Limitations and Opportunities for Wave Energy Utilization in the Baltic Sea: the case-study of Estonia

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Abstract

The EU plans to achieve climate neutrality by 2050, which requires it to be prepared to reduce emissions on its territory by 80% compared to 1990 levels. In Estonia renewable energy potential is primarily reflected in bioenergy-based cogeneration, wind energy, and in the production of green gas/biomethane, while solar energy only became widely promoted throughout the region in recent years. The target percentage of renewable energy use in Estonia for 2020 was 17.6%, with the current average in Estonia at 24%, with 30% planned by 2030. The intent of the Authors is to show limitations and opportunities of the application of wave energy in the Baltic Sea Region alongside with such widely adopted renewable energy sources as wind generation and photovoltaics as an alternative to fossil fuels.

This is a case-study on limitations and opportunities for wave energy potential in the Baltic Sea on the example of the Estonian territorial waters. A survey is conducted with industry experts in Estonia in order to understand possible and desired usage of wave energy in offshore and coastal applications including seafaring, ports, maritime traffic services, maritime rescue, sea tourism and marine planning. Other relevant studies on the subject in the region and in other areas are analyzed in order to take account the aspects that did not arise in the survey conducted. Mapping of limitations, including natural barriers, such as NATURA2000 reserves, salinity, depth, and their impact on wave energy prospects as well as political and legislative burdens is carried out and then tested against the expectations of the industry experts and other possible usage of wave energy in the region.

The quantitative value of the study lies primarily in mapping the marine environment. Locations where sea wave energy could be an appropriate means of providing electricity will be discussed. Areas where wave energy production is limited will be discussed in order to determine the reasons for the limitations and provide proposals for mitigating the obstacles, if possible. For instance, in practice this can translate to the installation of wave energy converters in nature reserves, provided that it does not disturb protected wildlife, e.g., if the unit is installed underwater or in a secluded location, and necessary environmental impact assessments are carried out.

Expected Results: 1) By taking limitations and potential into account and proposing an optimal theoretical model of wave energy converter (WEC) based on that, the paper contributes to the rising awareness and real application of wave energy conversion in environments with low wave intensity such as the Baltic Sea; 2) the article can also be used by the Estonian and similarly placed public administrations as a background research for energy-policy related decision making processes; 3) the case-study of how limitations and opportunities in applying wave energy in the Baltic Sea region can be used as a showcase for other regions that face similar issues.

Keywords: Wave energy, Renewable electricity supply, Marine resources, Wave energy converters, Baltic Sea

Introduction

Currently, every member state of the European Union is trying to achieve the target goals of the Paris Agreement (UNFCCC, 12 December 2015) plans for preventing climate change. The conventional means of achieving this goal were the diversification of energy sources with the addition of renewables to the more commonplace fossil fuel sources, modernization, and optimization of power grids, as well as the search for anthropogenic activities that harm the environment and their subsequent restriction, particularly concerning air quality.

Landlocked countries are increasingly concerned with the role of oceans in climate change as well. The sea stores everything that enters it as a massive accumulator, but besides life-giving solar energy it also accumulates the refuse and waste produced by inhabited areas and other anthropogenic activities. (Lesley & Christopher, 2020).

We cannot accurately estimate nor anticipate where and when a source of a new harmful substance or activity will emerge. While exploring our habitat we often stumble upon opportunities for correcting and preventing the harm that anthropogenic activities cause to the environment. We also try to assess risks and prevent new potential harmful sources from emerging by limiting anthropogenic activities at sea. (Mark, et al., 2021)

If we were to address the crux of the problem and attempt to inspect the process of the emergence of new technologies (both in energy and mechanics), we could surmise that the fact of an innovation's existence alone is not sufficient for the adoption of its technological principle. For this to happen the sector in which such a technology was to emerge should be ready for its practical adoption. To do this, it is necessary to regulate and adjust the innovations' point of origin, namely the legal systems of participating countries, on a daily basis.

Several Baltic nations have already included ocean energy in their government strategies in order to promote the development and adoption of wave energy, most notably Sweden, Denmark, and Finland. Government strategies in these three states are to promote ocean energy development with favorable taxation, research subsidies, and development programs, in order to increase the share of renewables in total energy production to reach carbon neutrality. (Pierre Ingmarsson, 2019)

In this article the impact of various types of restrictions and the emergence of new energy sources will be assessed. For this purpose, article will handle the study area, as a territory of the European Union, and carry out a qualitative analysis of the possibility of the emergence of marine energy in addition to already established renewable energy sources. Following that we will assess the types of restrictions that prevent or contribute to the emergence of new energy sources in the given state's energy market. And in conclusion, we will analyze which mechanisms are necessary to facilitate the emergence of innovative approaches to power generation in the European Union and to achieving climate neutrality.

1. Current state

If we try to assess the state of the wave energy industry in the Baltic region on the basis of existing scientific literature, we will come to the conclusion that it is at the very beginning of its journey: and several attempts have been made to study and describe the potential of energy from the sea wave in the Baltic region. (Bernhoff, et al., 2006) (Jakimavičius, et al., 2018) (Kasiulis, et al., 2015) (Soomere & Eelsalu, 2014) (Henfridsson, et al., 2007).

2. Main parameters of the studied area:

2.1. First limitation – Size and resource

It is an established fact that in order to convert sea waves into electricity they must fulfil the necessary criteria of height and mass, which produce waves capable of transmitting potential and kinetic energy in the form of heat or electricity. But in the Baltic Sea such high waves are exceedingly rare - the largest recorded wave in the Baltics had a height of 8.2 meters (Tuomi, et al., 2011), and the path that a single wave can travel in a straight line without obstacles reaches a maximum of 800 km (STREET, et al., 2014). The average significant wave height for the Baltic Sea is 0.5 m (Björkqvist, et al., 2018). Based on this, we can identify the first serious limitation - the limited surface area, depth, and longitude of the Baltic Sea, which reduces wave propagation and intensity and therefore limits the total wave energy resource (Figure 1).

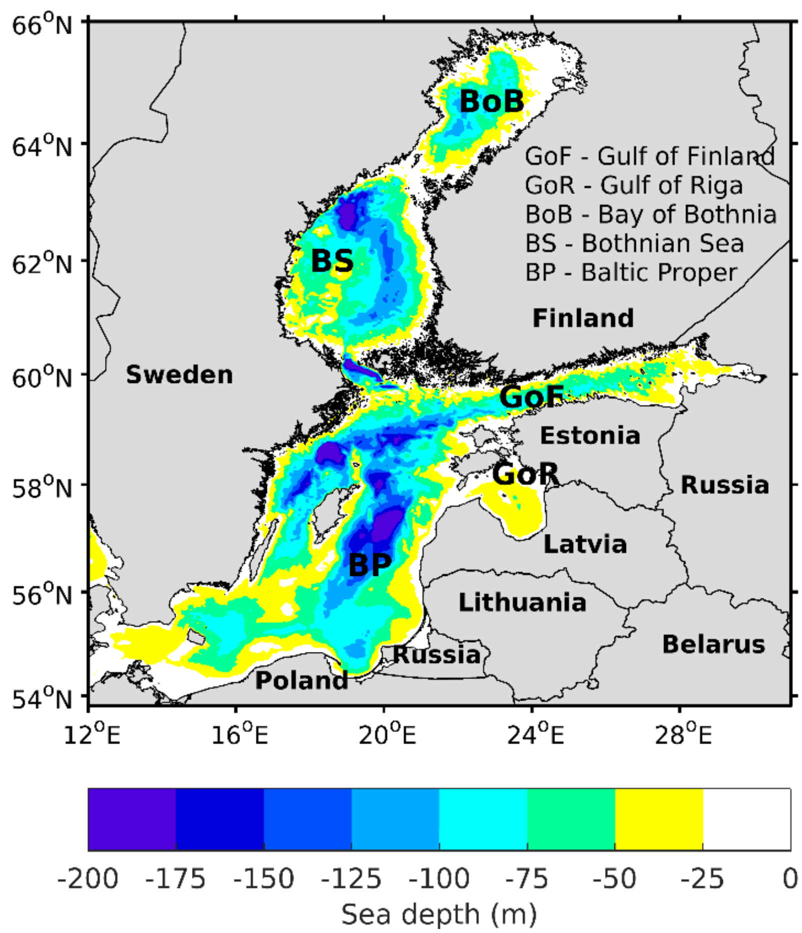

Figure 1. Study area with sea depths. (Author's figure 2021)

Several attempts have been made to estimate the wave energy resource contained in the Baltic Sea. As our article concerns the eastern coast of the Baltic Sea, namely Estonian territorial waters, we will rely on the studies of these locations during this study. (Jakimavičius, et al., 2018) (Soomere & Eelsalu, 2014). Based on the conducted simulations, it can be concluded that the energy resource of Estonian territorial waters is 611 MW of which approximately 73% can be industrially utilized (Soomere & Eelsalu, 2014).

2.2. Second limitation - Ice

The second limitation which serves as an obstacle to the adoption of wave energy in the Baltic region, is the ice formation during winter months, which at large part results from low salinity of the Baltic Sea. It is possible for a significant portion of the Baltic Sea to be covered with ice (Vihma & Haapala, 2009), which should be taken into account when designing a viable wave converter for local conditions. An ice cover strongly diminishes the propagation of sea waves, (Squire, 2018) making it an important factor to consider, as winter months are the most energy productive period in the Baltics. With regional ice formation patterns in mind, sufficiently durable materials must be used in the design of sea wave converters. The primary parameter of such a material should be its resistance to the mechanical effects of ice. Inertia-carrying ice fragments contacting the surface of the equipment can cause irreparable damage sufficient to put a wave energy converting device out of order.

Based on annual observations of ice coverage in regions of the Baltic Sea over the period 1971-2000, the following pattern can be observed within the regions of the study area: the annual average number of days of ice coverage has been 147 in the Bay of Bothnia (BOB), 101 in the Bothnian Sea (BS), 74 in the Gulf of Finland (GoF), and 0 in the Baltic Proper (BP) (Mats Granskog, 2006). As such, wave energy applications in the Baltic Sea are best applied south of the Bothnian Sea, which is consistent with more populated coastal regions of the Baltic.

2.3. Third limitation - Marine protected areas

When describing available resources, we must first assess their actual availability. In addition to the restrictions imposed by natural conditions, there are also restrictions imposed by public regulation. The largest network of restrictions in the Baltic region is connected to the NATURA2000 network (European Commission, 2021) (Figure 2).

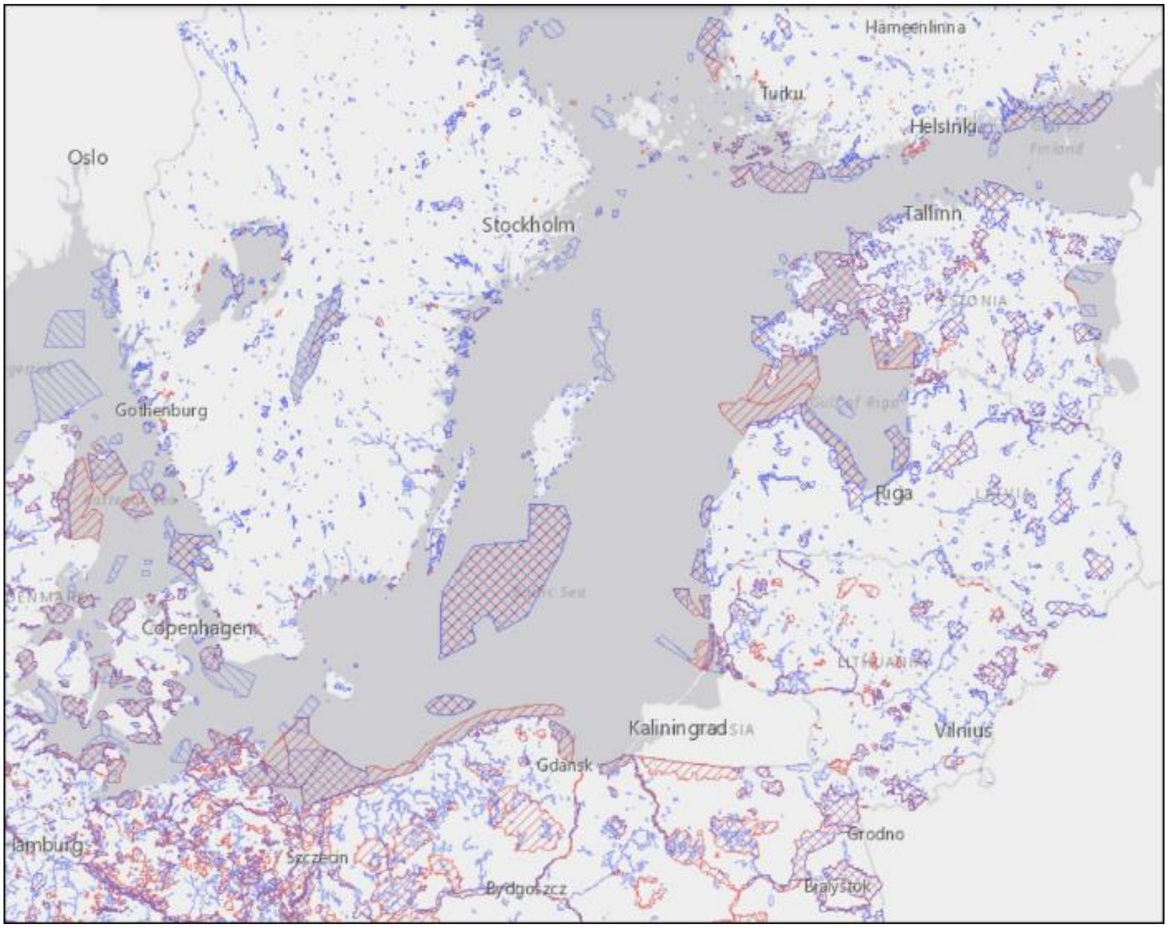

Figure 2. Protected nature areas in the Baltic Sea. (Natura 2000, 2021)

This network establishes protected areas in regions endangered by anthropogenic activities as a home and habitat for endangered flora and fauna. In addition to protected areas, public regulation mandates environmental impact assessments for any wave energy related installations in the sea, to determine their impact on local environments and wildlife, and prevent potential damage.

2.4. Fourth limitation - Energy conversion issues

Each energy converter possesses its own level of efficiency. At sea, this parameter is the lowest among renewable energy sources, as technological solutions to increase efficiency have so far been economically inefficient. If we assume that a wave energy converter can extract approximately 80% of the available resource immediately on-site, following subsequent transformations only 50% of the theoretically available energy would reach the coast. (Bernhoff, et al., 2006) Other limitations would be of temporary nature and caused by a specific locale's inherent features.

As the number of existing wave energy converter tests conducted on-site in the Baltic Sea is limited, we have exhausted the selection of existing sources on the topic during the writing of this paper, with primary sources mentioned above in the "Current state" section. This circumstance complicates the process of determining the suitability of WEC technologies for local environments and conditions – a factor that plays a larger role in a technology's operational efficiency than the base efficiency of the conversion system itself. Therefore, a greater number of physical tests in the marine environment of the Baltic Sea is necessary for proper evidence-based analysis of WEC technological compatibility with Baltic Sea conditions. Future research on the topic should focus on identifying WEC technologies that are most suitable for the Baltic Sea environment, with local marine conditions accounted for.

2.5. Fifth limitation – Awareness of wave energy

While conducting initial conversations with sector stakeholders we came to the conclusion that the limited awareness of ocean wave energy may be another obstacle for the adoption of wave energy in the Baltic Sea region. In order to test this hypothesis, in May 2021 a questionnaire was developed and distributed among 48 stakeholders within the energy and maritime industry, of which 9 submitted an answer (Table 1).

1. Which marine sector do you come from?	Research and education	Industry	Navigation markings	Ports	Energy
	3	2	2	1	1
2. Are you aware of wave energy applications in your sector?	Yes	No			
	7	2			
3. Please name possible uses of wave energy in your field of activities.	Electricity generation on land	Electricity generation at floating facilities			
	5	4			
4. In what time frame could you see wave energy becoming an alternative to the current energy sources you use?	2025-2030	2030-2035	2035+		
	4	3	2		
5. Would it be possible to use wave energy in a field other than your own	Yes	No			
	8	1			

Table 1. Energy and maritime industry stakeholder questionnaire results. (Authors' table, 2021)

The questionnaire consisted of six questions. Answers to the first question reveal that the respondents came from five sectors related to maritime – research and education (3 respondents), industry (2), navigation markings (2), ports (1) and energy (1). Secondly, 7 out of 9 respondents had heard of the usage of wave energy in their field of activity. Thirdly, all 9 respondents named possible usages of wave energy in their field of activities, namely as converted into electricity (5 respondents) or for electricity generation also at floating facilities (4 respondents). Fourthly, to the question in what time frame could they see wave energy becoming an alternative to the current energy sources they use, four respondents indicated years 2025-2030, three 2030-2035, and two 2035 and later. Fifthly, only one respondent answered negatively to the question, if it would be possible to use wave energy in a field other than their own. Sixthly, eight respondents indicated other possible uses of wave energy apart from their own field. In addition, although the questionnaire was anonymous, six respondents (67%) left their contacts indicating that they wish to receive information about the possibilities of using wave energy and the development of a wave energy converter in Estonia in the future.

Conclusion

There are approximately a hundred proposed wave energy converter concepts, and over 50 implemented projects. (Clemente, 2021) Accounting for the abovementioned limitations we can approximate the general parameters of a device that could be effectively utilized in the Baltic Sea waters. However, the goal of this paper is not to elevate any specific type of wave energy converter, but to determine the hypothetical scale and boundaries of an initially applicable wave energy converter for Baltic conditions, and we have demonstrated the limitations of implementing an innovative energy source, in the context of Estonian conditions. We can conclude that the approach proposed at the start of this article is optimal, with the sole addition to the possibility of connecting wave energy converters into parks or grids being their possible automation based on real-time forecasts. Such a system would rely on the installation of data-collecting buoys around wave energy converters, which would transmit live wave data to a converter in order for it to optimize its power output in real-time.

Accounting for the second limitation, we can assume that the energy flow in winter is at its highest at sites where the sea surface is not covered with ice, and absent at sites where the sea surface is frozen. Additionally, the ice can cause damage to a device, meaning that avoiding contact with ice should be prioritized when picking a location. With this in mind, it is necessary to create the conditions for relocating installed devices or removing wave energy converters entirely for low-production winter months. Additionally, the option of sinking the mechanism for the winter period should be considered.

Accounting for the third limitation, we can conclude that the availability of wave energy resources is often constrained by public regulation, which is a fact that should be respected in these circumstances. However, it is necessary to consider that the installation of wave energy converters can in some cases not only to cause harm to the surrounding environments, but also benefit the growth of artificial reef ecosystems, which can serve as a viable justification for the installation of wave energy converters in otherwise protected areas, provided that environmental assessments confirm the low impact of such installations.

And finally, accounting for the fourth limitation, we recommend that existing marine infrastructure be used for the installation of sea wave converters. Despite the fact that ports normally operate as territories where wave power is diminished through active means, such as the construction of breakwaters in order to avoid damaging the vessels moored on the premises, there are normally plenty of locations with sufficiently deep waters around ports, which can be used to install smaller scale wave energy converters. This would also serve the benefit of allowing potential developers to narrow down their choice of WEC technologies for such applications.

Contrary to the initial hypothesis on awareness of wave energy being a limitation to the usage of wave energy in the Baltic Sea area, the results of the questionnaire show support and interest for applying wave energy in various sectors and a general expectation of wave energy's imminent emergence.

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