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Vasily Shvets

Doctor of Economic Sciences, Professor,
Head of the Department of Management,
Dnipro University of Technology
ORCID: <https://orcid.org/0000-0001-7261-5993>

Serhii Kharin

Doctor of Technical Sciences, Professor,
Dnipro University of Technology
ORCID: <https://orcid.org/0000-0002-8500-163X>

Maryna Ivanova

Doctor of Economic Sciences, Professor,
Dnipro University of Technology
ORCID: <https://orcid.org/0000-0002-1130-0186>

Yuliia Dubiei

Doctor of Economic Sciences, Associate Professor,
Dnipro University of Technology
ORCID: <https://orcid.org/0000-0003-3415-3470>

Yuliia Papizh

Ph. D in Economics, Associate Professor,
Dnipro University of Technology
ORCID: <https://orcid.org/0000-0001-6460-7862>

**Швець Василь Якович, Харін Сергій Анатолійович,
Іванова Марина Іллівна, Дубей Юлія Володимирівна,
Папіж Юлія Сергіївна**
Національний технічний університет «Дніпровська політехніка»

**STRATEGY FOR THE DEVELOPMENT OF WIND ENERGY
IN EUROPE IN THE CONTEXT OF DECARBONIZATION AND
SMART ECONOMY AS A FACTOR IN ENSURING SUSTAINABLE
DEVELOPMENT AND FURTHER URBANIZATION**

**СТРАТЕГІЯ РОЗВИТКУ ВІТРОВОЇ ЕНЕРГЕТИКИ ЄВРОПИ
В УМОВАХ ДЕКАРБОНІЗАЦІЇ ТА СМАРТ-ЕКОНОМІКИ
ЯК ЧИННИК ЗАБЕЗПЕЧЕННЯ СТАЛОГО РОЗВИТКУ
І ПОДАЛЬШОЇ УРБАНІЗАЦІЇ**

Summary. This article analyzes wind energy development in Europe using statistical data from specialized international organizations. It indicates that, as of the end of 2024, Germany clearly dominates in terms of wind power capacity on the continent, with onshore wind turbines accounting for the majority of its wind installations. The United Kingdom, Spain, France, Sweden, and several other countries also hold significant positions. Denmark consistently leads in terms of the share of wind power plants in global electricity generation. The proposed measures for wind energy development include project scaling, investment, innovation, the production of critical materials for the energy transition, the production of specialized marine vessels, the construction of offshore energy islands focused on wind power generation and hydrogen production, and legislative measures to stimulate wind energy in the interests of decarbonization technologies, sustainable development, and the upholding of the values of modern civilization.

Keywords: international management, values, scaling, innovation, technology, standards, competitiveness, efficiency, critical materials, management in the production and non-production sectors, business analytics tools, regulation of foreign economic activity.

Анотація. У статті проведено аналіз розвитку вітрової енергетики Європи з використанням статистичних даних спеціалізованих міжнародних організацій з метою вироблення рекомендацій щодо зменшення технологічної залежності, соціальної нерівності та стимулювання довгострокових позитивних наслідків управлінських рішень в умовах смарт-економіки. Вказується, що за даними на кінець 2024 року, за потужністю вітрових електростанцій на континенті яскраво виражено домінує Німеччина, причому у структурі її вітрових установок більшу частину займають наземні та значно меншу частину – морські. Великобританія лідирує у Європі за потужністю морської вітрової енергетики. Зазначається, що за питомою вагою вітрових електростанцій у структурі виробництва електроенергії в Європі та в усьому світі домінує Данія. Аналіз також показав, що в даний час морська вітрова енергетика Європи стикається, зокрема, з обмеженням у пропускній спроможності електричних мереж у морі та прибережних районах, недостатніми можливостями портової інфраструктури. Наголошується, що розвиток вітрової енергетики відповідає стратегічному курсу на декарбонізацію та цілям сталого розвитку країн Європи, але поступається очікуваним темпам і потребує прискорення динаміки, удосконалення менеджменту у виробничій та невиробничій сфері, прийняття управлінських рішень, що потребують відповідного інструментарію та бізнес-аналітики. Акцент авторів робиться на будівництві морських енергетичних островів, у тому числі на значній відстані від континентів, особливістю яких є вироблення електроенергії за допомогою енергії вітру, виробництво водню, заправка воднем морських суден, а також транспортування зрідженого водню на континенти для подальшого використання. Заходи менеджменту розвитку вітрової енергетики, запропоновані у статті, передбачають масштабування всіх дій та проєктів, інвестиції, інновації, посилення динаміки та розширення географії ланцюжків поставок сировини та виробництва критичних матеріалів для енергетичного переходу, прискорення урбанізації, розвиток випуску спеціалізованих морських суден, законодавчі заходи щодо стимулювання вітрової енергетики на користь технологій декарбонізації, сталого розвитку, підтримки цінностей сучасної цивілізації.

Ключові слова: міжнародний менеджмент, цінності, масштабування, інновації, технології, стандарти, конкурентоспроможність, ефективність, критичні матеріали, менеджмент у виробничій та невиробничій сфері, інструментарій бізнес-аналітики, регулювання зовнішньоекономічної діяльності.

Problem statement. The economy of modern global civilization has achieved rapid growth, but it is also experiencing significant constraints from a number of factors. Many of these factors are extremely significant and will determine the prospects of the global economy. At the forefront of this debate is climate change, which is accelerating and causing economic and social damage, affecting all spheres of life and continents. Another critical factor is the growing demand for electricity, which is largely designed to overcome the negative effects of climate change through the use of modern energy technologies. At the same time, demand for electricity is also dictated by the overall progressive dynamics of human development, economic growth, rising living standards, and the innovative nature of civilization. The challenge is how to provide humanity with the necessary amount of climate-neutral electricity.

Analysis of recent research and publications. The modern global economy is characterized by high dynamics and constant changes in many markets, which is the subject of research by scientists at universities and specialized organizations, particularly in such relevant areas as decarbonization, sustainable development, climate change issues and their economic consequences, climate-neutral energy, competitiveness, innovation and investment management, which are interconnected and greatly influence each other and economic efficiency. Stasyuk V., Artemenko L., in the article [1], investigate the formation of an enterprise's environmental strategy as a factor in increasing competitiveness in the context of the transition to sustainable development, the implementation of the European Green Deal, and the spread of circular economy principles. The

article by Garasymlyuk M., Voloshyn M. [2] analyzes the impact of the European Union Taxonomy on attracting investment, the authors also substantiate the need for Ukrainian enterprises to adapt to new standards to maintain investment attractiveness and move towards climate neutrality. The article by Nestor O., Schultz E. [3] is devoted to the analysis of the European experience of public investment in green transformation at the local level. Various aspects of innovation management and the quality of business processes in the field of green economy and entrepreneurship are considered in the work of the authors Shpykulyak O., Lopatynskyi Y., Shelenko D., Kyfyak V., Shpykulyak V. [4] in the context of European integration processes. Sohns T.M., Aysolmaz B., Figge L., Joshi A. [5] explore the issues of sustainable development and effective management in the German economy. Kovalchuk T., Zaharii V. [6] analyze innovative strategies for the international competitiveness of Ukrainian enterprises. In the work of Couckuyt D., Van Looy A. [7] sustainable development is examined in the context of climate-neutral business process management. The processes of sustainable development, the transition to modern technologies and decarbonization, and process management are constantly evolving and therefore require further study.

Previously unsolved parts of the overall problem. There are numerous alternative energy development options, both in Europe and globally, with significant, yet limited, potential for investment, innovation, raw materials, and, equally important, human resources and the time available to address complex global energy challenges. Among these alternatives, it is necessary to select those that best

address the current conditions and prevailing trends, which have not yet been fully studied due to their complexity, as well as the constant changes in the global economy, primarily driven by innovation and expanding intellectual potential, which increases development opportunities but significantly complicates technologies and management systems.

The aim of the article to analyze the dynamics, positive and negative factors associated with climate-neutral energy trends and formulate a management model for the development of wind power in the context of the optimal use of existing natural and innovative potential.

Summary of the main research material. The global economy is increasingly experiencing the negative consequences of climate change, while humanity's needs for energy resources continue to grow. Under such conditions, accessible and cost-effective energy becomes a key prerequisite for increasing the competitiveness and effectiveness of national and global economies. The implementation of the principles of sustainable development goals and comprehensive decarbonization are considered as universal tools for solving climate, socio-economic and environmental problems that correspond to modern value orientations of the development of civilization. In this context, the concept of smart economy acquires special importance, which should be interpreted as an integrated economic system based on the widespread use of digital technologies in order

to increase efficiency, productivity and innovation in all areas of economic activity [8].

It is the combination of digitalization, energy transformation, and decarbonization processes that forms the basis for ensuring sustainable development and global competitiveness, while emphasizing the dynamic nature of the smart economy, which is constantly evolving in accordance with changes in the business environment and ecosystem of the global economy. In this regard, a comprehensive study of wind power, a key area of climate-neutral energy in Europe and a highly promising sector, is of interest.

Wind power is a key area of climate-neutral technology development and has strong potential to become the main source of electricity globally. An analysis of the document *Wind energy in Europe. 2024 Statistics and the outlook for 2025–2030* [9], which was published in February 2025, showed, in particular, the following (Table 1, Fig. 1):

- in 2024, 16.4 GW of new wind power capacity was built in Europe as a whole, including 12.9 GW of such plants built in EU countries;
- the overwhelming majority, namely: 84% of new capacity in Europe in 2024, was built onshore;
- as assumed in the review [9], in the period up to 2030, approximately 75% of new wind power capacity will be built onshore, but it is quite likely that the share of offshore installations will gradually but steadily increase in the future;

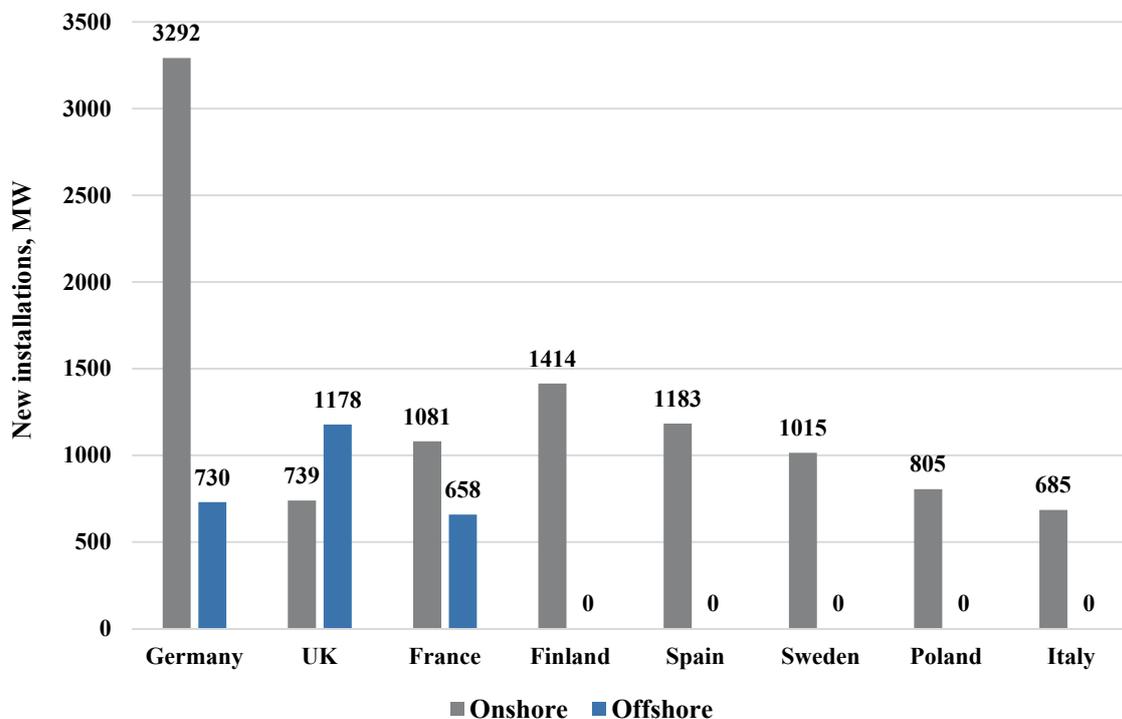


Figure 1 – New onshore and offshore wind installations in Europe in 2024

Source: [9]

Table 1 – New additions, total wind capacity and the share of wind in electricity demand in 2024

Countries	New installations in 2024 (MW)			Cumulative capacity (MW)			Share of wind in power mix in 2024		
	On-shore	Of-fshore	Total	On-shore	Of-fshore	Total	On-shore	Of-fshore	Total
Austria	160	-	160	4,028	-	4,028	16%	-	16%
Belgium	151	-	151	3,386	2,261	5,648	7%	9%	16%
Denmark	50	-	50	4,960	2,652	7,612	29%	26%	56%
Estonia	330	-	330	711	-	711	14%	-	14%
Finland	1,414	-	1,414	8,286	71	8,357	24%	-	24%
France	1,081	658	1,739	22,883	1,500	24,383	10%	1%	11%
Germany	3,292	730	4,022	63,551	9,121	72,672	24%	6%	30%
Greece	128	-	128	5,354	-	5,354	22%	-	22%
Ireland	333	-	333	4,836	25	4,861	33%	-	33%
Italy	685	-	685	12,915	30	12,945	8%	0%	8%
Lithuania	522	-	522	1,750	-	1,750	27%	-	27%
Netherlands	161	-	161	6,968	4,738	11,706	15%	14%	29%
Poland	805	-	805	10,233	-	10,233	14%	-	14%
Portugal	45	-	45	5,938	25	5,963	27%	0%	28%
Romania	50	-	50	3,150	-	3,150	12%	-	12%
Spain	1,183	-	1,183	31,173	7	31,180	25%	-	25%
Sweden	1,015	-	1,015	17,008	192	17,200	31%	-	31%
Total EU-27	11,474	1,387	12,861	210,356	20,623	230,979	17%	2%	19%
Norway	-	-	-	5,087	101	5,188	11%	-	11%
UK	739	1,178	1,916	15,703	15,933	31,636	13%	17%	30%
Türkiye	1,310	-	1,310	13,793	-	13,793	11%	-	11%
Total Europe	13,787	2,565	16,352	248,257	36,657	284,914	16%	4%	20%

Source: [9]

– Germany consistently leads Europe in new wind turbine commissioning in 2024, with a clear preference for onshore wind energy and, to a much lesser extent, offshore wind energy;

– the UK and France also saw significant new capacity commissioning, though they still trailed Germany in this regard;

– wind power's share of total energy generation in the EU as a whole reached 19% in 2024. Denmark led Europe and the world in this indicator, with a unique 56% share. Ireland trailed significantly behind Denmark at 33%, Sweden at 31%, and Germany at 30%;

– the volume of new installations in the EU in 2024 was still lower than projected, and, as noted in the report [9], this is due to numerous challenges with energy networks, construction permitting, complex bureaucratic procedures, and an unfavorable investment climate;

– offshore wind energy, in addition to the challenges associated with onshore installations, faces, in particular, capacity constraints on offshore and coastal electricity grids, as well as insufficient port infrastructure and a limited supply of specialized vessels for offshore installation construction and grid installation in more challenging environments;

– wind energy development is in line with the strategic course for decarbonization and the goals of European governments, but is lagging behind

expectations and requires accelerated momentum and appropriate management decisions.

The review [9] provides important summary data: currently in Europe there are 285 GW of installed wind power capacity (Table 1), including 248 GW of onshore and 37 GW of offshore; at the same time, in the EU-27 countries there are 231 GW of installed wind power, of which 210 GW are provided by onshore wind farms and 21 GW are provided by offshore wind farms, which are, as a rule, located relatively close to the coast.

Europe's offshore wind power capacity in 2024 is projected to be 36,657 MW, significantly behind onshore wind power, which has a capacity of 248,257 MW, or 6.8 times greater. The clear leader in offshore wind power on the continent (Table 1, Fig. 1) is the UK, with a capacity of 15,933 MW (slightly higher than its onshore wind capacity of 15,703 MW, a unique global figure). Germany (9,121 MW) and the Netherlands (4,738 MW) also hold significant positions. Slightly smaller capacities are concentrated in Denmark (2,652 MW), Belgium (2,261 MW), and France (1,500 MW). Other European countries have significantly lower figures.

In terms of the share of wind energy (Fig. 2) [9] in the energy balance in 2024 in Europe and the world, Denmark was clearly in the lead – 56%, other countries were noticeably behind it, but also had fairly high rates: Ireland – 33%, Sweden – 31%, Germany –

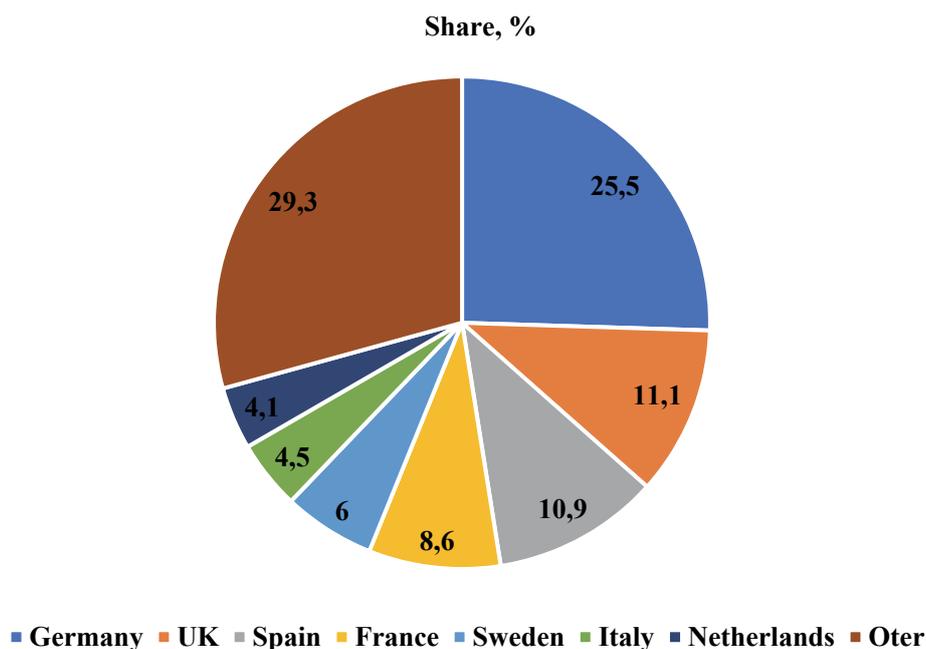


Figure 2 – Share of countries in European wind power capacity in 2024

Source: [9]

30%, UK – 30%, Netherlands – 29%, Portugal – 28%, Lithuania – 27%, Spain – 25%, Finland 24%, which indicates significant success in decarbonization, which needs to be developed further.

As of 2024, the overall structure of installed wind power capacity in Europe clearly shows the dominance of individual leading countries. According to [9], the leading position is occupied by Germany with a share of 25.5%, which exceeds the combined figures of the next two countries – the United Kingdom (11.1%) and Spain (10.9%). France forms only 8.6% of European wind power capacity, which is largely due to the high level of development of nuclear power, which restrains the expansion of alternative sources. Sweden also occupies a significant place with a share of 6%, followed by Italy (4.5%) and the Netherlands (4.1%). Together, these countries accumulate about 70% of all wind power capacity in Europe and actually determine the strategic guidelines for the climate-neutral energy policy of the continent. Further analysis of the intensity of introduction of new wind capacity in 2024 based on data [9] allows us to assess not only the technical and economic dynamics of the industry's development, but also the managerial prerequisites for such concentration and leadership.

It is the identified unevenness of the location and pace of wind power capacity expansion that necessitates the use of an integrated approach to the management of the production and non-production sectors in the energy sector. The development of wind energy as a capital-intensive and technologically complex industry requires effective management of production processes, which includes planning the construction

and operation of wind power plants, coordination of supply chains, rational use of material, financial and labor resources, ensuring the continuity of production cycles and compliance with environmental and safety standards. At the same time, achieving high indicators characteristic of leading countries is impossible without properly built management of the non-production sector, which ensures the management of human capital, the quality of engineering, service and regulatory services, effective interaction with state institutions, investors and local communities. Thus, it is the integration of production and non-production tools that is the key factor explaining the success of individual European countries in the development of wind energy and confirms the feasibility of using integrated management to ensure sustainable growth of the industry.

To determine the capacities of wind power plants in European countries, it is advisable to use business analytics tools when assessing the parameters of wind generation development in European countries. Depending on the purpose of the study, the scale of the analysis and the availability of statistical data, various analytical tools can be used that most fully meet the tasks and ensure correct information processing. Some software solutions require pre-setting for the specifics of energy indicators and demographic data, while others allow you to automate the calculation and visualization procedures of results [10].

Within the framework of the task of calculating the capacity of wind power plants per capita in a given European country, the choice of business analytics tools is determined by the need to integrate data on

installed wind power capacity and population. Such analysis requires accurate aggregation of indicators, their normalization per capita and comparison between countries, which necessitates the use of analytical platforms capable of working with large amounts of statistical information. The use of business analytics tools ensures the validity of calculations, increases the accuracy of assessing the level of wind energy development and creates an analytical basis for further management and strategic conclusions.

Using data from [9, 11], we will calculate the per capita capacity of wind power plants in European countries (Fig. 3). Sweden has the highest level of this indicator in Europe and worldwide, with a value of 1.61 kW per person. Other Scandinavian countries – Finland (1.49 kW per person) and Denmark (1.27 kW per person) – also have very high specific indicators. Norway (0.92 kW per person) differs from all countries in the world in its extremely high share of hydroelectric power plants and availability of hydro resources (88.7% in 2024, according to data from [12], wind 9.29%), therefore the level of wind energy here, although high, is not as significant as in the previously considered countries.

An analysis of the efficiency of new wind turbines has revealed a significant increase. Document [9] states the following in this regard: “The anticipated capacity factors of new onshore wind farms built in Europe in 2024 is 30–45%. And around 50% for offshore wind. The average power rating for new onshore turbines installed in 2024 was 4.6 MW. For offshore turbines it was 10.1 MW.” It can be stated with certainty that the capacity and efficiency of

offshore wind power plants, at least from the moment the investments associated with their construction have paid off, are significantly higher, which makes it advisable to make management decisions on their construction.

The growth of capacity and efficiency of offshore wind farms significantly affects urbanization processes, since after the return on investment they provide a stable and relatively cheap source of "clean" energy for cities, increasing their energy security and creating conditions for economic growth. The development of offshore wind energy stimulates the expansion of urban infrastructure, the formation of industrial, logistics and service clusters, especially in coastal regions, which contributes to the concentration of the population and the emergence of new specialized urbanized centers. At the same time, reducing emissions and environmental pollution increases the quality of life and investment attractiveness of cities, creating the prerequisites for sustainable and smart-oriented urban development.

In addition, urbanization is characterized by socio-economic differentiation of territories, which is manifested in income levels, access to services, and the quality of the living environment. To ensure sustainable development, it is important to take into account the need for spatial balance and integration of all components – not only economic, but also social, environmental and cultural [13].

Offshore wind energy development model.

In the future, offshore wind energy could become not just an important, but the most important energy source for humanity, at least until the problem of

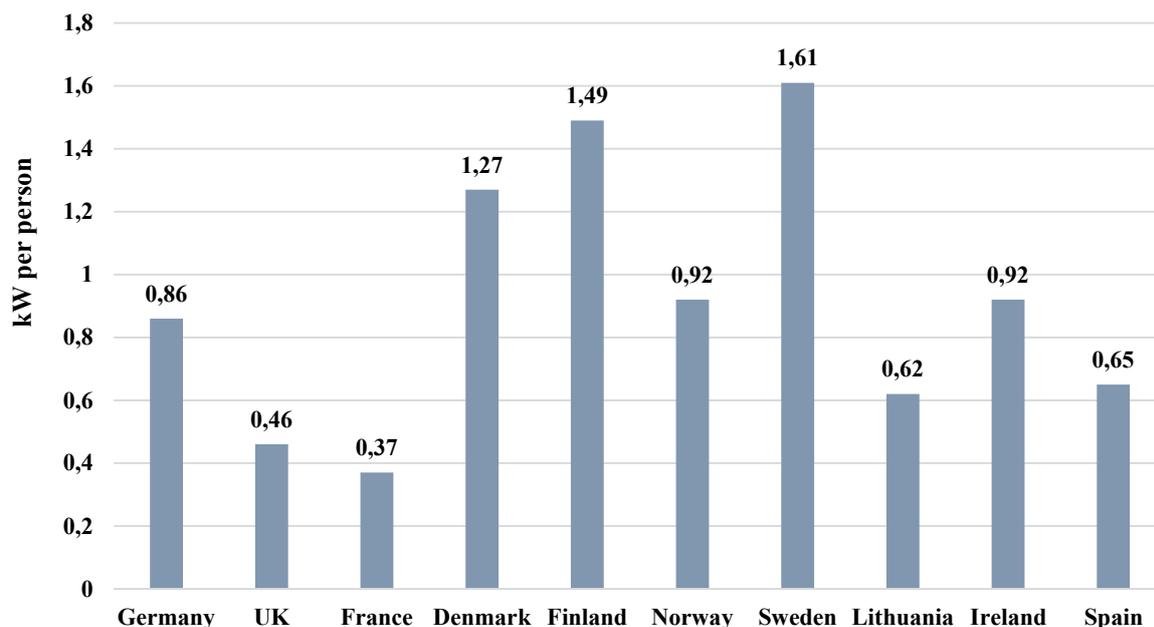


Figure 3 – Specific capacity of wind energy by European countries in 2024

Source: calculated by the authors using data from [9, 11]

producing practical energy through nuclear fusion is successfully solved. Offshore wind farms are significantly more complex, but equally more efficient, than land-based ones. The potential of offshore wind farms, given the size of the world's oceans and the potential for using floating wind turbines to generate electricity without transmitting it long distances to continents, is significant. Instead, they can be used to produce hydrogen by electrolysis and liquefy it for subsequent fueling of marine vessels. Such vessels will use hydrogen as fuel, and specialized vessels will deliver the liquefied hydrogen to continents where it is consumed. This will create energy islands.

For the development of offshore wind farms, in particular to increase capacity factors, plant output, and efficiency, the following is advisable (Fig. 4). Training specialists in this field requires a dramatic increase in the number of engineers and workers to manufacture electrical installations in factories, construct them offshore, deploy and operate electrical networks on specialized marine vessels, and perform many other tasks. Developing wind turbines requires a significant increase in production and a highly resilient supply chain for critical materials such as lithium, cobalt, rare earth elements, copper, and others.

Scalability is a key efficiency factor that can ensure the successful development of wind energy, decarbonize the global economy, and enhance the competitiveness of not only energy-related and mechanical engineering industries, but also all sectors of the economy by providing the low-cost energy needed by Europe. A key element in increasing output

could be the introduction of common standards for energy-related equipment and infrastructure across European countries. Effective management, innovation, and international cooperation are also key elements of efficiency.

In this regard, the need to improve the regulation of foreign economic activity and the development of international management is of particular relevance, since the large-scale deployment of wind energy is based on global supply chains, cross-border movement of capital, technologies and human resources. The import of critical materials, high-tech equipment and specialized vessels, as well as the export of engineering solutions and services require coordinated customs, trade and technical regimes, harmonization of standards and minimization of barriers within the European and global markets. In these conditions, international management acts as a tool for coordinating the activities of transnational companies, partner networks and project consortia, ensuring effective management of risks, resources and investments. Thus, the combination of regulatory support for foreign economic activity with modern approaches to international management is a necessary prerequisite for the sustainable scaling of wind energy, deepening decarbonization and strengthening Europe's competitive position in the global economy.

Conclusions. Thus, an analysis of European wind energy development revealed the following. As of the end of 2024, Germany clearly dominates in terms of wind farm capacity on the continent, with land-based and offshore accounting for the majority of its wind turbines. The United Kingdom, Spain, France,

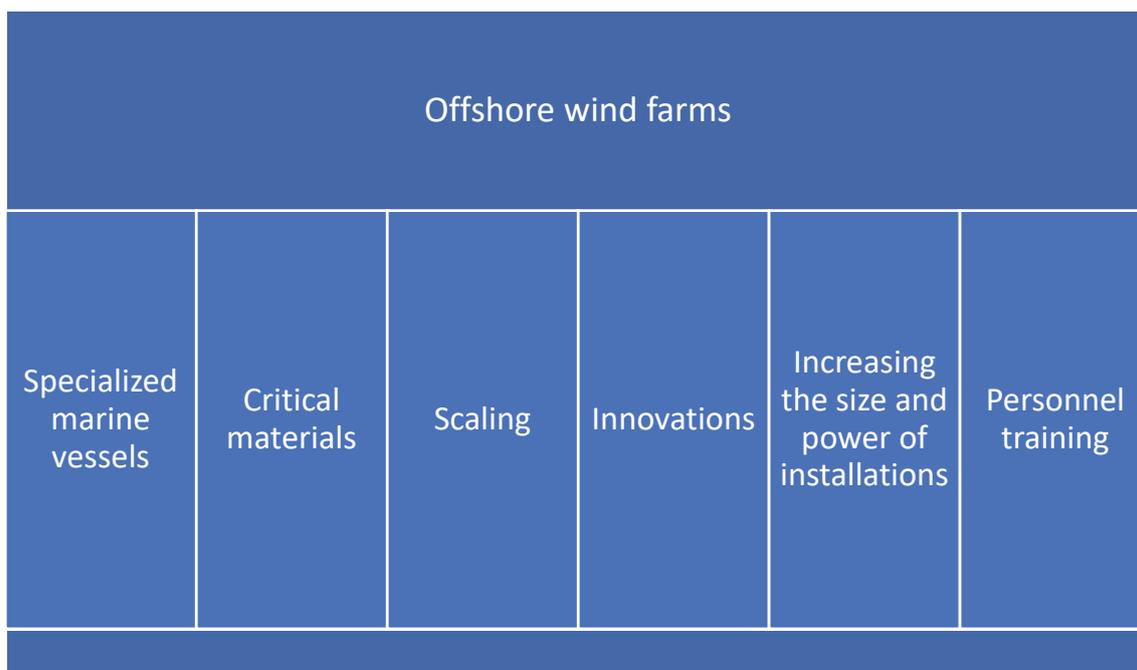


Figure 4 – Offshore wind farm development model

Source: developed by the authors

Sweden, Italy, the Netherlands, Denmark, and several other countries also hold significant positions in the European wind energy market. It has been shown that the capacity and efficiency of offshore wind farms are significantly higher, making management decisions on their construction feasible. Management measures for wind energy development include scaling up all

activities and projects, developing offshore energy islands, investment, innovation, enhancing the dynamism and geographic expansion of raw material supply chains and the production of critical materials for the energy transition, developing specialized marine vessels, and implementing legislative measures to stimulate wind energy.

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