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GIS-based MCDM dual optimization approach for territorial-scale offshore wind power plants

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ABSTRACT

Despite the relevant potential of offshore resource to substantially mitigate the effects of climate change through the generation of renewable electricity, the full exploitation of such wind resource currently remains incomplete. To promote offshore wind energy projects, it is crucial to engage in comprehensive planning processes that encompass technical, social, environmental, stakeholder, and political considerations. Within this framework, this paper presents a combined approach based on Geographical Information Systems (GIS) and Multi-Criteria Decision-Making (MCDM) methodology to optimize the selection of offshore wind farm locations. The proposed methodology includes annual net electricity production as a critical factor in the decision-making process, which has been previously optimized with regard to the wake effect. Subsequently, the determination of potential locations involves key criteria such as technical feasibility, environmental impact, economic viability, and power generation potential. This MCDM-GIS approach was applied and evaluated in a case study along the Spanish coastline, considering 92 initial alternatives. The results indicate that the offshore wind energy targets established for Spain in 2030 and 2050 should be reevaluated, as the optimal utilization of the available area represents only 16% of the total potential area. Based on the aforementioned criteria, a suitability map was generated by integrating all relevant map layers, including their respective buffer zones.

1. Introduction

1.1. Background & Significance

Climate change, driven by greenhouse gas (GHG) emissions from fossil fuels' combustion, is a global crisis (Uusitalo et al., 2017). Moreover, in recent years there have been a surge in energy demand due to technology and population growth (Olabi and Abdelkareem, 2022), with fossil fuels still dominating in 2021 (ene, 2023). To meet the Paris Agreement goals and curb temperature rise, it is vital to reduce fossil fuel reliance (Lima et al., 2020), especially in the electricity sector (ele, 2023). Transitioning to renewable energy sources (RES) and nuclear energy effectively reduces GHG emissions in electricity generation (Ang and Su, 2016), and governments are promoting sustainability through the integration of renewables (Elavarasan et al., 2020).

Among RES, the wind sector, including onshore and offshore wind farms (WF), is a favourable choice for power generation (Molina-García et al., 2019). In the last three years (2020–2022), 906 GW were installed, including 64 GW from offshore wind farms (OWF) (GWR, 2023a). Despite the challenges in offshore wind energy due to working at sea (Esteban et al., 2011), offshore capacity has grown by 1180% in the past decade (Fig. 1). Unlike onshore WF, offshore wind energy is not land-constrained and has fewer environmental concerns (Sun et al., 2012). Moreover, OWF can provide energy to remote areas while promoting low-GHG electricity (Zheng et al., 2018). Ongoing research aims to integrate offshore wind energy into power systems, including power-to-X conversion, the North Sea Wind Power Hub, and different offshore storage solutions (Fernández-Guillamón et al., 2019).

The International Energy Agency (IEA) projects a global OWF potential of over 120 TW, capable of generating 420 TWh annually (International Energy Agency (IEA), 2020). Emerging markets offer a potential of 3.1 TW within 200 km from the coast (esm, 2019). The IEA envisions offshore wind growth until 2040, with scenarios projecting 365 GW and 560 GW of capacity (International Energy Agency (IEA), 2020). China

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