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The techno-environmental potential of offshore pumped hydro storage: A case study of the Dutch North Sea

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Abstract

Energy storage systems (ESS) are required to overcome the challenges of large-scale integration of variable renewable energy. Specifically, offshore ESS can increase the utilisation of offshore transmission cables and reduce stress on the grid. Marine pumped hydro storage (PHS) is a promising technology in this domain [1]. This study focuses on the role of a subsea PHS system in offshore wind farms, taking the Dutch North Sea as a case study. This novel technology stores electricity on the seabed by pumping water to a reservoir subject to the hydrostatic pressure of the overlying seawater, and releases it by letting the water flow back through a set of turbines to a second reservoir at atmospheric pressure, thus utilising the change in potential energy associated with pressure difference.

Anthropogenic activities increasingly deploy marine environments as sites of operation. Besides traditional uses like fisheries, navigation, defence and
mining, the climate and biodiversity crises respectively call for the uptake of offshore renewable energy systems and biodiversity-enhancing structures such as artificial reefs. These activities affect the marine host ecosystems, though impacts can be both beneficial (providing artificial habitats) and detrimental (disturbing species) [2].

The European Topic Centre on Inland, Coastal and Marine waters highlights the importance of marine spatial planning and environmental impact assessment (EIA) methods in elucidating conflicts of interest between the development of offshore renewable energy and protection of the marine environment [3]. Though the environmental impacts of offshore renewable energy projects such as wind and even wave farms have been investigated and are safeguarded by EIA legislation, only few studies can be found on offshore energy storage. Research on offshore ESS mainly focuses on either the (life-cycle) environmental impacts of a technology, or on the technical and/or economic performance in terms of efficiency, feasibility or costs and benefits. The combination is lacking for specific technologies and areas, such as subsea PHS. Therefore, this study integrates a techno-economic modelling approach with EIA methodology with the objective of obtaining the techno-environmental potential of subsea PHS as a novel

offshore energy storage system.

First, a literature review is conducted to compose a framework for the assessment of biological, chemical and physical impacts of offshore energy storage systems, consisting of a list of impact indicators and, if available, threshold values. Second, the framework is applied to a case study of subsea PHS in the Dutch North Sea. The *technical potential*, i.e., the optimal installed capacity from a technical point of view, is determined by modelling the Dutch planned offshore wind farms until 2030, allowing for installation of the storage technology to minimise curtailment of wind energy in the system. The model is formulated as a mixed-integer linear program. Third, the impact indicators are investigated for the resulting technology size and, taking threshold values into account, the *environmental potential* is determined. Last, trade-offs between technical performance and ecological effects are identified and discussed.

References

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