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Analysis of Locational Factors for Enhancing Comprehensive Benefits in Offshore Wind Energy: A Systematic Review

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Abstract: Off-shore wind energy is an emergent and promising research field, although traditional onshore wind energy has already been explored for several decades. It has already been discovered that constructing wind turbines in the maritime space takes apparent advantages but meanwhile also creates disturbance that cannot be neglected. In academia, various locational factors have been described to estimate the rationality of different off-shore wind energy in certain regions. This study takes systematic research into the existing literature, compares each of the wind energy locational factors, analyzes how these factors determine the wind energy effects, and ultimately provides a clear summary of locational factors that are necessarily or mostly considered for the construction of off-shore wind energy facilities. As an academic review, the purpose of this study is to reveal vital factors and improve the comprehensive benefits of offshore wind energy. The result is that currently wind energy efficiency and benefits are highly relevant to natural environment factors, social technical factors, and financial factors. Other factors related to ecosystems are gradually raising the awareness of scholars, which can only be found in the latest research. It is common to figure out conflicts between different kinds of factors; thus, balance and optimization are required.

Keywords: Offshore wind energy, locational factors, comprehensive benefits.

1. Introduction

The appeal for reduction, even elimination, to the release of carbon dioxide prompted humans to rapidly develop clean renewable energy. There is no doubt that off-shore wind energy will make great contributions to achieve the carbon neutrality emission target by 2050. Compared with the traditional wind energy on the land, the off-shore wind turbines possess higher wind speed and fewer instances of static wind period, which appears to be more efficient [1]. The development of offshore wind energy varies between different countries and regions. In the application field, western developed countries have adapted this renewable energy earlier and more than other developing countries, which further promotes the domestic research devotion [2]. For example, Germany is considered to be the current global frontrunner in adapting off-shore wind energy [3]. As for developing countries like Jordan, previous studies show that there is huge wind energy potential in the farthest south Apaba-shore at the border of Sandi Arabia, and the area of the offshore site is nearly 53.8 km^2 [4]. It can be predicted that off-shore wind energy will play a more and more important role in the electricity

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generation system of human society. Scholars have revealed some of the locational factors that help to refine the existing wind energy farm or make feasible design.

In Section 2, the natural environment factors would be introduced, which can be further divided into wind energy potential and oceanographic features. The technical factors that can enhance the energy generation will be discussed in Section 2.2, and Section 2.3 contains financial factors. Other factors that are not common but also important will be involved at the end of this paper. All these factors are practical if carefully regarded to equip off-shore wind energy with comprehensive benefits, both in economy, society, and the environment for sustainable development. The value of location factors research lies in providing a criterion for an evaluation system of comprehensive benefits. With the help of this review study, other scholars will intuitively see the factors considered in the design of past offshore wind power evaluation models.

2. Analysis of locational factors

Offshore wind energy refers to the establishment of wind farms in coastal areas such as intertidal zones and nearshore waters to convert wind power into electrical energy. It is a clean and renewable way of utilizing the offshore wind resources. Like any other renewable energy, the locational factors of offshore wind energy generation are compound and various.

2.1. Natural environmental factors

2.1.1. Wind energy potential

Wind energy potential is fundamental to be considered, and almost every research into off-shore wind energy contains the analysis of wind power. In most circumstances, the wind energy potential is closely associated with the climate and geographic conditions. The difference in wind energy potential will possibly result in the development gap in wind energy application between regions around the world.

To quantitatively describe the wind energy potential in a certain region, Xia states that the potential of the wind power is highly relevant to its character of continuous operation, while the intermittent nature causes the reliability challenge [5]. Most scholars regularly measure the wind's intermittent nature by the wind speed distribution, wind energy density, and wind direction. Especially in the region where the climate is highly influenced by the monsoon, the energy efficiency will be more sensitive to the wind direction [1]. Usually off-shore wind turbines tend to require conditions of high wind speed, high power density, and stable wind direction. But in reality, the determination of the capacity size of a turbine is influenced by multiple factors [6].

Other factors like regional popularity density and distance from the coastal city, which can be considered as social factors to some extent, will also indirectly impact the wind energy potential [7].

2.1.2. Oceanographic features

The off-shore wind turbines are mostly constructed in the maritime area. It always has higher risks and more difficulties to operate large machinery and maintain facilities in the ocean. Sun emphasizes that oceanographic features like seafloor morphology, bathymetry, and land-sea interactions are common factors in many estimate models for off-shore wind turbines [6]. Their study draws the direct conclusion that the water depth is one of the key factors in determining the location of the offshore wind energy.

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2.2. Social technical factors

Looking back to the traditional renewable energy industries (solar, wind, hydropower, etc.), energy storage technology and energy regulation skills are widely applied to the mitigation of unpredictable energy fluctuation. To raise the efficiency of off-shore wind energy, these former strategies can also be adopted, which means that countries that have more experience in developing renewable energy will be more suitable for off-shore wind energy. The electrochemical storage system described by Yu can flexibly regulate the off-shore wind energy and optimize the grid scheduling [8]. Besides, Xia also introduced a distributionary robust optimization (DRO) model that can mitigate the intermittent variability of wind power [1].

To promote the power generation capacity, some scholars have devoted themselves to providing a multiscale hybrid method that can ensure the accuracy of wind power prediction as far as possible. Sun and Zhang claim that the accurate prediction of wind energy is paramount for reliable and stable energy operation [9]. Besides their prediction model, another research is made to take a theoretical analysis of meteorological data, where wind velocity distribution is tested and helps to find a better physical design of a power station [7].

The technology to invent new wind turbine blades can also advance wind energy efficiency and reduce the cost of facilities. Both the design of the turbine blade and the materials used for production can be constantly improved, especially when adapting to different environmental conditions. It is believed that the aerodynamic optimization of the wind turbine blade design is a key element in maximizing the profits of wind energy systems [10]. So, the advanced social technology could promise a bright future for the development of offshore wind energy.

2.3. Financial factors

Compared with fossil fuel, off-shore wind systems are not affordable for every country because of the expensive cost. That is probably why developed countries attached more interest than the developing countries. Although some regions have good capability of wind energy potential, the limitation of social economic feasibility hinders the wide spread of wind energy application. For example, Faouzi emphasized that many regions in India and Pakistan are not suitable to construct large-scale wind energy systems if taking financial stability and profitability into consideration [11]. These financial factors can also be discovered in China when scholars set several criteria to find a proper location for off-shore wind turbines.

The financial factors of offshore wind are multiple and complex. In the study made by Stephen, a vital reality is revealed: in the operational phase of the off-shore wind farm, the energy generation facilities can have an influence on other financial industries, including commercial fisheries and experiential recreation [2]. Whether this influence is negative is difficult to define without critical analysis. The off-shore wind farm can act as marine-protected areas (MPA), helping to enhance biodiversity and commercial fisheries.

Ultimately, the perfect infrastructure, especially a matched net of power grid lines will help to exert the most benefits of off-shore wind systems because the electric power generated in the ocean should be consumed on urban land, thus making the electric transmission with the high efficiency fundamental. Sun draws a conclusion in their study that in China the present off-shore wind farms are always located near the marine aquacultural areas and close to the power grid line [6].

2.4. Other factors

In Faouzi, when evaluating the feasibility of the wind energy for sustainable energy sources, two factors--public acceptance and relevant policy--are also specially noted, which means social culture and public awareness can make a difference in off-shore wind energy promotion [11]. Firoozi also

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regard occupation, infrastructure improvement, and other human livelihoods as important factors when planning the wind energy program [10].

In recent research, Stephen innovatively appeals for regarding ecosystem services (ES) as locational factors [2]. They claimed that studies in the past only focused on human profits while ignoring the environmental effect. Even in their research discovery, the impact of offshore wind farms on the marine environment is predominantly negative. Marine life especially several birds and fish, is strongly negative to keep surviving, and the ocean's natural aesthetic might get damaged. Many unintended negative risks like habitat loss, collision risks, noise, and electromagnetic field remain to be further studied and solved. Sun also raises awareness of the potential conflict with maritime activities caused by the construction of off-shore wind farms [6]. It was also mentioned in the study that the research into the decommissioning stage and deeper water structure of the offshore wind farm is still a paucity. More than 86% of possible impacts are unexplored [2].

3. Future trends and limitations

In the future, the research on offshore wind energy will continue to be conducted in different regions around the world, especially in developing countries with high wind energy potential and high electricity consumer demand. The life cycle of the offshore wind power turbine also deserves high attention from scholars because the construction, operation, and decommissioning of the offshore wind farm will cause different impacts on the environment and human society [2]. Other aspects, like the deep-water floating structure and the design diversity in different ocean maritime spaces, will apparently become the trends of the research.

4. Conclusion

Off-shore wind systems are under rapid development with the large demand of completing the international net zero emission target by 2050. With mature technology and vast ocean space for wind farm construction, recent studies created several models to help properly locate the wind farm and expected to achieve comprehensive benefits.

This paper reviewed some of the wind energy technologies and off-shore wind models for estimation, summarized most of the locational factors that were considered, and divided them into four criteria: natural environmental factors, technical factors, social financial factors, and other factors. These factors are expected to provide a systematic reference for the design of future off-shore wind farms and help to improve their comprehensive benefits.

In specific circumstances, the interaction of each factor is complex. The future study may focus more on the interaction between each factor, especially the natural environmental factors and social financial factors. These two factors are crucial for sustainable development while being conflicting most of the time, making it urgent to innovate the core principle of more advanced offshore wind energy technology.

By the way, this study does not provide a specific quantitative criterion that helps to estimate the weight between each locational factor, which is a limitation that requires further study. It is worth considering that after evaluating the benefits of certain offshore wind energy farms, which factor should be judged to take the primary responsibility for the design flaw if the energy benefits are far from expectations. Thus, in the future, the location analysis requires a proper quantitative standard to precisely identify the weakest factor that limits the comprehensive benefits.

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