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ORIGINAL RESEARCH ARTICLE

Assessment of wave climate and energy resources in the Baltic Sea nearshore (Lithuanian territorial water)

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Summary The main task of the present research was to analyse wave climate and evaluate energy resources in the Lithuanian territorial waters of the Baltic Sea. Wave and wind parameters were analysed according to long-term measurement site data. Distribution of wave parameters in the Baltic Sea Lithuanian nearshore was evaluated according to wave modelling results. Wave energy resources were estimated for three design years (high, median and low wave intensity). The results indicated that in the coastal area of Lithuania, waves approaching from western directions prevail with mean wave height of 0.9 m. These waves are the highest and have the greatest energy potential. The strongest winds and the highest waves are characteristic for the winter and autumn seasons. In the Baltic Sea Lithuanian nearshore, the mean wave height ranges from 0.68 to 0.98 m, while the estimated mean energy flux reaches from 0.69 to 1.90 kW m^{-1} during a year of different wave intensity. Distribution of energy fluxes was analysed at different isobaths in the nearshore. Moving away from the coast, both wave height and wave power flux increases significantly when water depth increases from 5 to 20 m. Values of the mentioned parameters tend to change only slightly when the sea is deeper than 20 m. In a year of median wave intensity, the mean wave energy flux changes from 1.10 kW m^{-1} at 10 m isobaths to 1.38 kW m^{-1} at 30 m isobaths. The identified differences of wave height and energy along the selected isobaths are insignificant.

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1. Introduction

Ocean waves are considered as a clean and renewable source of energy with a tremendous worldwide potential for electricity generation. Essentially all of the energy contained in a wave (95%) is located between the water surface and the top one fourth of the wave length. This energy can be extracted in different ways, which has given rise to a large variety of available and deployed technologies (Kempener and Neumann, 2014). However, no single device or generic type has been proven superior to others and it is likely that different types will suit separate deployment zones that can be exploited (O'Hagan et al., 2016).

The highest global net power (excluding areas where $P < 5$ kW m^{-1} and potentially ice covered ones) is computed for regions of Australia and New Zealand — 574 GW, South America (W) — 324 GW and Europe (N and W) — 286 GW (Mørk et al., 2010). Since seasonal variations are generally significantly larger in the northern hemisphere, the southern coasts of South America, Africa and Australia are particularly attractive for wave energy exploitation (Falcao, 2010).

The Baltic Sea, a relatively shallow inland sea of the Atlantic Ocean, also receives increased attention when marine power resources are being discussed. One of the first attempts to evaluate a technical energy resource for the Baltic Sea was made by Swedish scientists (Bernhoff et al., 2006); the potential calculated by them is in the range of 24 TWh. The report of Henfridsson et al. (2007) stated that annual wave energy is equal to approximately 56 TWh for the Baltic Proper. This result should be considered as the gross wave energy potential for the whole Baltic Sea. The annual average energy flux is estimated to 5 kW m^{-1}. Waters et al. (2009) found that the average energy flux off the Swedish Coast is approximately between 2.4 and 5.2 kW m^{-1}.

A study by Latvian experts (Avotiņš et al., 2008) concluded that the wave potential of the Baltic Sea is satisfactory for converting energy. Soomere and Eelsalu (2014) assessed the wave energy potential of the eastern Baltic Sea and concluded that the best location for wave energy converters is in the nearshore at water depths of 15—20 m. On average, the wave energy flux is 1.5 kW m^{-1} and reaches up to 2.55 kW m^{-1} in selected locations of the north eastern Baltic Proper. The wave energy resources are much smaller (normally around 0.6—0.7 kW m^{-1}) in the interior of the Gulf of Finland and in the Gulf of Riga.

Lithuanian experts also acknowledge that the southeastern Baltic Sea provides a great potential and possibilities for electricity production from offshore renewable energy sources (Blažauskas et al., 2015). The wave power flux for annual wave heights in the Baltic nearshore at Klaipėda varies from 1.6 kW m^{-1} in a high intensity year to 0.4 kW m^{-1} in a low intensity year (Kasiulis et al., 2015).

The assessment of global wave energy potential revealed that the majority of energy can be extracted when significant wave height ranges from 1.5 to 5.5 m and when energy (mean) period is between 7 and 14 s (Mørk et al., 2010). Similar results were published in another study (Lenee-Bluhm et al., 2011): the sea states with the greatest contribution to energy have significant wave heights between 2 and 5 m and energy periods between 8 and 12 s.

High waves are rare in the Baltic as the enclosed nature of the basin means that all wave generation must take place within the basin itself and is therefore limited by the fetches of the basin. In the Baltic Sea, the longest fetches are approximately 800 km (Street et al., 2014). All-time highest significant wave height of 8.2 m was recorded in the Baltic Proper in December 2004 (Tuomi et al., 2011). However, according to most reconstructions, the long-term significant wave height in the open part of the Baltic Proper slightly exceeds 1 m (Soomere, 2016).

At the southeastern part of the Baltic Sea, southwest and west were indicated as the most frequent wave approach directions. These directions also correspond with the typical direction of the strongest and prevailing winds at the Lithuanian coast (Kelpšaitė and Dailidienė, 2011). Average annual wave heights near Klaipėda at 6 m depth for the year of different wave intensity are as follows: high intensity — 0.89 m, median intensity — 0.67 m and low intensity — 0.53 m (Kasiulis et al., 2015).

Various models can be applied to simulate wind-generated waves. One of such models is a third-generation wave model SWAN (Simulating Waves Nearshore) (Booij et al., 1999; Ris et al., 1999), developed at the Delft University of Technology. This software for computing random short-crested wind-generated waves in coastal regions and inland waters is widely used for estimation of wave energy potential (Akpınar et al., 2012; Benassai et al., 2013; Iglesias et al., 2009; Iglesias and Carballo, 2009, 2010; Tsoukala et al., 2016). Another widely used model which simulates the development of the sea state in two dimensions is WAM (Hasselmann, 1988). It was also applied in numerous studies (Iglesias et al., 2009; Mazarakis et al., 2012; Staneva et al., 2016) and is often employed in the Baltic Sea wave investigations (Kelpšaite et al., 2011; Soomere and Eelsalu, 2014; Soomere and Raamet, 2011a,b; Street et al., 2014). The model applied in the current study, the Nearshore Spectral Wind-Wave Module of MIKE 21 (MIKE 21, 2012), describes evolution of wind-generated waves in nearshore areas and was successfully used in wave studies as well (Gopaul and O'Brien-Delpesh, 2006; Johnson, 1998; Tsoukala et al., 2016; Vannucchi and Cappietti, 2016).

Analysis of different scientific publications showed that there is no detailed evaluation of wave distribution and energy resources in the Baltic Sea nearshore at the Lithuanian coast. Such evaluation would be useful when selecting the potential location for wave energy converters in the future. Therefore, the main task of this research is the analysis of wave and wind parameters according to long-term observation data, mean wave height and energy flux distribution in the Baltic Sea Lithuanian nearshore according to wave modelling results. Wave energy resources were estimated at different nearshore depths in a year of high, median and low wave intensity.

2. Research object and data

The research object is the Baltic Sea nearshore at the Lithuanian coastline. The Klaipėda Seaport, located at a navigable strait, is the northernmost ice-free port on the eastern coast of the Baltic Sea (Fig. 1). The continental coast of the Lithuanian coastline is located north of the port,

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