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Wind Farming in the Baltic

On power generation and the future of Polish offshore wind farms.

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Air moves with respect to Earth's surface as a result of the uneven distribution of heat over major landmasses, with sunlight being absorbed to different degrees by land and oceans, and due to the rotation of the globe. Temperature and atmospheric pressure variations over different regions cause the flow of air which we call wind. Wind carries kinetic energy which humankind has been harnessing as a source of power for millennia, for example in sailing. Windmills are first mentioned in the Code of Hammurabi back in the 18th century B.C., where they are described as devices for pumping water and irrigating fields.

Today, wind power is used as a renewable resource for generating electricity by wind turbines which are designed for maximum efficiency. Their most important elements are blades which are turned by the aerodynamic force of airflow. The general principle at work here is the same as for aircraft wings, helicopter blades and sails. The flow of air causes a pressure

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differential over the blade surface which generates lift and resistance. Carefully setting the position of the blades relative to wind direction drives the rotor connected to the generator (either directly or using gears) to convert the kinetic energy of wind into electrical energy. Wind farms can be located on- or offshore.

Why offshore wind power?

It is universally known that climate change is the main factor driving the loss of biodiversity. Rising temperatures all over the globe are leading to damage and destruction of land and marine ecosystems. Wind power generated by offshore farms is widely regarded as a fundamental means of low-emission power generation in Europe, since it should help reduce the emission of greenhouse gases and preserve biodiversity.

Under an EU directive from 2009, energy from renewable sources was meant to contribute 20% of all energy used in the EU by 2020. In 2018, the European Parliament adopted an amended version of the renewable energy directive setting the goal for the EU as at least 32% by 2030. Another key goal is the reduction of greenhouse gas emission by at least 40% in comparison with 1990.

Wind power is the largest contributor to low-emission, renewable energy in the EU, and forecasts predict that this will continue in the coming decades. In 2018, wind power contributed 18.4% of the total potential of electrical energy generated in the EU with 170 GW from onshore and 19 GW offshore farms.

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Assuming that energy from renewable sources may constitute 50% of total power generation in the EU by 2030, wind power (on- and offshore) could contribute 21% of total energy.

In December 2019, the European Commission launched the European Green Deal. It outlines a clear vision of Europe reaching climate neutrality and decarbonizing the power generation system by 2050, stressing the key role of renewable energy sources, in particular offshore wind farms, in reaching this goal. Climate neutrality (also known as carbon and emission neutrality) describes a net-zero emission of greenhouse gases (including CO_2) – that is, achieving a balance between the emission and absorption of greenhouse gases.

In order to meet these targets, the wind power sector needs to grow significantly. According to the most optimistic scenario of the long-term strategy of the European Green Deal, the total energy generated offshore in Europe will rise to 450 GW, 85% of which will originate from the Atlantic coastal regions of France, Ireland and the UK (85 GW), the North Sea (212 GW) and the Baltic (83 GW). In order to generate 380 GW, the total area dedicated to wind farms would need to be 76,000 km^2 (assuming 5 MW/km^2), that is around 2.8% of the total area of the northern sea basins.

An important element of the planning process is identifying optimal locations for wind farms. Currently, offshore wind farms are built in shallow waters (depths of up to 60 m) at a safe distance from the coast and shipping routes. According to the WindEurope report published in February 2019, European wind farms are at an average distance of 33 km from the coast (41 km in 2017) and at an average depth of 27.1 m. The first offshore wind farm was built in Vindeby in Denmark in 1991; the UK generates 45% of all wind energy in Europe (measured in MW), followed by Germany (34%), Denmark (8%), Belgium (7%) and the Netherlands (5%).

The proposed locations of wind farms in Poland's exclusive economic zone are shown in Fig. 1. The sites are in relatively shallow regions (20–50 m) at a safe distance from shipping routes (min. 2 nautical miles) and do not interfere with areas protected for environmental or defense reasons or used to extract aggregate or hydrocarbons. The total area of the selected locations is approx. 2,245 km^2, which – assuming a density of turbines of around 8 MW/km^2 – means a potential total energy generation of approx. 18 GW. The real potential may end up being lower due to environmental limitations in and around the wind farms. Reasons might involve creating bird migration corridors or having to refrain from erecting some of the turbines due to adverse geological conditions. This is why governmental planning reports estimate that offshore wind farms in Polish waters will generate a total of between 8 and 11 GW by 2040. However, according to the report published by the wind energy industry association WindEurope, the optimistic scenario indicates that Poland's region of the Baltic has the potential to generate up to 28 GW. This would

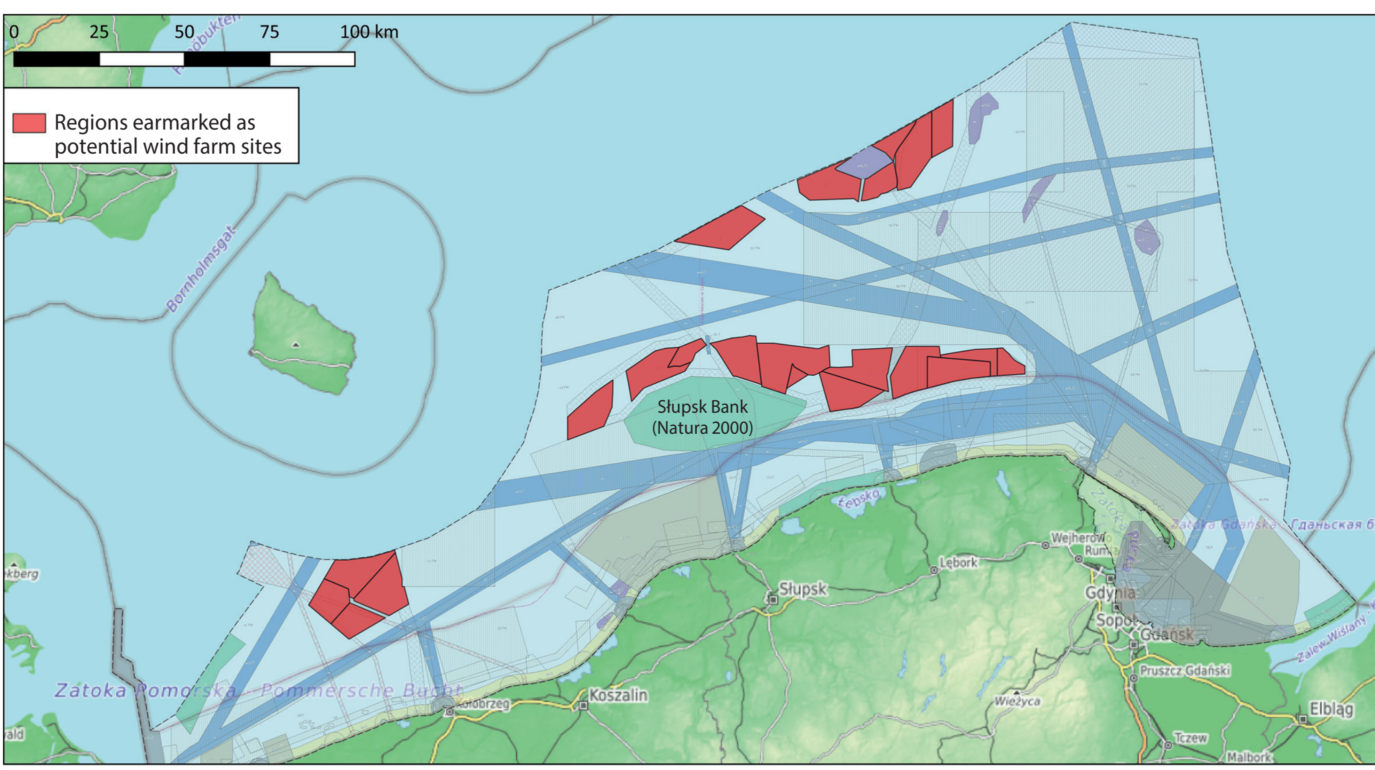
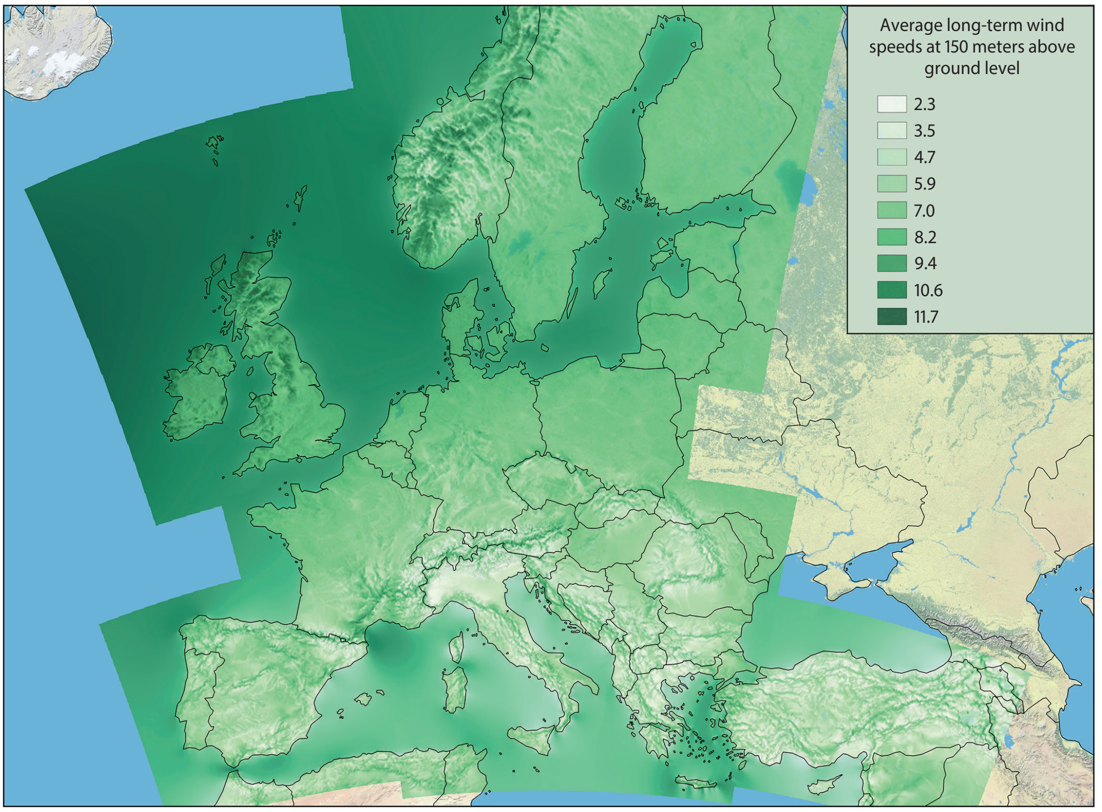


Fig. 1
Proposed locations for offshore wind farms within Poland's exclusive economic zone

SOURCES: VERSION 4 OF THE PZPPOM PROJECT; TOPOGRAPHIC OVERLAY: OPENSTREETMAPS



SOURCES: WINDSPEEDS: NEW EUROPEAN WIND (HTTPS://MAP.NEWEUROPEANWINDATLAS.EU/) TOPOGRAPHIC UNDERLAY

Fig. 2
Average wind speeds in Europe and Turkey at 150 meters above ground level

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require identifying new regions for development of wind farms, for example in the eastern reaches of Poland's economic zone. Since this part of the Baltic is deeper, however, such wind farms would likely need to be built on floating platforms.

Figure 2 shows a map of average wind speeds over several years in Europe at 150 m above ground level. Marine regions typically feature no obstructions and are expansive and flat with low friction coefficients, meaning that wind speeds at a given height are faster (by approx. 1.5–2.5 m/s) than over nearby land, making offshore wind farms more efficient. Better wind energy resources justify the construction of offshore wind farms in spite of their being more complex and expensive. Although wind conditions in Polish waters are not as favorable as those of the North or Irish Sea where first wind farms were built, they are still sufficiently good to justify building offshore wind farms.

Another important factor is the fact that a single construction project results in the creation of a powerful, efficient wind farm. A single offshore wind farm can generate power of up to 1.5 GW, while onshore farms in densely populated areas generate just 100–200 MW.

The main limitation to developing offshore wind farms is the difficulty in building permanent structures at depths greater than 60 m. However, the development of floating platforms could significantly expand our capacity for generating wind power. Examples include the Hywind project off the Scottish coast and Windfloat off the coast of Portugal. An important element of the development of renewable energy technologies is bringing together offshore wind power with processes such as hydrogen production and energy storage, which would help wind power make a greater overall contribution.

Wind turbines in energy production

The wind energy sector, both on- and offshore, is dominated by horizontal axis wind turbines (HAWT). Although alternative configurations exist (such as vertical axis wind turbines, VAWT), the development of material technologies and design and production methods have all contributed to a marked improvement in the efficiency and power of HAWTs. The power of a turbine depends on the diameter of the rotor; therefore, it is directly linked to the total area of the blades able to capture the kinetic energy of wind and transfer it to the generator. Increasing the diameter of the rotor and the height of the turbine results in greater power being generated due to the greater windspeeds higher above sea level. This is due to the distribution of speeds in the atmospheric boundary layer. Another advantage of offshore wind farms is the uniform terrain lacking obstacles such as forests or built-up areas and a lower level of turbulence at the turbine, making the conditions more stable.

Mold of a 75 m blade for a Siemens B75 turbine, at a factory in Hull

Currently, the largest offshore turbines can generate up to 9.5 MW (MHI Vestas); their diameter is 164 m and the top of the blade in the upright position soars to 187 m above sea level. The blades of such turbines are longer than the wingspan of an Airbus A380 and the height of the entire structure, including the section below the water level, exceeds the height of Warsaw's landmark building, the Palace of Culture and Science (237 m). As their dimensions increase, their power rating increases accordingly; in 2019 this was 7.8 MW, up by 1 MW on the previous year. In the wake of the ongoing development of methods of designing and manufacturing turbines, in 2020 General Electric and Siemens Gamesa unveiled a range of new solutions which will be gradually introduced in the coming years. Both turbines, General Electric's Haliade-X and Siemens Gamesa's SG 14–222, use rotors with diameters of approx. 220 m to generate up to 14 MW of power.

The efficiency of offshore wind farms is the function of wind conditions, the technology used by the turbines, and their relative distribution within the farm. Wake loss is an important consideration, since it can cause losses of up to 40% of the energy generated when one turbine is positioned behind other turbines on the windward side (Fig. 3). The aerodynamic wake effect can be reduced by selecting the optimal distance between turbines in the dominant wind direction at the design stage or by applying innovative technologies making it possible to move the turbines during operation. Since wakes extend for many kilometers beyond offshore wind farms, the effect must also be taken into consideration when planning the locations for new farms in Polish waters to avoid positing overly optimistic forecasts of the amount of renewable energy being generated, as was the case in Germany.

Under the wind conditions found in the Polish region of the Baltic, contemporary wind turbines of the 12–14 MW class will generate energy at an efficiency of approx. 40–45% (theoretical maximum power while operating non-stop). Power generation will depend on the number of turbines erected in a given farm, its size and layout and the presence of other wind farms. As-

Fig. 3
Visualizations of the wakes stretching out behind wind turbines, caused by condensation in humid air. The Horns Rev wind farm

suming the more optimistic variant (45%), the 11 GW of energy generated by offshore wind farms planned as part of Poland's energy policies by 2040 should meet approx. 25% of the country's energy demand as of 2020. This value is equivalent to the annual demand of around 17 million households in Poland. However, by the time the farms are operational in 2040, both the average energy demand and the way the energy market operates will be very different due to increased efficiency, the prosumer movement, distributed generation, development of new ways of storing energy, ongoing digitalization and all the social changes that go in tandem with these. All this means that the figures mentioned above should be seen as rough estimates.

WOJCIECH SULARZ

Grey seal taking a rest on a beach near Dębki

Environmental impact

Placing wind farms offshore has a significantly lower impact on the landscape and causes no noise concerns (apart from noise during installation). According to legislation governing the use of offshore areas, building artificial islands, structures and installations harnessing sea waters, currents and wind to generate electricity is only permitted within economic zones (Fig. 1). On most days of the year, wind farms are almost invisible from shore; they can be spotted if atmospheric conditions are particularly clear or at night, due to the blinking warning lights atop the turbines.

There are currently no wind farms in Polish waters, although surveys and measurements are ongoing to determine environmental conditions in regions marked for development. The data will be used to prepare reports on the potential impact of wind farms on the environment to make the best decision for the given location.

Using wind power to generate electricity does not use water or cause air, soil, or water pollution. However, unsuitably located or designed wind farms can pose a danger to sensitive habitats and species. This is why, prior to the construction of offshore wind farms and the laying of electricity cables, construction companies conduct extensive surveys and measurements in order to prepare an inventory of biotic and abiotic resources at the proposed site and along the cable route. In terms of the abiotic components, the surveys explore the geological features of the terrain (including geophysical and geological studies, collecting soil samples and testing sediment for traces of pollutants), determine the contour of the seabed, and test for major changes in depth. Hydrological studies measure the direction and speed of sea currents and examine the chemical and physical parameters of water at the site. The local weather conditions are also measured, including wind speeds, temperature and humidity. Biotic components include the local fauna such as fish, birds, bats and protected mammals such as porpoises. Organisms living in the benthic zone (near the seabed), including phytobenthos and zoobenthos, are also considered. These studies determine the extent to which the site is used by the given species, environmental conditions and any actions which need to be taken to minimize impact. All these results are used to prepare a report on the environmental impact of the proposed wind farm. Such a report lists any measures which need to be taken to minimize the environmental impact at each stage of the construction and operation of the farm. For example, underwater noise generated when drilling foundations into the seabed can be mitigated by using bubble curtains. It should also be noted that as well as the natural environment, the surveyors also investigate any anthropogenic objects found at the site, including those related to cultural heritage, as well as checking for any unexploded ordnance.

When planning the development of wind farms in the southern Baltic, it is important to assess their potential cumulative impact as well as that of individual farms. This is especially important when considering bird habitats. Figutre 1 shows the Natura 2000 region at the Słupsk Bank, which is a feeding and wintering site for seabirds such as long-tailed ducks, black guillemots, red-throated loons, and black-throated loons. Any wind farms on the northern or north-eastern slope of the bank would create a barrier for birds flying to the site. Wind farm development plans show that dense spacing of wind farms would make parts of the region uninhabitable for seabirds; this means that it is essential to leave undeveloped corridors interspersed among the farms to provide birds unobstructed access to the Słupsk Bank. Another major issue is noise pollution during the construction stage.

The issues outlined above show the importance of carrying out thorough and accurate survey work when identifying locations suitable for wind farms, so as to prevent local damage, protect wildlife habitats and minimize environmental impact. ■

Further reading:

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Our Energy, our Future: How offshore wind will help Europe go carbon-neutral, WindEurope 2019.

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