10.0	1.4	0.0	17.1
Portugal	4.3	49.1	0.0	0.0	6.5	0.0
Romania	0.1	0.9	0.0	0.1	0.1	0.2
Slovakia	0.2	0.0	0.0	0.0	0.2	0.0
Slovenia	0.0	0.0	0.0	0.1	0.0	0.0
Spain	31.3	16.1	23.0	47.9	8.9	0.0
Sweden	244.9	205.7	97.0	154.0	67.3	22.1
UE average	12.2	7.4	8.0	7.6	6.4	8.5

Source: own analyses based on data [80–85,94].

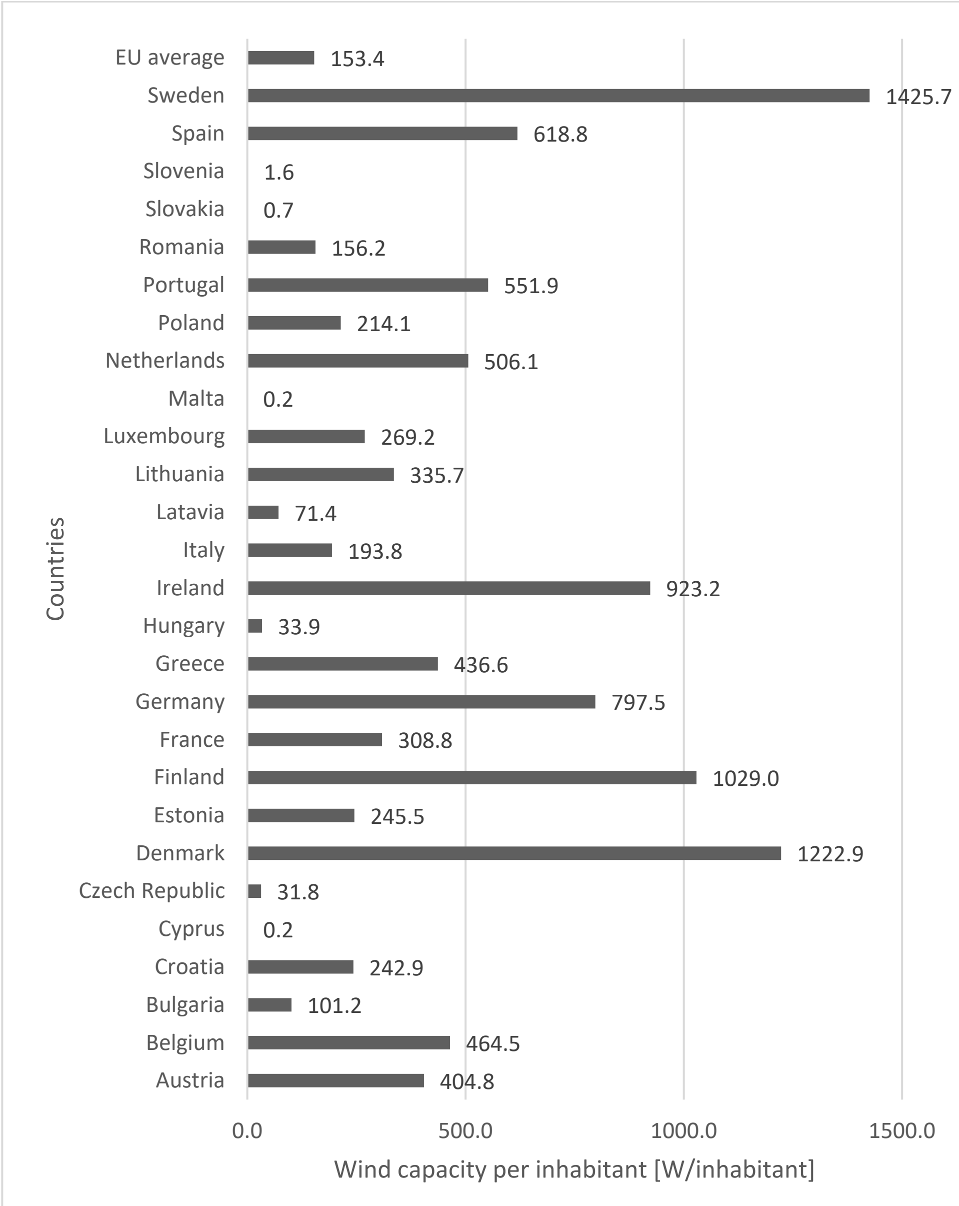

Figure 4. Wind capacity in European Union countries per inhabitant in 2022 (W/inhabitant). Source: authors own analysis based on data in [80–85].

The year 2022 was the best in the case of installed wind capacity in the analyzed period. The average installed wind capacity in the studied EU countries per person was 12.4 W/inhabitants. The highest value of wind capacity installed per person in 2022 was in Finland with 438.6 W/inhabitants. In second place was Sweden with 244.9 W/inhabitants, which was followed by Lithuania with 95.6 W/inhabitants, the Netherlands with 54.8 W/inhabitants, and Belgium with 51.1 W/inhabitants.

Analyzing Table 9, it can be noted that in recent years new investments in wind energy occurred first in Scandinavian and other northern countries, namely Sweden, Denmark, Finland, Belgium, and Ireland. From the other countries, it is worth noting Germany, which invested heavily in wind energy in 2017–2018, and Greece, which, as of 2020, as in fifth place in terms of investment in wind energy in the European Union. In 2022, an increase in wind capacity installed per person was observed in Lithuania.

Table 9. European Union countries with maximum wind capacity installed per capita in the years 2017–2022.

	2022	2021	2020	2019	2018	2017
First place	Finland	Sweden	Netherlands	Sweden	Denmark	Ireland
Second place	Sweden	Denmark	Sweden	Ireland	Estonia	Germany
Third place	Lithuania	Finland	Belgium	Belgium	Sweden	Denmark
Fourth place	Netherlands	Netherland	Finland	Spain	Ireland	Belgium
Fifth place	Belgium	Greece	Greece	Finland	Germany	France

Source: authors own analysis.

To invest in wind energy, economies must have adequate funds. For this reason, it seems that wealthier economies are more willing to invest in wind energy compared to poorer countries. To test this, an analysis was conducted into the relationship between wind energy production measured in W/inhabitant and the level of GDP per capita for each country. Since some countries have very few installations of wind energy, which could distort the results, it was decided to exclude from the analysis countries whose level of wind capacity was below 200 MW. In this way, six countries were excluded from the analysis.

Figure 5 shows a graph of the relationship between wind energy capacity per inhabitant in the studied EU countries and the level of GDP per capita. In the figure, the dashed line represents the regression band. It signifies the area around the regression line that represents the deviation from the average predicted value of the dependent variable. The regression band is used to assess the accuracy of the regression model and illustrates the range within which predicted values can differ from the actual observed values. The regression band was drawn for a confidence level of 0.95.

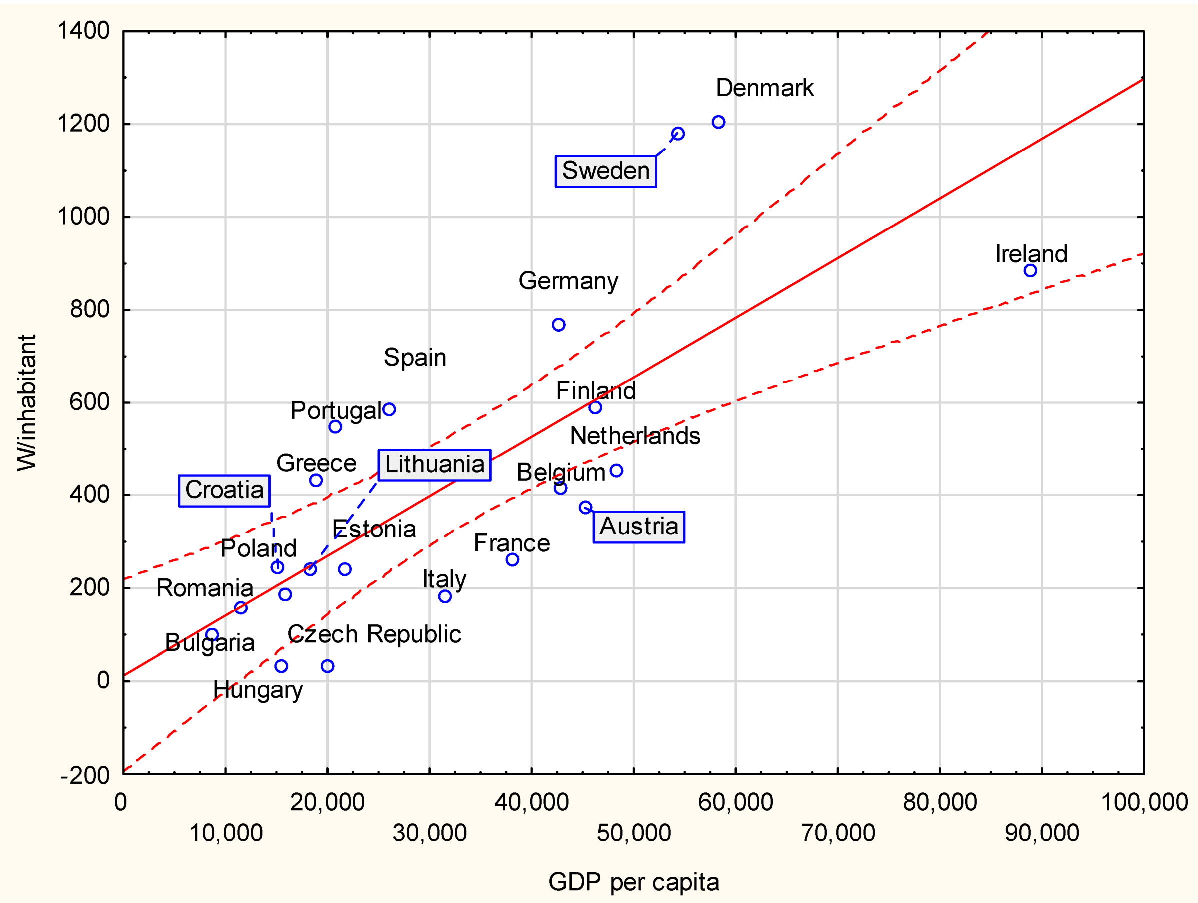

Figure 5. The relation between GDP/per capita and W/inhabitant of wind energy capacity for analyzed countries. Source: authors own analysis.

The analysis showed that there was a statistically significant correlation between the data at the level of statistical significance, $\alpha = 0.05$, which was 0.75. According to Gulford's classification, this correlation can be considered strong.

This analysis supports hypothesis H1 in the sense that there was a statistically significant correlation between GDP per capita and wind energy use in the studied European Union countries.

The relationship between the studied variables can be expressed by the following equation:

Wind capacity per inhabitant = 12.43 + 0.013x GDP per capita.

In the Figure 5 the main line the solid line indicates the trend line, the dashed lines indicate the 0.95 confidence interval.

The analysis showed that the countries' involvement in wind energy development was correlated with their wealth. The higher a country's per capita income, the more the country invested in creating new wind farms and increased its share of wind energy in its energy mix. Two groups of countries are worth noting from the figure:

- Countries that had significantly higher levels of wind energy use relative to their wealth included Denmark, Sweden, Germany, Spain, Portugal, and Greece. Here, we have two groups of countries, namely the northern countries—the Scandinavian countries and Germany—and the Mediterranean countries—the Iberian Peninsula and Greece.
- Countries in which the level of wind energy use was lower than their wealth would suggest included, in particular, countries such as Hungary, the Czech Republic, Italy, France, Austria, Belgium, and Netherlands. These are mainly countries located in the central and western parts of Europe.

Since wind farms are often built on coasts with strong winds, it was decided in the next step to analyze the relationship between the length of a country's coastline and wind capacity per inhabitant. In this case, too, a statistically significant correlation was found (at a statistical significance level of $\alpha = 0.05$). The correlation coefficient was 0.47, which can be considered as an average value according to Guilford's [95] classification.

The conducted research supports hypothesis H2 as follows: there is a relationship between the length of the coastline and the use of wind energy in the studied European Union countries. The relationship between the length of the coastline for the studied countries and wind capacity per inhabitant is expressed by the following formula:

Wind capacity per inhabitant = 354.58 + 0.0137x coastline length.

Figure 6 shows the relationship between the length of a country's coastline and its wind energy capacity in W/inhabitant. The figure shows that the country that ranked first in terms of wind energy capacity per inhabitant in the EU was Denmark, which developed its wind energy resources largely due to its developed coastline. A similar situation exists, for example, in Greece, which is developing its wind energy capacity in proportion to the length of its coastline.

In the Figure 6 the main line the solid line indicates the trend line, the dashed lines indicate the 0.95 confidence interval.

In the case of the northern European countries (Ireland, Germany, and Finland) and the Iberian Peninsula (Spain and Portugal), the development of wind energy was faster than the length of these countries' coastlines would suggest.

It is worth noting that countries that do not have a coastline—the Czech Republic and Hungary—were very poorly advanced in terms of wind energy investment. The only exception was Austria, which, despite its lack of a coastline, had a relatively high level of investment in wind energy during the study period. The data shows that while a lack of a long coastline does not completely prevent the use of wind energy, it certainly makes it significantly more difficult.

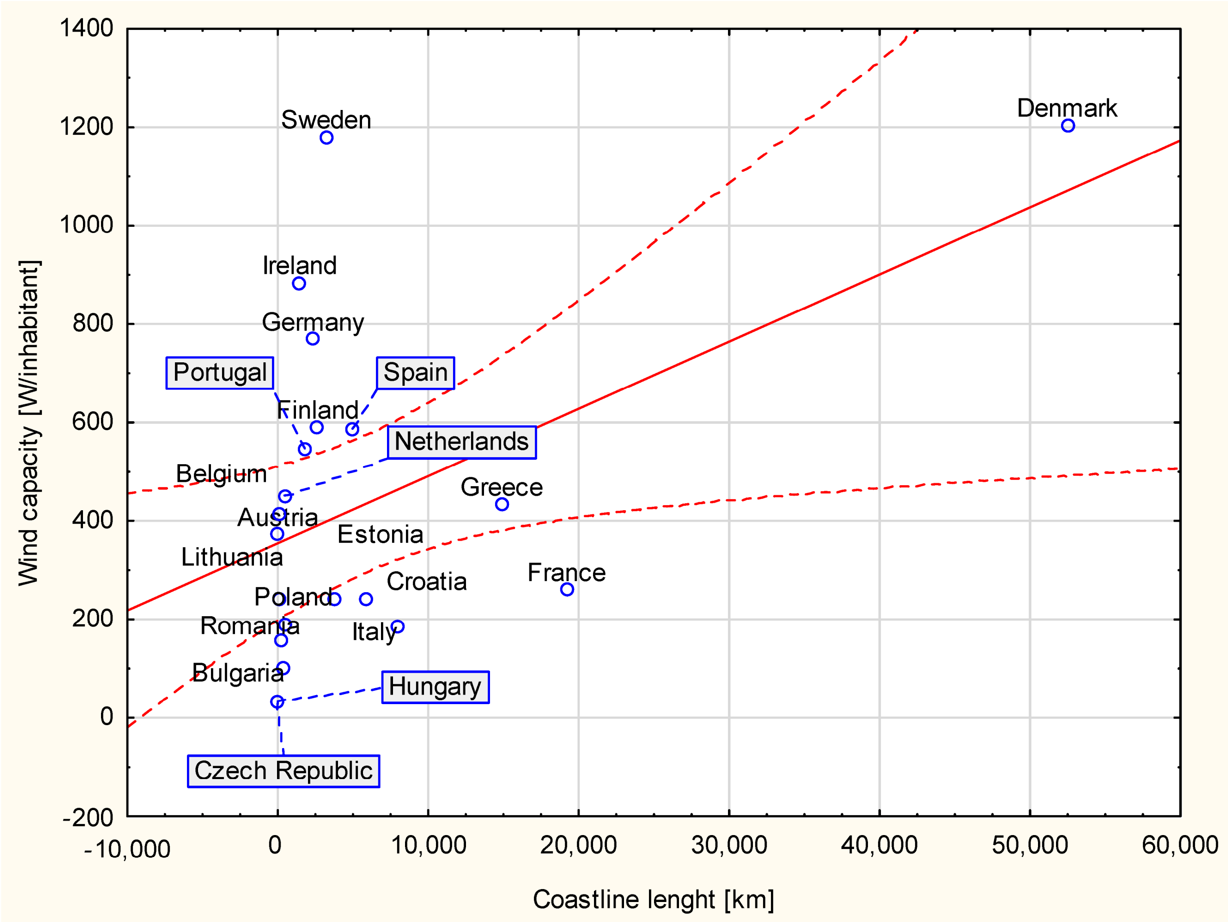

Figure 6. The relationship between countries' coastline lengths and wind energy capacity in W/inhabitant. Source: authors own analysis.

Studies have also shown that investment in wind energy is influenced by cultural factors, particularly the propensity of people in a country to deal with new, unstructured situations [96–98]. The analysis of the data carried out showed the existence of a statistically significant relationship (at the level of statistical significance of $\alpha = 0.05$) at -0.7 between wind capacity per inhabitant and the value of uncertainty avoidance (this is one of the indicators characterizing the culture of a country according to the concept of G. Hofstede [91]). This correlation can be considered, according to Guilford's classification [95], as high.

The presented research results support hypothesis H3 in the sense that there is a statistically significant correlation between the attitude to the uncertainty of the residents of a country and the use of wind energy in the studied European Union countries.

In countries where people are not afraid of novelty and look at change as an opportunity, it is much easier to make investments in new, non-standard forms of energy such as wind energy. In contrast, in a country where people are averse to change and look at everything new as a threat, investments in new technologies are significantly hampered. To illustrate the relationship, Figure 7 shows a scatter plot between the variables studied (wind capacity per inhabitant and uncertainty avoidance index).

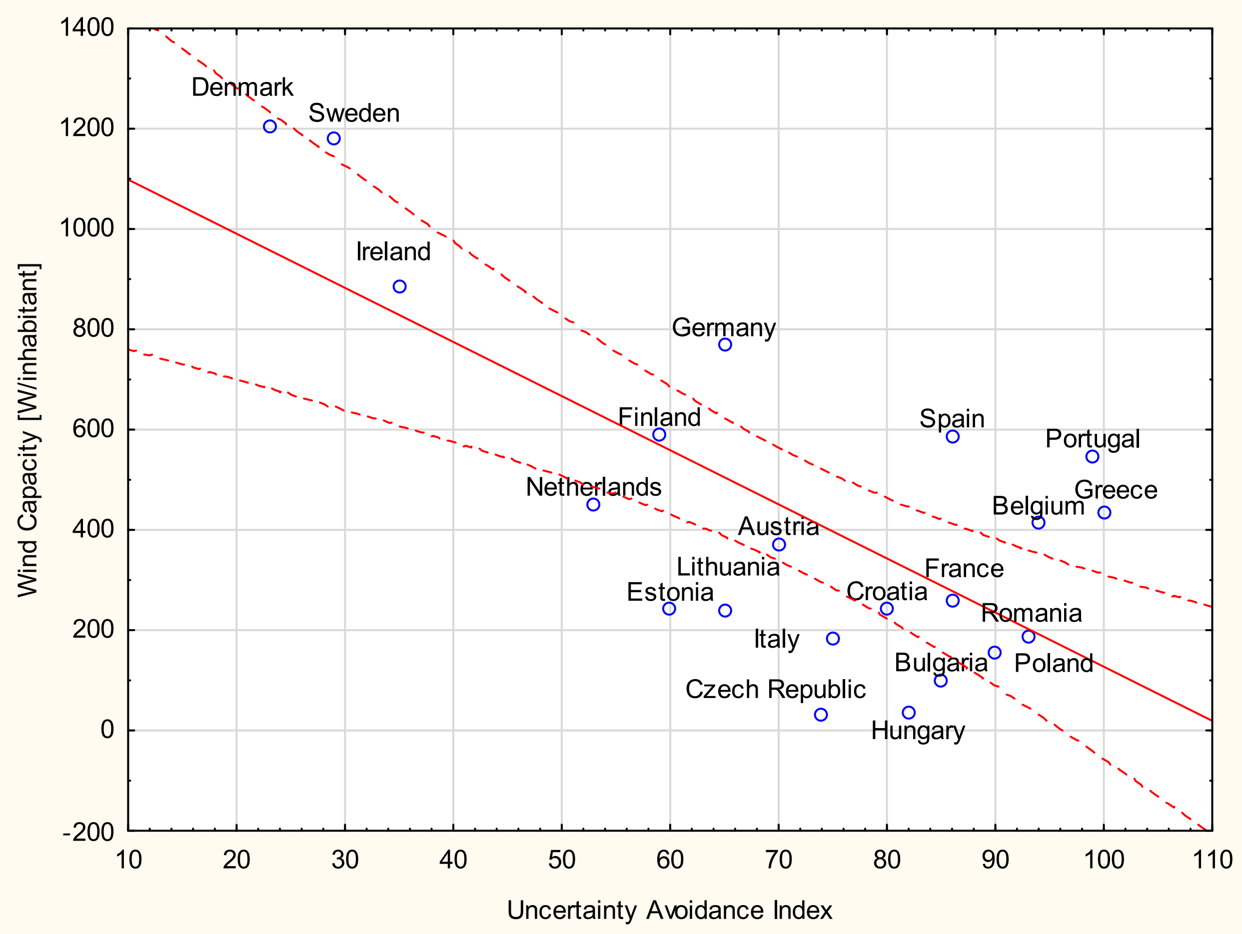

Figure 7. The relationship between uncertainty avoidance index of each country and wind energy capacity in W/inhabitant. Source: authors own analysis.

The figure shows that the countries with a low uncertainty avoidance index such as Denmark, Sweden, and Ireland also invested very heavily in wind energy. It is worth noting that the three countries with the highest investment in wind energy were at the same time the three countries with the lowest uncertainty avoidance index among the studied European Union countries.

In the case of medium or high uncertainty avoidance index values, the results were not so clear-cut. For these countries, there was not always a direct link between uncertainty avoidance and wind energy investment.

In particular, countries such as Germany, Belgium, and some of the Mediterranean countries (Spain, Portugal, and Greece) invested more in wind energy in the study period than the uncertainty avoidance index for these countries would suggest.

In contrast, in Italy and the former "Eastern Bloc" countries—Lithuania, Estonia, the Czech Republic, Hungary, and Bulgaria—one can observe a significantly lower level of investment in wind energy than the uncertainty avoidance index for these countries would suggest. At the same time, it is worth noting that the Czech Republic and Hungary are countries without a coastline and therefore lack one of the very important factors conducive to investment in wind energy.

5. Discussion

The EU countries are leaders in the field of wind power engineering. In 2021, the main ambitious goal presented by the European Commission in its report was to double the annual capacity of wind installations from 15 GW to 30 GW per year. According to the subject literature based on WindEurope data, wind power engineering is currently meeting 16% of the demand for wind energy [99]. As shown by the data in the individual countries, this demand varied the most in Denmark with 48%, followed by Ireland with 38%, Germany with 27%, Portugal with 24%, and Spain with 22%. According to the IEA, by 2027, wind energy will have strengthened its leading position among the renewable energy sources in the EU [53]. According to WindEurope, in the years 2023–2026, approximately 90 GW of new onshore wind turbine capacity will be installed, which will amount to an average of ca. 17.4 GW per year [27,100]. In 2021, the largest number of onshore wind farm installations were in Sweden (2.1 GW), Germany (1.9 GW), and France (1.2 GW). Investments in wind energy can significantly help to reduce greenhouse gases in accordance with the European Union policy directive implemented in this respect (Directive 2001/77/EC; Directive 2003/30/EC; Directive 2009/28/EC) [32]. The main reason for such a dynamic increase in the importance of wind power engineering is the increase in technological advancement and innovation in this area [45], Brussels 2020. It is technological progress and the introduction of innovative solutions such as the aforementioned hybrid projects covering islands with wind turbines and power nodes located on land, vertical-axis wind turbines (alternatives to the horizontal-axis wind turbines used so far), and other innovative solutions such as so-called mini power plants or home wind farms [45] that have contributed to the development of wind power engineering. Hybrid projects refer to the integration of different renewable energy sources to create a more reliable and consistent energy supply. In the context of wind power engineering, hybrid projects involve combining wind turbines with other sources, such as solar photovoltaic (PV) panels or energy storage systems [68]. This approach ensures a more stable electricity output by utilizing wind energy when available and supplementing it with solar or stored energy during periods of low wind. For example, on islands where grid connections may be challenging, hybrid projects can provide a sustainable and stable energy supply [71].

All this has resulted in the fact that currently, the cost of wind energy is EUR 0.3 in the best wind facilities compared to the mid-1980s, when the cost was EUR 0.30 [68]. This is also related to the fact that more and more EU countries have introduced laws and regulations promoting the development of renewable energy sources [101]. The European Union has adopted several Renewable Energy Directives that set binding targets for the share of renewable energy in the overall energy mix of member countries. These directives establish clear and ambitious objectives for the expansion of renewable energy sources, including wind power, and provide a framework for national governments to design their renewable energy policies [102].

Given the environmental and social costs, wind power engineering is definitely cheaper than that based on fossil fuels [103]. As presented in the literature analysis, wind energy is the fastest developing renewable energy source, but this growth is very diverse in the individual EU countries [43]. The availability of wind resources plays a crucial role in determining the potential for wind energy development in a given country [104]. Countries with abundant wind resources, particularly in coastal and windy regions, are more likely to have a higher wind energy capacity [45]. This is due to many factors, which can be broadly divided into technological, environmental, and social factors [65]. In individual countries, the above-mentioned factors are influenced by indicators related to climatic conditions, economic level, and citizens' awareness of the advantages and disadvantages of using wind energy. These indicators were highlighted in this article. The results of the analysis of wind power engineering development in the individual EU countries studied were presented on the basis of GDP per capita, calculated according to purchasing power parity, the cultural indicator of uncertainty avoidance, and an indicator regarding the correlation between wind energy capacity and the length of the coastline in the individual EU countries studied. This study revealed that all these indicators were very diverse in the studied European Union countries, thus influencing the use of wind energy and the implementation of more and more innovative solutions in this area. An increase in wind energy consumption, in accordance with the recommendation of the European Commission, should be closely connected with the technological development of wind power engineering and the search for increasingly innovative solutions. It is also important that new solutions in wind power engineering should comply with the legal requirements.

All this caused that currently the cost of wind energy is EUR 0.03 in the best wind facilities compared to the mid-1980s, when the cost was EUR 0.30 [68]. It is also related to the fact that more and more EU countries have introduced laws and regulations promoting the development of renewable energy sources [101,102]. Given the environmental and social costs, wind power engineering is definitely cheaper than the one based on fossil fuels [103]. As presented in the literature analysis, wind energy is the most developing renewable energy source, but this growth is very diverse in individual EU countries [43]. The European continent exhibits a wide range of climatic conditions and geographic features, such as coastal regions, plains, and mountainous areas [44]. These variations create diverse opportunities for wind energy development. Coastal regions and areas with strong prevailing winds tend to have a higher potential for harnessing wind energy [45]. Also the implementation of national and regional policies and regulatory frameworks greatly influences the growth of wind energy [104]. EU member states have set their own renewable energy targets, and their commitment to promoting wind power through supportive policies and incentives impacts the rate of growth [105–108].

In Figure 8, data about the wind energy consumption in the studied EU countries in the years 2016–2022 are presented. It can be observed that year by year, the usage of this type of renewable energy has increased. Similarly, the typical usage of solid fossil fuel energy in the studied EU countries is decreasing, as can be observed in Figure 9 (the data contain the years 2016–2021 because the Eurostat data for the year 2022 are not available). This is connected with the process of decarbonization of the EU economy. Of cause, other types of renewable energy can be used besides wind energy, for example solar energy. But the observation of this trend can give us an insight in the sense that the process of changing the energy mix and increasing the amount of wind energy in it has continued through all the analyzed years.

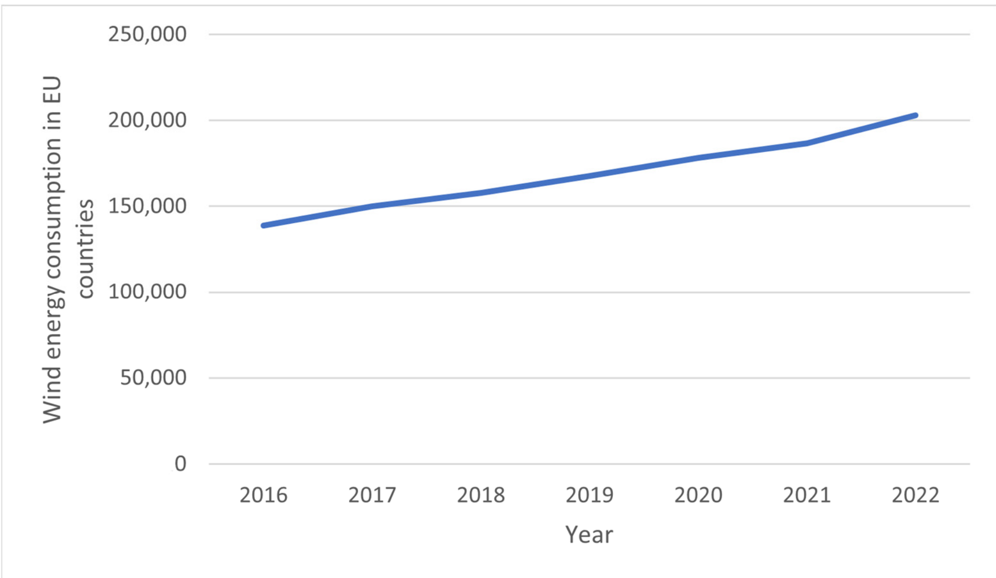

Figure 8. Wind energy consumption in EU countries in the years 2016–2022. Source: own analyses based on data [80–85,94].

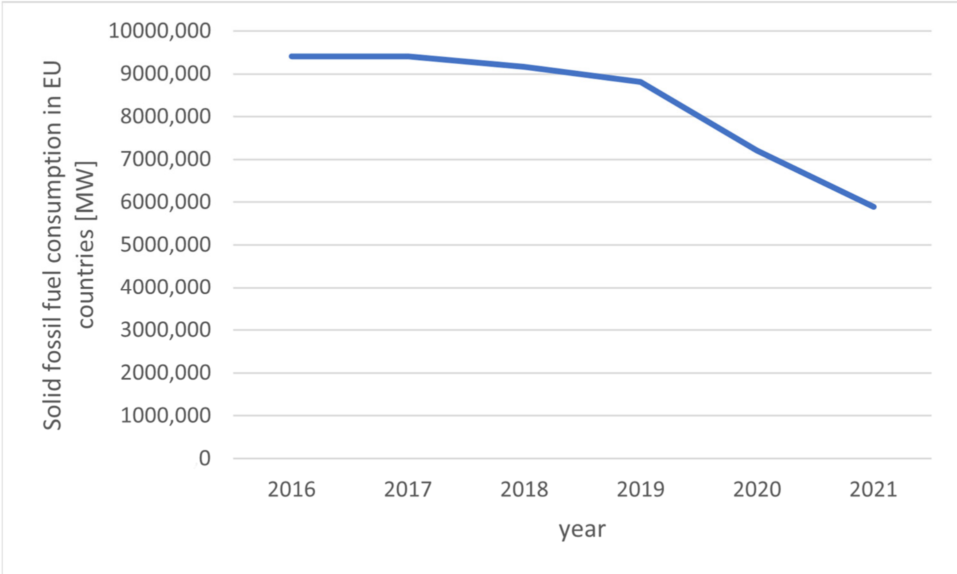

Figure 9. Solid fossil fuel energy consumption in European Union countries in the years 2016–2021. Source: own analyses based on data [106].

An interesting problem is to analyze why countries such as Denmark, Sweden, and Ireland with a low uncertainty avoidance index have invested heavily in wind energy. It can be stated that these countries have a strong commitment to environmental sustainability and are conscious of the need to reduce greenhouse gas emissions and combat climate change [109]. Investing in wind energy aligns with their green values and demonstrates their dedication to transitioning to clean and renewable energy sources [110]. Also, in these countries, people prioritize energy security and independence. By investing in wind energy, they can reduce their reliance on imported fossil fuels and diversify their energy mix, making their energy supply more resilient and less susceptible to geopolitical risks.

Denmark, Sweden, and Ireland have abundant wind resources, particularly in their coastal areas, which make wind power an attractive and cost-effective option for electricity generation [111]. Their geographic location and strong winds provide an excellent opportunity for harnessing wind energy potential. The analyzed countries have implemented supportive and stable policy frameworks that incentivize the development of renewable energy sources, including wind energy [112]. Long-term government support, feed-in tariffs, tax incentives, and subsidies have encouraged private investments in the wind power sector. There is strong public support for renewable energy initiatives in these countries. The general population values sustainability and environmental protection, which translates into widespread acceptance of wind energy projects and fewer barriers to their implementation [113].

Another interesting problem is why Spain and Portugal are developing wind energy faster than could be inferred from the length of their coastlines. Although both countries have coastlines, they also have diverse geographic landscapes that provide ample opportunities for wind energy development beyond coastal regions [114]. Inland areas and mountainous terrains in Spain and Portugal often experience favorable wind conditions, allowing for the establishment of wind farms away from the coast. Spain and Portugal benefit from abundant wind resources, not only along the coast but also inland [115]. These favorable wind conditions make wind energy a viable and attractive option for electricity generation, even in regions without direct coastal access. It can be stated that these countries have integrated wind energy into their existing energy infrastructure effectively [116]. This integration has been facilitated by advancements in grid technology and smart grid systems, allowing for the efficient distribution and utilization of wind-generated electricity.

The observed consumption patterns in wind power engineering have several potential long-term consequences for energy security, climate change mitigation, and the achievement of sustainability goals. As wind power engineering continues to grow, it can significantly contribute to enhancing energy security in the European Union. Wind energy is a domestic and renewable energy source, reducing dependence on imported fossil fuels and enhancing the EU's energy independence. This can mitigate the geopolitical risks associated with fossil fuel imports and contribute to a more stable and secure energy supply [117].

Also, the expansion of wind power engineering offers a promising pathway for mitigating climate change. By replacing fossil-fuel-based electricity generation with clean and renewable wind energy, greenhouse gas emissions can be significantly reduced. Wind power's low carbon footprint can help the EU achieve its climate targets and commitments under international agreements like the Paris Agreement [118].

Wind power engineering aligns with the EU's sustainability goals, including the promotion of clean and sustainable energy sources. By increasing the share of wind energy in the energy mix, the EU can work towards reducing its environmental impact and transitioning to a more sustainable energy system. The adoption of wind energy can also promote sustainable economic development and create green jobs in the renewable energy sector. The growth of wind power engineering is a crucial component of the EU's energy transition towards a low-carbon and sustainable energy future. By prioritizing wind energy as a key renewable energy source, the EU can accelerate its shift away from fossil fuels and reduce its reliance on finite and environmentally harmful resources [117].

The consumption patterns of wind energy observed in the paper present some important challenges that should be overcome to achieve long-term benefits [118,119]:

- The intermittent nature of wind energy poses challenges for grid integration. As wind energy capacity increases, there is a need for grid infrastructure upgrades and energy storage solutions to balance fluctuations in power generation and ensure grid stability.
- Despite its environmental benefits, wind power projects may face opposition from local communities due to visual and noise impacts, environmental concerns, and other issues. Ensuring public acceptance and community engagement is essential for successful wind energy deployment.
- Continued investment in research and development is necessary to improve the efficiency and cost-effectiveness of wind energy technologies. Advancements in materials, turbine design, and energy storage can further enhance the competitiveness of wind power engineering.
- The long-term success of wind power engineering depends on stable and supportive policy frameworks. Governments must maintain consistent policies that promote renewable energy and provide long-term incentives to attract investment in wind power projects.

Open innovation is a collaborative approach to problem-solving and innovation that involves actively seeking external ideas, knowledge, and expertise from a diverse network of stakeholders, including individuals, companies, research institutions, and communities. Unlike traditional closed innovation, where organizations primarily rely on internal resources and research and development (R&D) efforts, open innovation emphasizes the importance of sharing and leveraging external knowledge to drive innovation and create value [120].

Open innovation can be a powerful tool to increase wind energy usage by leveraging the collective knowledge and resources of a diverse network of stakeholders, including companies, research institutions, governments, and communities. Collaborative research and development can help advance wind energy technology and accelerate the commercialization of new solutions [72]. Open innovation can enable stakeholders to share knowledge, resources, and expertise to co-create new wind energy solutions. For example, a company may partner with a research institution to develop a new type of wind turbine that is more efficient and cost-effective [73]. Crowdsourcing can be used to engage a large group of individuals to generate new ideas and solutions for wind energy usage. A company may launch an open innovation challenge, inviting the public to submit their ideas for improving wind energy technology, reducing costs, or increasing adoption [121]. In the context of wind energy, an open innovation challenge could especially take the form of a competition or contest, where participants are encouraged to submit their ideas, concepts, or prototypes related to various aspects of wind energy [122]. These challenges are typically structured with specific objectives and criteria, providing guidance to participants on the areas where innovative solutions are sought [123].

Engaging with local communities can help increase public support for wind energy projects and enable stakeholders to better understand community needs and concerns [124,125]. Open innovation can be used to involve community members in the design and implementation of wind energy projects, ensuring that their perspectives and ideas are taken into account [126].

6. Conclusions

Wind power engineering is the fastest dynamically developing sector among the renewable energy sources in the EU. Based on the analysis of the literature data, it can be concluded that the largest resources of wind used in wind power engineering in the EU are located in the northern part of the Netherlands and Germany [24,127]. Favorable conditions for the development of wind power engineering can be found locally in most EU countries to a greater or lesser extent. Due to such a dynamic development of this renewable energy sector, innovative solutions are being searched for, and factors that may have an impact on increased wind energy production are being analyzed. This article examined the correlation between the data regarding the development of wind power engineering in individual EU countries, GDP per capita calculated according to the purchasing power parity for 2021, and data on the cultural indicators of individual countries. The impact of cultural indicators was analyzed on the basis of the cultural indicators of a given country; in particular, the uncertainty avoidance indicator was taken into consideration. To calculate the wind capacity and installed wind capacity per capita, data on the population in the European Union countries [83] were used. The analysis of the relationship between the wind capacity and the coastline length relied on the data regarding the length of the coastline in the individual countries of the European Union. For the needs of the analysis, research questions and research hypotheses were formulated. Based on the described methodology of the statistical research, conclusions providing answers to the research questions and research hypotheses were presented. The analysis of the statistical data showed that the involvement of countries in the development of wind power engineering was correlated with their wealth. The higher the per capita income in a given country, the more it invested in new wind farms and the higher the share of wind energy in the energy mix was in the study period. Countries that were characterized by a clearly higher level of wind energy use compared to their wealth included Denmark, Sweden, Germany, Spain, Portugal, and Greece. We have here two groups of countries, namely the northern countries—Scandinavian countries and Germany—and the Mediterranean countries—the Iberian Peninsula and Greece. Another group includes countries in which the level of wind energy use was lower than what could be inferred from their wealth, in particular Hungary, the Czech Republic, Italy, France, Austria, Belgium, the Netherlands. These are mainly countries located in the central and western part of Europe.

This analysis supports the H1 hypothesis that there is a statistically significant correlation between GDP per capita and the use of wind energy in European Union countries. Since wind farms are often built on coasts with strong winds, in the next stage, the relationship between the length of the coastline in a given country and wind capacity per inhabitant was analyzed. In the case of northern European countries (Ireland, Germany, and Finland) and the Iberian Peninsula (Spain and Portugal), the development of wind energy was faster in the study period than could be inferred from the length of the coastline in these countries. Countries that do not have a coastline—the Czech Republic and Hungary—were very poorly advanced in terms of wind energy investments. The only exception was Austria, which, despite its lack of a coastline, was characterized by a relatively high level of investment in wind power engineering. The conducted research supports the H2 hypothesis that there is a relationship between the length of the coastline and the use of wind energy in European Union countries. The last stage of the study was devoted to the analysis of how investments in wind power engineering are influenced by cultural factors, particularly the readiness of people in a given country to deal with new, unstructured situations. The conducted analysis revealed that countries with a low uncertainty avoidance index, such as Denmark, Sweden, or Ireland, invested heavily in wind energy. It is worth noting that the three countries with the largest investments in wind power engineering were characterized by the lowest uncertainty avoidance index among the studied European Union countries. In the case of medium or high values of the uncertainty avoidance index, the results were not so unambiguous. In these countries, a direct correlation between uncertainty avoidance and wind energy investment did not always exist. In particular, countries such as Germany, Belgium, and some Mediterranean countries (Spain, Portugal, and Greece) invested in wind energy in the study period to a greater extent than could be inferred from the uncertainty avoidance index for these countries. However, in the case of Italy and the countries of the former "Eastern Bloc"—Lithuania, Estonia, the Czech Republic, Hungary, and Bulgaria—the level of investment in wind energy was clearly lower than might be concluded from the uncertainty avoidance index for these countries. It is worth noting that the Czech Republic and Hungary are countries without a coastline, which is one of the very important factors supporting investments in wind energy. The presented research results support the H3 hypothesis that there is a statistically significant correlation between the attitude to uncertainty of the inhabitants of a given country and the use of wind energy in said country.

On the basis of the results presented in this paper, we can formulate the following policy recommendations connected with the widespread use of wind energy in European Union countries:

- Governments should continue to provide financial incentives, such as feed-in tariffs, tax credits, and subsidies, to encourage private investment in wind power projects. These incentives can help to offset the higher initial costs of wind energy infrastructure and make it more attractive for investors.
- It would be worth considering allocating more resources to R&D in the field of wind power engineering. Collaborative research projects between governments, research institutions, and private companies should be encouraged to drive innovation and develop more efficient and cost-effective wind energy technologies.
- Governments should simplify and expedite the permitting of and approval processes for wind energy projects. Governments should create clear and efficient regulatory frameworks that ensure environmental protection while reducing unnecessary bureaucratic hurdles that can delay project implementation.
- Public awareness campaigns should be launched to educate citizens about the benefits of wind energy and address any misconceptions. Local communities should be engaged in the decision-making process for wind power projects, ensuring that their concerns are heard and considered.
- Governments should focus on expanding offshore wind capacity, especially in countries with significant coastlines and high wind resources. Offshore wind farms have the potential to generate large amounts of clean energy whilst minimizing the visual and noise impacts on local communities.
- Governments should invest in modernizing and expanding the electricity grid to accommodate the increasing share of wind energy. Smart grid technologies and energy storage solutions should be implemented to enhance grid flexibility and stability.
- Cross-border collaboration between EU countries should be encouraged to share best practices and experiences in wind power development. Joint research projects and

knowledge exchange can accelerate progress and create a more integrated European wind energy market.

- Ambitious renewable energy targets at both the EU and national levels should continue to be set. Establishing long-term commitments and clear objectives would provide stability and certainty for investors, driving further growth in wind power engineering.
- Comprehensive and consistent policy frameworks that prioritize renewable energy sources, including wind power, should be developed. Policy continuity and stability are essential for attracting long-term investments and ensuring sustained growth in the sector.
- Partnerships should be facilitated between governments and private sector stakeholders to accelerate the deployment of wind energy projects. Public–private collaborations can leverage expertise and resources to overcome technical and financial barriers.
- Governments should allocate funding and resources for research focused on the integration of intermittent renewable sources like wind energy into the grid. Innovative solutions should be developed to balance fluctuations in power generation and ensure stable grid operations.
- International cooperation and knowledge exchange beyond EU borders should be encouraged to facilitate the sharing of experiences and best practices with non-EU countries. Collaborative efforts can promote global renewable energy adoption and address climate change on a larger scale.
- Dedicated funds or financial mechanisms should be created to support the transition from fossil fuels to renewable energy sources, including wind power. These funds can provide grants, low-interest loans, or investment incentives for renewable energy projects, especially in countries with a lower GDP per capita.
- Governments should encourage the development of community-based renewable energy projects, including wind farms. Governments can provide technical assistance, funding, and policy support to empower local communities to participate in and benefit from wind energy initiatives.
- Research hubs or centers of excellence dedicated to wind energy research and innovation should be established. These hubs can facilitate collaboration between academia, industry, and government, driving advancements in wind turbine technology, grid integration, and efficiency.
- Wind energy considerations should be incorporated into urban planning and development processes. The installation of small-scale wind turbines should be encouraged in urban areas, on rooftops, and in industrial zones to diversify energy sources and promote local generation.
- Governments should promote the development of hybrid projects that combine wind energy with other renewable sources like solar photovoltaics and energy storage. Incentives for integrated projects that optimize energy generation and enhance grid stability should be provided.
- Governments should allocate funding for research into the potential environmental impacts of wind energy projects, particularly in ecologically sensitive areas. Strategies to minimize and mitigate any negative effects on local ecosystems and wildlife should be developed.

The main scientific value of this paper lies in its examination of the development of wind energy in EU countries as an alternative resource to fossil fuels. It contributes to the existing body of knowledge by presenting empirical data and analysis related to wind energy capacity and by exploring the correlations between GDP per capita, coastline length, and the use of wind energy. This paper formulated and tested hypotheses related to the correlations between GDP per capita, coastline length, and the use of wind energy. By presenting research results that support these hypotheses, this study contributes to understanding the factors that influence wind energy adoption in EU countries. The scientific value of this paper lies in its contribution to the understanding of wind energy development in EU countries, the exploration of factors influencing its adoption, and the implications for energy policy and sustainability efforts.

Also, this paper highlights the importance of wind power engineering for achieving energy security and reducing greenhouse gas emissions in the EU. It discussed the ambitious goals set by the European Commission and the need for legal solutions and incentives to accelerate wind energy development. The findings have policy implications for promoting renewable energy sources and decarbonization efforts. It recognizes the complex interplay of these factors and their impact on the growth and diversity of wind energy adoption across EU countries. In terms of contextualization and comparison, this paper contextualized the findings within the broader context of EU energy policies, climate change concerns, and the increasing importance of renewable energy sources. It also compared the wind energy capacity and development among different EU countries, highlighting variations and differences.

On the basis of the results discussed in the paper it is possible to formulate some social implications of our research:

- This paper highlighted the role of wind power engineering in reducing greenhouse gas emissions and mitigating climate change. This emphasis can contribute to raising environmental awareness among the general public, encouraging more support for renewable energy initiatives. By engaging local communities in the decision-making process for wind power projects and addressing their concerns, this paper promotes the social acceptance of such projects. This inclusive approach can lead to increased community engagement and cooperation.
- The expansion of wind power engineering can have positive economic effects by creating new job opportunities in the renewable energy sector. This can enhance social wellbeing and provide employment stability in regions with wind energy installations.
- The findings related to the impact of cultural factors, such as uncertainty avoidance, on wind energy investment imply that societal attitudes and values can influence renewable energy adoption. This suggests the possibility of cultural and behavioral shifts toward more sustainable energy practices.
- This paper's focus on public awareness campaigns and educational efforts can lead to increased knowledge and understanding of wind power engineering. This can empower individuals to make informed decisions about energy consumption and contribute to the transition to renewable energy sources.
- The emphasis on cross-border collaboration among EU countries to share best practices and experiences can lead to strengthened international cooperation and knowledge sharing. This can contribute to a sense of solidarity and common purpose among member states.

A limitation of this study lies in the fact that the findings of this study are specific to EU countries and may not be directly applicable to other regions or countries with different socio-economic contexts and energy landscapes. Therefore, caution should be exercised when generalizing the results beyond the scope of this study.

Author Contributions: The main activities of the team of authors can be described as follows: conceptualization, B.S.-Z.; methodology, B.S.-Z.; software, B.S.-Z. and R.W.; validation, B.S.-Z. and R.W.; formal analysis, B.S.-Z.; investigation, B.S.-Z. and R.W.; resources, B.S.-Z. and R.W.; data curation, B.S.-Z.; writing—original draft preparation, B.S.-Z. and R.W.; writing—review and editing, B.S.-Z. and R.W.; visualization, B.S.-Z., supervision, B.S.-Z. and R.W.; funding acquisition, B.S.-Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: This research was funded by the Silesian University of Technology: 13/010/RGJ23/0074, 11/040/BK_223/0029, 13/010/RGJ23/0074 and 13/990/KPW21/0166.

Conflicts of Interest: The authors declare no conflict of interest.

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