Local Wave Height Amplification by use of a Submerged Lens

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ABSTRACT
The potential for increasing the wave energy flux by focusing the wave energy is studied in the Havsul area, offshore the western coast of Norway. In relatively shallow water, bathymetry gradients result in wave refraction effects and the paths of wave energy transport are modified. Neglecting the effect of ocean currents, refraction effects induced by an ellipsoidal shaped lens, placed at the sea floor upstream the plant, is studied using the framework of linear wave theory. The lens is designed to increase the significant wave height at the potential wave power plant. Using more than 50 years of hindcast data, it is found that the inclusion of the lens increases the wave energy flux by 29%.

KEY WORDS: Wave refraction; Wave spectrum; Wave energy; Energy amplification.

INTRODUCTION
The ocean wave field represents a large amount of energy. Offshore, where the fetch length is only limited by the dimension of the wave generating phenomena (e.g. the low pressure system), large waves regularly develop. As the waves propagate toward land, they are affected by the presence of coastal landforms such as islets and archipelagoes, which act as barrier for the waves, as well as decreasing bathymetry that causes wave breaking. Therefore the energy potential of the wave field will usually be considerably lower near shore than it is over open water. Since it is often more advantageous to install wave power plants near land, where maintenance can be made regularly and the connection to the electricity grid is less demanding than for offshore power plants, methods to amplify the wave power potential locally should be considered.

When the wave length is comparable to the ocean depth, variations in bathymetry will affect the wave energy propagation, since wave energy propagation speed depends on the local water depth. Therefore waves that propagate toward shallow water may bend and wave energy focus. This is often referred to as depth induced wave refraction. A detailed description of wave energy focusing downstream a shoal was given by Berkhoff, Booy and Radder (1982). The study showed that a potential utilization of the wave refraction phenomenon is to place a lens at the sea floor, where it acts to locally amplify the wave energy flux. The theory of wave energy focusing by a submerged lens has been confirmed by both theoretical and experimental studies (e.g. Griffiths and Porter, 2012; Grue, 1992; Stannes, Løvhaugen, Spielkavik, Mei, Lo and Yue, 1982; Mehlum, 1982). For wave energy applications the lens will have to be designed in a way so that wave energy converge in a fixed region downstream the lens.

In this study the potential effect of wave energy amplification by the use of a submerged lens is elaborated and evaluated at a near shore location. The applied method is based on the backward ray tracing technique presented by Mathiesen (1987) and the conservation of wave action (Bretherton and Garret, 1968). The study area under consideration is the Havsul area, offshore western Norway. Here a large potential for offshore wind power has been documented (Christakos, Reuder and Furevik, 2013; Frøysa, 2010; Johnsen, 2005). As demonstrated by Azzellino, Ferrante, Kofoed, Lanfredi and Vicinanza (2013) it is expected that a combination of power plants for wave and wind energy production will increase the energy potential and allow for a more efficient utilization of the electricity grid. In order to assess the potential effect of local wave energy amplification, the wave energy spectra are compared to the non-pertubated scenario, i.e. the wave energy obtained without modifying the rays by the use of a lens.

METHODS
Wave power
The wave energy flux can be calculated according to the following formula (e.g. Cornett, 2006)

\[ P = \frac{\rho g H_s^2 c_g}{16} \alpha(T_e, h), \] (1)

where \( P \) is the wave energy flux per unit of wave-crest length, \( \rho \) the density of seawater, \( g \) the gravity constant, \( H_s \) the significant wave height, \( c_g \) the group velocity, \( T_e \) the energy wave period and \( h \) is the water depth. \( T_e \) is linearly related to the peak period, \( T_p \)

\[ T_e = \alpha T_p, \] (2)