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Analysis of sea waves energy resources in the Baltic Sea and technical possibilities of their usage for energy generation in Poland

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Abstract
Due to the current ecological situation in the world, the demand for renewable energy is growing. Its use does not burden the environment because resources are renewed in a short time, unlike traditional fuels - coal or oil. It can be concluded that the main task of humanity is to choose the appropriate technology for obtaining renewable energy and adapt it to local conditions. The aim of the work is to present the technical, economic and environmental potential of using the wave energy of the Baltic Sea and the possibility of converting this energy into electricity. The theoretical and technical potential of sea wave energy that Poland could use was estimated. The most advanced methods of converting wave energy into electricity were presented, and the most promising technical solutions were selected for use in the Polish Exclusive Economic Zone and off the coast of our country. The selection of the most promising technologies - single and combined wave energy converters was based on reports on the operation of the first experimental wave power plants and wave converters operating in other waters. In terms of technology and economics, obtaining energy from sea waves is much more difficult than using solar or wind energy. However, along with the development of offshore wind farms and access to the infrastructure of the National Power System and the need to give up traditional, emission-related energy sources, wave power plants may have a chance for development in the Polish energy sector. It is an untapped source of renewable energy with great energy potential.

Keywords
Sustainable energy development, renewables, sea waves energy, Baltic Sea, Poland

Introduction

Due to the current ecological situation in the world, there is an increasing demand for renewable energy. Its use does not burden the environment because resources are renewed in a short time, unlike traditional fuels - coal or crude oil. It can be concluded that the main task of humanity is to choose the appropriate technology for acquiring renewable energy and adapt it to local conditions. Wave energy converters have the potential to increase the world's energy supply in the future in a sustainable manner and reduce dependence on fossil fuels. They will also allow for the reduction of CO_2 emissions and reduce their harmful effects on the environment. Among renewable energies, wave power is rapidly developing, aiming to exploit a potential that, in some cases, is comparable to wind power or solar power (Brooke, 2003).

The aim of the work is to present the technical, economic and environmental potential of the use of the Baltic Sea wave energy and the possibility of converting this energy into electricity. The study estimated the theoretical and technical potential of sea wave energy that could be used by Poland. The most advanced methods of converting wave energy into electricity were also presented, and the most promising technical solutions were selected for use in the Polish Exclusive Economic Zone and off the coast of our country. The selection of the most promising technologies - single and combined wave energy converters was based on reports on the operation of the first experimental wave power plants and wave converters operating in other waters. In terms of technology and economics, obtaining energy from sea waves is much more difficult than using solar or wind energy. However, along with the development of offshore wind farms and access to the infrastructure of the National Power System and the need to give up traditional, emission-related energy sources, wave power plants may have a chance for development in the Polish energy sector. It is an untapped source of renewable energy with high energy potential.

Literature review

The Baltic Sea is increasingly becoming the subject of discussions regarding marine energy resources. One of the first attempts to evaluate the technical energy resources for the Baltic Sea was made by Swedish scientists (Bernhoff et al., 2006). The potential they calculated is in the range of 24 TWh. Henfridsson et al. (2007) in the report found that the annual wave energy is approximately 56 TWh for the Baltic Proper. This result should be considered as the gross wave energy potential for the entire Baltic Sea. The average annual energy flux is estimated at 5 kW per meter of a crest. Waters et al. (2009) found that the average energy flux off the coast of Sweden is approximately 2.4 to 5.2 kW / m.

A study by Latvian experts (Avotiņš et al., 2008) found that the wave potential of the Baltic Sea is sufficient for energy conversion (Jakimavičius, 2018). Even in difficult weather conditions (where the wind speed is ~ 25 m / s, the average wave height is 3.5 m, and the average wave period is 8.4 s), the power density of the wave can reach over 50 kW / m^2. This proves that the annual total wave energy can be very high, even in a shallow and sheltered sea such as the Baltic (Matczak and Schultz-Zehden, 2013).

Wave energy density varies throughout the year depending on wind speed, wind direction and general weather conditions. The annual average wave energy density in the Baltic Sea is 2 kW / m^2. In the case of the Polish coast, wave energy resources are potentially sufficient and would allow sufficient amounts of electricity to be generated (Henfridsson et al., 2007).

The dominant wind direction seems to be the west wind, which means that the highest energy density is in the eastern part of the Baltic Sea, with relatively high densities also in its south-central part, where the Polish economic zone is located.

The wave energy potential is estimated at more than 2 TW, where only 1.5 TW can be recovered from the tides (Thorpe 2000). Assessment of the global wave energy potential has shown that most of the energy can be harvested when the significant wave height is 1.5 to 5.5 m and the (average) period is 7 to 14 s (Mørk et al., 2010). Similar results were published by Lenee-Bluhm et al. (2011). They found that the sea states with the highest energy contribution have significant wave heights between 2 and 5 m and periods between 8 and 12 s.

"The wind transfers the wave's energy to the water when the wind speed is greater than the wave speed. The minimum speed of the wind causing orderly waves is 6.3 m / s. There is energy dissipation in the wave. Therefore, for a given wind speed, there is a maximum wave height it can cause. If the wave height has not yet reached the maximum size for a given wind, the heave is defined as transient; when the waves have reached their maximum size, it is defined as steady (Paquier et al., 2015).

High waves are rare in the Baltic Sea as the enclosed nature of the sea means that wave formation must take place within the basin itself and is therefore limited by the wave run of the body of water. The in-run length, together with the wind speed, determines the main wave parameters: wave height, period and others. The time of wave travel and its speed determine the minimum path needed for wave travel. Therefore, the wave determined for a high-speed wind can occur only in sufficiently large waters and with a sufficiently long winding time from a specific direction over the entire wave travel area. The longest run-offs in the Baltic Sea are approximately 800 km (Street et al., 2014). The highest significant wave height in history - 14 m - was recorded in the region of the northern Baltic Sea in December 2004. However, according to most studies, the long-term height of a significant wave in the open part of the Baltic Proper slightly exceeds 2 m, and in the areas included in the Pomeranian poviat, the height may be 1.6 m (Soomere, 2016).

It is estimated that the potential energy generated by the waves of the Baltic Sea can be used both on a small and large scale. However, the actual amount of energy used will depend on many different factors, not only the parameters and wave potential.

The main factors influencing the profitability of a wave power plant include:

• type of technology used (low cost and high efficiency),

• energy transmission range (distance from the main network or direct recipient),

• possibility to combine with other applications (e.g. use of the same network system, minimizing the distance to the recipient).

All over the world, the technology of acquiring and processing energy from waves is the main focus of work and experiments on the construction of wave energy converters (WEC). On the other hand, the methods of transmitting energy from sea areas are well developed. The energy transmission towards the shore is relatively simple due to the very favourable nature of the Baltic Sea basin. In addition, if the offshore grid meets the high requirements of offshore wind farms, connecting a set of wave energy converters to it may be effective.

The excess energy produced can be used to produce hydrogen or aluminium. However, generating electricity from waves itself can be difficult, despite the fact that many theoretical methods for its conversion have been developed. The biggest problem is the variability of wave height and the strength of the power plant components. Wave power plants can be divided into marine, coastal and coastal. Another division points to the way we convert sea wave energy into electricity.

The first device collecting energy from sea waves was built in 1799 in France, but it was not until 1970 that the first oscillating column was built, in which water powered a generator (Vicinanza et al., 2014). At the end of the 20th century, research was started to assess wave power's technical and market potential.

Countries with long coastlines and strong winds, such as Great Britain and Ireland, already generate up to 5% of the required electricity using wave energy. Based on the available information from 2017. there were 209 ocean energy projects registered, including 47% wave energy, 49% tidal energy, 1% salinity gradient, and 6% sea and wind waves. A large concentration of demonstration projects is in Great Britain, Ireland and France. This is due to the distribution of the natural resources of this type of renewable energy. In terms of status, only 16% of projects have been installed or launched, 31% have been completed or decommissioned, 10% have been cancelled, suspended or suspended, and 42% are in the planning, approval or construction (extension) phases.

An interesting example of using natural RES resources can be Japan, where the development of only 1% of the coast in the continental part of the country could generate about 10 gigawatts of energy. Currently designed solutions, apart from known floating micro-power plants, use water microturbines at breakwaters. This is a unique idea because about 40% of the coast of Japan is surrounded by pyramidal breakwaters. Therefore, installations of this type will be able to fulfil two functions - to generate energy and protect the coast (Lenee-Bluhm et al., 2011).
The methods of converting wave energy to electricity are:
A Wave Energy Converter is a device that converts the kinetic and potential energy associated with a moving wave into useful mechanical or electrical energy.

The most important ways to convert wave energy to electricity:

• pneumatic - waves cause air movement in the oscillating column that drives the air turbine,

• mechanical - the buoyancy force is used to move perpendicular to the bottom, which causes the rotor connected to the generator to rotate,

• induction - the movement of floats is used to generate electricity through the use of coils moving with the floats in a magnetic field,

• hydraulic - only the tops of the waves overflow through the walls of the stationary tank, and the water flowing from the tank drives the turbine (Czerwiński, 2001).

Design work on wave energy converters led to the development of various WEC solutions: in the form of a small turbine (35 cm, 1.3 kW) - using the energy of the surge (OIST, 2013-2018), a wave star (Wave Star ApS, 2011 - suspended implementation), wave - bob (Wave Energy, 1999-2013), REWEC-3), FO3 etc. (Margheritini et al., 2012).
A point absorber is called a buoy or a float. It is small compared to the wavelength on which it floats. Typically, it can absorb energy in all directions, tracking the movement of water on or near the surface of the sea or in the case of underwater devices, moving up and down as the water pressure changes as the wave moves. Useful energy is generated by transmitting vertical movement to resistance, which can take many forms depending on the resistance configuration, power take-off and the type of transmission of the device from shore.

Some point absorber generators have a floating surface with an integrated PTO (linear generator) and are attached to the seabed, such as the Archimedes Wave Swing (AWS). AWS has the advantage that it works pointwise, i.e. it absorbs energy from waves travelling in all directions and "extracts" about 50% of the incident wave power (Leijon et al., 2008).

Other advantages of this system include its simplicity, lack of visual impact and the possibility of quick and easy replacement. It is also very profitable and has a good energy production ratio to the amount of material costs. This technology is suitable for any marine environment, including the Baltic Sea, as these devices can operate under the harshest sea conditions. The main problem is the insulation of the electrical components that are underwater.

The Oscillating Water Column (OWC) consists of a partially submerged structure that forms an air chamber with an underwater opening. This chamber contains air which is compressed as the incident wave causes free water surface to rise inside the chamber. Compressed air exits through an opening above the water column that leads it to the turbine and generator. As the water inside drops, the air pressure decreases and the air is drawn back through the turbine. This system is intended for use on the open ocean coast with high wave power. So it will not be used in the waters of the Baltic Sea.

The sea serpent gave its name to the next device - the Pelamis, which was a set of elongated floating devices that extended parallel to the direction of the wave and thus effectively "ride" the waves. As the incoming wave passes along the device, it generates movements inside the device that are used to generate energy.

The three-segment version of the Pelamis system is 130 m long and 3.5 m in diameter and provides 750 kW of power. It performs best in areas with high wave potential, such as the North Sea.

The overflow devices capture the water as the waves fall into the tank. The water, passing through a conventional water turbine (most often a Kaplan turbine) that produces energy is returned to the sea. The capture device may use "collectors" to concentrate the energy of the waves. The most famous device of this type - TAPCHAN (short for TAPered CHANnel), is a system in which sea waves are focused on a narrowing canal on the shoreline. Unfortunately, onshore TAPCHAN systems are characterized by low productivity, so they are only effective in regions with a deep coastal zone and a low tidal range (<1 m). This technology is not applicable in the Baltic Sea. Another solution is the overflow power plant, known as the "wave dragon". It was constructed in 2009 and installed in the North Sea near Denmark. It was the world's first offshore (Internet-1) sea wave power converter. Seven hydro sets, consisting of Kaplan turbines and synchronous generators with permanent magnets with a rated power of 2.3 kW each, produce about 40 MWh per year (Tedd, 2006). Due to the large size of the "wave dragon", it could potentially serve as a floating base for MW (multi-wave) wind turbines, thus increasing the annual power output at a minimal cost. The Wave Dragon MW project has attempted to scale-up operating and maintenance systems and identifies redundancy needs in monitoring systems (2009). Team members carried out an environmental impact assessment (EIA) that confirmed the minimal impact of the Wave Dragon MW on the physical, biological and human environment. It has been found that the potential impact on the seabed environment of the cable installation can be minimized by careful selection of installation sites.

When talking about the integration of a wave energy device with other marine devices, it is worth mentioning breakwaters - hydrotechnical structures serving to protect against waves. They are used at the entrance to the ports and on the promenades to prevent damage to the quays.

Theoretically, the combination of a WEC device with breakwaters is economically more cost-effective (Vicinanza 2013). as construction, installation, maintenance and operation costs are shared (Zanuttigh et al., 2009). reduce diesel oil consumption for electricity production (Nayar 2012), and secure the area in the process of wave dispersion. Additional benefits can be obtained by desalinating the water by pumping it through a reverse osmosis filter (Polinder and Scuotto, 2005), which would extend the life of the WEC (Schoolderman et al., 2011).

The integration of the WEC with the breakwaters took place in 1984 (Ojimaet al., 1984). The first implemented prototype for this type of integration was tested in Sakata (port), Japan, in 1989 (Takahashi et al., 1992). This port breakwater consists of five OWC chambers built separately as a port wall (Vicinanza and Frigaard, 2008). Positive results from previous research have increased the number of breakwaters inventions. Currently, there are several types of WEC concepts tailored for integration purposes, including overflow device, OWC, and tokowey engine. The OWC concept is the most frequently used and most efficient concept in breakwater-WEC integration, while in the Baltic Sea conditions, the best application is the integration of breakwaters with the WEC overflow due to the small wave power and sufficient depth.

In 2007, the Maritime University of Szczecin conducted a wave energy study to protect a part of the Polish coast - high and steep cliffs- from the hazardous effects of extreme storm waves. Passive methods, known and used so far, have been rejected, and thus a new active technology was created, consisting in damping the waves before they reach the shore (Kuźniewski and Grządziel, 2010). The breakwater is installed and immersed at a distance of several to several hundred meters from the shore. At the same time, with force compensation, the wave energy dissipates, and the wave height decreases. The efficiency of such integration increases when additional components with improved damping properties are installed. The structure of the active underwater breakwater was built on the basis of a patent. The advantages of such a solution include protection of the shoreline against erosion resulting from storm waves, environmentally friendly technology, no impact on the nature of the coast, reduction of breakwater exploitation costs, tourist and recreational attractiveness of the shoreline due to the lack of landscape interference (Chybowski and Kuźniewski, 2015). The design of breakwaters focuses on the need to reduce the amount of wave energy transferred by a combination of several principles, such as wave breaking, porous flow, wave reflection, transmission and shedding (Vicinanza et al., 2012). There are currently two types of breakwater configurations, i.e. a permanent breakwater (structure fixed to the bottom or in the ground below the bottom) and floating (portable structures that can be anchored anywhere). In Poland, both emerged and submerged breakwaters and active breakwaters are used (Igliński et al., 2017). However, the most common (90% of structures) on Polish coasts are compact breakwaters (according to the division in terms of structure, there are also openwork bridges supported on pillars). They will provide the best protection against waves and against sediment spreading.

Discussion of results

The mechanisms by which WECs can potentially affect the marine environment vary and may vary depending on the classification of the wave energy transducers, their orientation towards the wave front and their life process (installation, operation and decommissioning). In fact, draw attention to the fact that although some of the effects of introducing MREI (Marine Renewable Energy Installations) into the marine environment will be the same, regardless of the installation, other effects will be specific to a specific device.

The interactions of the WEC with the marine environment can be defined as negative and positive (Tvaronavičienė et al., 2018). Potential effects on marine organisms were investigated by Inger et al. (2009), Nelson et al. (2008) and Witt et al. (2012). The authors recognize the impact of the WEC on coastal tidal and demersal habitats, fish and large marine vertebrate habitats (sea birds, marine mammals and large fish).

Wave energy harvesting devices can induce physical and biological changes in habitats. Bald et al. (2008) proposed an effective scheme that classifies the level of effect as compatible, moderate and severe depending on the environmental receptor and the device's life cycle.

Physical changes that can occur are changes in hydrodynamics (Shindina et al., 2018), including wave (height decrease and wave climate changes) (Vo, 2020), ocean currents and tidal currents. This can alter the sludge size distribution and thus promote the accumulation of organic material.

Biological changes can be changes in the biodiversity and abundance of fish, birds, mammals and benthos species. The impact of noise can cause changes in the behaviour of cetacean populations (Wilson et al., 2007). Marine mammals, diving birds, and large fish that swim close to the surface (for instance, giant sharks) are at risk of colliding with or becoming entangled in the underwater elements of the WEC (Leeney et al., 2014). The risk of a collision between emerging mammals and birds will depend on how aware they are of the presence of surface structures. Semi-aquatic species most likely use floating devices as landing / sleeping / breeding sites, and the risk of injury may be entering / leaving structures. At the same time, introducing new elements may also introduce new species that may affect existing ones.

Choosing the right technology and adapting it to local conditions can result in optimal wave energy production. Most likely, the wave energy farms would be distributed and adapted to environmental conditions and would include marine protected areas as well as geophysical conditions.

Most studies are expected to develop marine wildlife, including marine weeds, barnacles and other invertebrates, especially on buoys. There is also some indication that serial installations of submerged energy transducers will create a "safe haven" for marine life, becoming closed surface artificial reefs. If the cables are laid out on a rocky bottom, the rocks will need protection, causing artificial reefs to form. The advantage of such a phenomenon, thanks to the emergence of a new habitat, can be the increase in marine biodiversity (Hnatyshyn2018). From a nature conservation point of view, such zones can positively impact fish populations, size and species richness. The foundations of wave energy devices can function as so-called secondary artificial reefs, locally strengthening the biomass for several sedentary and mobile organisms. On the other hand, wave power farms will be a handicap to commercial fishing, especially when trawling and nets are involved.

Of course, in the case of wave energy converters, a very positive effect on the climate can be found, especially the reduction of CO_2 emissions. However, the significance of this activity on a large scale depends on the correct installation of single and combined systems of obtaining alternative energy, as it is essential to connect wave systems with already existing installations, e.g. buoys or devices for environmental monitoring.

Submarine cables are usually buried on the seabed and then above the low water level with a connection to the ground station. Such technology can temporarily increase sedimentation intensity, reduce water clarity, and loss to benthos, pelagics and intertidal zone organisms (Freeman et al., 2013).

Certain types of wave power generating devices (OWCs) can be hazardous due to their electromagnetic fields, vibrations and oil spills, having a negative effect on marine mammal echolocation, fish reproduction and benthic macrofauna. Underwater noise is known to affect not only seals, dolphins and whales but also several species of fish that use the Earth's magnetic field for navigation (Li et al., 2011).

Unfortunately, the risk of injury to marine mammals as a result of their collision with devices installed in open water and with elements of fixing the structure to the bottom should also be taken into account. The presence of power structures attached to the seabed can cause the washing out of the seabed adjacent to moored devices or around buried cables.

The landscape may also be disturbed by the presence of devices on the water surface (their target size is therefore important), construction vessels and machines present during underwater construction, and the presence of the substation itself, which should also be taken into account when locating the power plant.

Issues requiring further research.

Sea cables generate electromagnetic fields, but whether they affect marine species is still unknown. Floating structures on the surface of the water have been shown to attract both young and adult fish. There is no clear explanation for this, but several hypotheses exist. They can provide protection against predators, provide food availability, spawning substrates and resting places (Streimikiene, 2020). The buoy at the test site can be expected to function as a fish aggregation device. However, as noted earlier, the activity of the electromagnetic field can also be hazardous to the environment.

Environmental effects vary according to the scale of the project and depend on the location and ecosystem of the area. In Europe, most MREI studies require an Environmental Impact Assessment (EIA) to determine the impact of development on the environment and biological and physical processes (Gill et al., 2012).

The energy policy of Poland and the European Union results from the gradual depletion of fossil fuels, the need to diversify energy sources and ensure an increase in energy security and an increase in energy demand. Increasing the use of renewable energy sources is an opportunity to implement economic development in accordance with the principle of sustainable development (Štreimikienė, 2021). The global energy potential contained in renewable energy sources can provide annually many times more resources than the total energy consumption currently amounts to.

The economic potential of wave power is estimated at around 2,000 TWh per year - representing 10% of the world's total electricity consumption. The investment costs in this sector amount to EUR 820 trillion. The cost of generating electricity from waves has shown a significant reduction over the last twenty years, averaging around € 0.08 per kWh at a discount rate of 8%. Compared to the average EU electricity price of around EUR 0.04 per kWh, the price of electricity generated from waves is still high - 0.004-0.7 (Astariz et al., 2015). However, it is assumed that this cost will decrease with the development of technology.

It is commonly believed that the energy producer pays for the installed capacity (P, in kW) and then receives payment for the produced energy (W, in kWh) once a year. The Swedish windmill's best-performing utilization rate is 29%. In theory, in Sweden, hydropower (all types of water-based energy) has a much higher utilization rate, up to 60%. The utilization factor for wave and tidal energy is typically between 30-40% of the rated power (Allan et al., 2011). The estimated utilization rate for the Pelamis system is between 25 and 40%, depending on the conditions prevailing in a given location. Other sources say that the utilization factor for wave power - the ratio of the average generated power to the power of a power plant - can be as high as 50% or 4,380 h / year.

Therefore, the costs incurred during the lifetime of a wave energy farm can be divided into four categories:

- pre-operative costs;
- capital cost;
- operation and maintenance costs;
- decommissioning costs.

Pre-operative costs include engineering tasks such as site investigation, design, environmental impact study, and approval process. The capital cost includes: structure, mooring systems, power take-off shaft (PTO) and control systems, connection to the onshore electricity grid and installation. For wave energy, just over half of the cost is related to PTO structures and control systems. Other elements, such as connection to the grid, play a similar role in sharing the costs. Finally, O&M costs account for a significant portion of the total lifetime costs, although capital costs account for approximately 70% of the total costs (Dalton et al., 2015). The use of average cost values normalized by installed capacity (based on kW or MW) is an appropriate approach due to the scarcity of project or device-specific cost data in the public domain (Svazas et al., 2019). Pre-operative costs depend on the project's location, as each country has its own regulatory framework, fees, and rates. The costs of initial research, design and other engineering tasks related to the commissioning of the wave farm range from EUR 550,000 to EUR 2.5 million, and the consent costs can be estimated at 2.83% of the nominal power expressed in watts.

The investment cost includes the purchase of all equipment and design elements and their installation. Table 1 shows the capital cost values used in the previous work, which depend on the degree of development of the installation. Importantly, the capital investment is made before the start of the operation of energy farms, thus creating a debt that must be repaid during the estimated 20 years of operation of the installation (Carbon 2006). Thus, the time for return on capital investments is relatively long and subject to uncertainty over market regulation and energy prices, which are quite volatile. Due to the advancement of wave technology, when developing a wide range of wave energy converters (WEC), it is not easy to quantify the overall cost of the WEC. Literature suggests that the cost of a WEC, including the PTO system and its installation, is in the wide range of EUR 2.5–6 million per MW installed (Raamet, 2010). The cost of the WEC structure depends on the material and total weight. Steel is often the material of choice, and the reference cost is EUR 3,400 / tonne.

Table 1. Valuation of capital costs based on available data.

Category	Installed capacity (MW)	Capital costs	Units	Year
Initial demonstration	5	6,912	$ kW–1	2011
Demonstration	20	5,035		
Advertisement	50	4,347		
Geography (high cost)	>1	16,050	$ kW–1	2013
Geography (average cost)		8,780		
Geography (low cost)		5,480		

Sources: own study based on Previsisc M, 2012. The Future Potential of Wave Power in the United States. Prepared by RE Vision Consulting on behalf of the US Department of Energy. World Energy Council, 2013. World Energy perspective. Cost of Energy Technologies.

The cost of installation depends on several factors, in particular, the proximity of the ports with the necessary equipment available in the time required to install all the project equipment. Moreover, weather conditions can strongly influence the installation and its maintenance. Operating conditions depend on the state of the sea and wind levels and the system's availability. Offshore operations are typically not performed at wind speeds above 12 m / s or wave heights above 2 m (Harris and Wolfram, 2004). The operating cost is estimated at 15-20% of the investment costs (equipment, mooring, transmission elements, etc.).

In addition, the cost of assembly must be considered. Mooring systems are widely used in the WEC. Chain mooring is the most widely used system and can be calculated as EUR 300 per tonne. It varies depending on the diameter and overall length of the mooring rope. The latter is usually estimated as 3–5 times the water depth (Stavytskyy et al., 2018).

The cost of a PTO system - including generator, power electronics, control and safety systems - can be estimated at EUR 5,000 per kW for technology. The generated electricity must be exported to land. First, the electricity generated by all devices must be concentrated in a hub or take-off point where it can be properly processed and delivered to the onshore grid. In the early stages of development, individual devices are likely to be connected directly to the grid connection point.

The cost of a submarine cable consists of the cost of the cables and their installation. Both cost components are a function of the cable length, which depends on the layout of the farm and the distance from the transformer.

In addition to the initial costs, an estimate of the lifetime service cost of the installation should be made. Calculating this cost is a complex process as there is not enough experience in operating wave energy installations. Nevertheless, it is possible to obtain estimates based on the experience of oil and gas extraction and offshore wind energy. Thus, the operating costs of offshore installations are often EUR 30 per megawatt hour. This cost includes scheduled maintenance, unscheduled maintenance, insurance, and other costs (land lease, administration, etc.). Scheduled maintenance is usually performed during the summer months to minimize weather downtime and loss of production. However, unexpected breakdowns are inevitable and unplanned maintenance is also required. Recent experiences in the field of offshore wind energy can be taken as a benchmark (O'Connor et al., 2013) to determine the cost of land insurance and rental. In addition, it should be considered that after 10 years, the WEC installations have to be temporarily removed from the sea for a full revision which is estimated to cost around 4.2% of the initial expenditure. More detailed values can be obtained depending on the farm attributes (e.g. turbine layout and turbine configuration), local conditions and maintenance strategy.

The decommissioning cost should also be considered. The dismantling operation can be considered as the reverse of the installation. It has been proposed to estimate decommissioning costs at half of the installation costs or at 0.5-1% of the initial investment.

In economics, an externality is a cost or benefit that affects a third party that has chosen not to bear that cost or benefit. Externalities often occur when the production or consumption of a private price balance for a product or service cannot reflect the real costs or benefits of that product or service for society as a whole. In the presence of externalities, the market equilibrium ceases to be effective: "deadweight loss" appears, and the Pareto optimum deteriorates - market failure appears.

There are two breakdowns of externalities: according to the type of impact and the type of costs. In the case of the first division, the effects may be negative (land take, air pollution, water abstraction and pollution, noise, waste generation, impact on the environment in the event of an accident or landscape transformation) or positive (additional energy production, income, use effects, synergy - connection to a common network, construction of common roads). However, on the basis of the second division, two types of costs can be distinguished: private and social.

Private costs are a measure of the best use of resources among the alternatives available to an electricity producer.

By contrast, the social cost of production, which includes both private and external costs, concerns the best alternative use of resources available to society as a whole. Since the price of a good or service producing externalities will tend to equate to the marginal cost to the producer (and the marginal personal utility to the buyer), electricity prices are biased.

This difference between private and social costs affects the electricity market's rules and is particularly important for the renewable energy sector. Market prices are key signals with regard to the type of product (in this case, electricity from different sources) and the amount of production (amount of electricity) to be produced. In this respect, the price of electricity generated by conventional sources associated with negative externalities (external costs) is artificially low. Hence, consumers will buy more of this type of electricity at an artificially low price than at a price reflecting the full cost of production. As a result, more electricity will be produced from conventional energy sources than would be possible if all costs were taken into account.

On the other hand, electricity from tidal and wave energy, which is associated with positive externalities (Galetovic and Muñoz 2013), will be "poorly produced" as the marginal cost is now higher. Indeed, if the spill-over effects were included in studies comparing the economic viability of different technologies, the cost competitiveness of renewable energy would change significantly. Coal and fuel technologies see a significant increase in their equalizing cost value when their negative externalities are internalized - exceeding the cost of certain renewable energies such as onshore wind.

Conclusions

The paper provided an analysis of the energy resources of the Baltic sea waves of the Polish coast and the technical and economic possibilities of obtaining their energy, taking into account the fact that at the current level of development of the world's hydropower industry, there are many types of wave energy converters that can also be used in the Baltic Sea areas, including in the area of the Polish coast.

The results of the analysis showed that work should be undertaken to implement the WEC integration technology with the already existing sea facilities: breakwaters, and OWT in order to reduce the costs of operating both technologies. Investing in systems of this type would have a positive impact on the climate, as well as on the stability and energy independence of Poland. What is needed is research directly on the Baltic Sea and its potential energy resources, the impact of infrastructure on the environment and finding technologies suitable for low-energy waves. There are also gaps in small-scale design studies, even in combination with other projects; indeed, most of the existing converters have not yet been tested in the Baltic Sea environment.

The analysis of the energy resources of the waves of the entire Baltic Sea and areas of the Polish coast, with particular emphasis on the use of the Polish Exclusive Economic Zone, allowed us to conclude that the estimated value of wave energy from the entire Baltic Sea is 24 TWh per year. The theoretical potential of wave power in the area of the designed offshore wind farms is 6 GW. The technical potential of the power coming from the waves in the area of the designed offshore wind farms using the technology amounts to approximately: WaveBob - 262 MW; WaveStar - 1200 MW; WaveDragon- 1880 MW

The technical potential of the capacity that can be obtained from the coastal area can be 4 GW. Therefore, the total technical potential of the power possible to install wave energy converters in the area of the Polish coast is greater than the peak power of the largest Polish coal power plant (Elektrownia Bełchatów). Therefore, it seems advisable to develop these technologies in Poland.

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