BENEFITS AND CHALLENGES OF CALIFORNIA OFFSHORE WIND ELECTRICITY: AN UPDATED ASSESSMENT

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Overview

Offshore wind (OSW) technology has recently been included in California's plans to achieve 100% carbon-free electricity by 2045. As an emerging technology, many features of OSW are changing more rapidly than established renewable options and are shaped by local circumstances in unique ways that limit transferrable experiences globally. This paper fills a gap in the literature by providing an updated technological assessment of OSW in California to determine its viability and competitiveness in the state's electricity generation mix to achieve its near-term energy and environmental goals. Through a critical synthesis and extrapolation of technical, social, and economic analyses, we identify several major improvements in its potential. First, we note that, while estimates of OSW's costs per MWh of installed capacity have generally documented and projected a long-term decline, recent technical, microeconomic, and macroeconomic factors have caused significant backsliding of this momentum. Second, we project that the potential dollar value benefits of OSW's greenhouse gas reduction capabilities have increased by one to two orders of magnitude, primarily due to major upward revisions of the social cost of carbon. Several co-benefits, including enhanced reliability, economic growth, and environmental justice, look to be increasingly promising due to a combination of technological advances and policy initiatives. Despite these advancements, OSW continues to face several engineering and broader challenges. We assess the current status of these challenges, as well as current and future strategies to address them. We conclude that OSW is now overall an even more attractive electricity-generating option than at the beginning of this decade.

Methods

Our assessment builds on the key features included in the the original study conducted by the senior author of this paper (Rose et al., 2022), and relies on a critical synthesis of the literature alongside interviews with experts in several domains related to OSW. The study highlights the direct benefits of OSW, which include the provision of relatively inexpensive electricity and reductions in greenhouse gas (GHG) emissions. Co-benefits relate to improved electricity system reliability, reduction in ordinary air pollutants, reduction in land-based environmental impacts, job creation, equity and environmental justice gains in both urban and rural areas, and California's potential leadership in OSW manufacturing support service industries. Furthermore, the study identified several challenges to be addressed, including the need for new transmission lines, expanded seaport and cargo vessel capacity, supply chain limitations, and concerns relating to ambient and ocean environments, wildlife, the fishing industry, the military, and decommissioning. Comparing these benefits and challenges together, we evaluate the progress toward California OSW being a viable and competitive renewable electricity generating technology.

Results

OSW has faced some economic headwinds in recent years that have temporarily constrained its value proposition for California's electric grid (NREL, 2024). However, OSW still exhibits several advantageous system, economic, and environmental attributes that are expected to improve as the industry matures. Recent increases in costs are likely to be offset by OSW deployment experience, supply chain and infrastructure improvements, and government policy support. In terms of co-benefits, the reliability of OSW is improving with advances in wind turbine technology and battery storage. In terms of environmental co-benefits, OSW can play an instrumental role in replacing natural gas plants, preventing land intrusion, and advancing environmental justice. Lastly, OSW continues to provide substantial job creation co-benefits, estimates of which have increased in recent studies.

Successfully developing OSW in California and capturing its myriad benefits will ultimately depend on how broader challenges and pitfalls are addressed. Effective transmission buildout will require more advanced interregional transmission planning, streamlined coordination, and improved permitting frameworks. Overcoming inadequacies in

the supply chain depend on significant port infrastructure upgrades, vessel construction and repurposing, expansion of domestic component manufacturing, and consistent government support. Government support and industry collaboration are also needed to address community vulnerabilities and cultivate a robust workforce to support a California OSW industry. Increased stakeholder partnerships are required both to garner support for OSW projects and to ensure their associated benefits are distributed equitably within and across local communities. Lastly, identifying mutually beneficial project agreements is critical to achieving a sustainable clean energy industry.

While it is imperative for the success of the OSW industry to rigorously evaluate, consider, and address all of these challenges and pitfalls, it is also important to acknowledge that no solution is perfect. Such challenges should not discourage investments in the energy transition and efforts to rapidly test and deploy renewable energy technologies. It is also important to consider that other alternative energy sources, especially the fossil fuel sources that OSW would aim to displace, come with their own set of significant drawbacks. It is essentially a question of which alternative strikes a better balance. In light of the current evidence to support OSW, and given the urgent need to rapidly decarbonize the electric grid, it is clear that OSW has the potential to offer far more benefits than drawbacks if it is implemented and planned correctly and holistically.

Conclusions

In light of the potential benefits and challenges posed by OSW electricity in California, we conclude that the technology has a bright future. It adds to the mix of technologies that can reduce GHGs and other forms of pollution, promoting the overall sustainability of electricity service provision. Expert consensus indicates that OSW is on the verge of being cost-competitive with most other renewable energy technologies and can improve electricity system reliability, especially in combination with solar energy. Attaining larger scale of development will be crucial to achieving this competitive threshold. Furthermore, there is strong reason to believe that costs will decline through production, economies of scale, and deployment, as witnessed in other clean energy technologies.

The economic benefits of OSW include substantial contributions to equity by offering employment opportunities in lagging rural regions. Environmental justice benefits are derived from ordinary air pollutant reductions in urban areas, where most remaining fossil fuel electricity generating installations are located. OSW is not, however, without its engineering and broader challenges. These obstacles and shortcomings can be overcome through design improvements, best practice operating experiences (including lessons from operating experiences of similar technologies), and stakeholder involvement in the siting, construction, and operation of OSW facilities.

A host of uncertainties face the OSW industry, including political considerations, which we have not speculated on, in favor of sticking to facts and expert opinions on the direct and broader ramifications of OSW construction and operation. While planning and operating experience will provide some of the greatest insights to advance OSW in California, the industry can also benefit from future research in several key areas. First, the extent of additional benefits from meeting the surging demand for electricity driven by data centers, artificial intelligence, electric vehicles, and electrification of the built environment. Second, research on strategies and complementary approaches to reduce OSW operating disruptions and enhance overall system reliability. Lastly, as climate impacts become more severe, energy infrastructure in California and across the globe will experience heightened risks. More research into the individual and system level resilience aspects of OSW will therefore be valuable to enhancing the industry's future viability.

Overall, we conclude that OSW is an increasingly attractive electricity generating technology, and the conditions in California are well suited to its development. While there are headwinds to bringing this technology to scale, the potential benefits are worthy of pursuit. If climate policy continues to gain momentum in the state and across the U.S., OSW should be considered an integral part of the solution.

References

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