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Sustainability Assessment of Wind Farms

Jake Hobbs

Abstract

Sustainable energy solutions are becoming increasingly popular as the shift away from conventional fuel-based energy solutions continues. Solar, wind, and hydro solutions are the most frequently used renewable energy sources. Modern wind energy solutions are usually constructed using a design of a large three-bladed horizontal axis wind turbine (HAWT). The blades are upwind facing, which helps support the turbine tower against environmental strain and torque ripple produced from the spinning motion of the blades. HAWTs are usually organised into large groups referred to as wind farms. Wind farms are becoming increasingly popular with their ability to adapt to offshore and onshore environments. In both scenarios, wind turbines have a relatively low footprint, with the land underneath still available to be utilised for agricultural and aquacultural purposes. This paper investigates the sustainability of wind farms by surveying a range of papers. The papers will cover the development, construction, and continued operation of wind turbines providing insights into the sustainability issues. Reviewing these papers will allow for an informed revision to the code of sustainability for future implementations of wind farms. The paper concludes with a case study to apply the suggested sustainability code in a contextual scenario and recommendations for the general engineering profession.

Keywords: Sustainability; Windfarm; Renewable energy; New Zealand.

1. Introduction

Global energy demand has and continues to increase as populations increase around the globe. As the global population rises, food consumption, water and consumer goods increase proportionally. The increased consumption of consumer goods demands more electricity be used to meet the production demand for the goods.

The traditional conventional approach of using non-renewable sources of energy such as coal, oil, and natural gas is becoming increasingly unpopular due to the by-products and limited supply. Processing non-renewable energy sources result in the release of greenhouse gases directly impacting global warming. Alongside greenhouse gases, air, and water pollution increases, affecting people and animals that depend on their surrounding environment.

As awareness has increased around the detrimental effects of conventional energy solutions. Interest in moving away from traditional approaches has increased. In recent years, sustainable energy solutions have gained considerable traction, with solar, wind and hydro solutions being the most commonly adopted approaches. Energy generation using wind as a renewable source produces around 5-6% of New Zealand's total electricity production [1-2], aligning with the global wind power contribution of 6%[3] and is set to increase with more wind turbines scheduled for installation [4].

As energy solutions move away from conventional approaches such as coal, oil, and petrol. Clean energy technologies like solar panels and wind turbines will naturally make up a higher percentage of electricity contributed to the national grid. These technologies are

considered eco-friendly and sustainable, making them increasingly popular in an environmentally conscious world. Initial construction requires large quantities of steel, fibreglass, plastic, iron, copper, and aluminium [5], installation requires suitable location and environmental impacts to be considered.

1.1. Objective

This paper aims to survey a range of papers to gather insights into sustainability issues involving wind farms' development, construction, and operations. This survey will help guide the creation of a code of sustainability suitable for modern wind turbine applications. The code of sustainability will then be used in a case study to assess its ability to be applied to a real-life scenario. The paper concludes with recommendations for engineers in the future considering implementing wind turbine solutions.

2. Literature Review

This section contains a systematic literature review that surveys two papers covering the sustainability issues of wind turbines/farms in New Zealand (NZ). Analyses of papers will reveal essential details about wind farms' construction, placement, and regulations. Sustainability is not just limited to environmental considerations but also encompasses social and economic factors to ensure that all project pillars are supported. These details will help shape the revised code of sustainability produced in section 3.

2.1. New Zealand Wind Energy Association

The New Zealand Wind Energy Association (NZWEA) represents over 65 companies with interests in the wind energy sector to provide the energy sector, government, and public with a reliable source of information. NZWEA's framework for the best practices of wind farm development in New Zealand [6] provides an overview of critical sustainability considerations when developing wind farms in NZ.

Development of wind farms occurs in several stages, according to NZWEA, and at each stage, sustainability considerations need to be made to ensure that the development proceeds acceptably. In the early stages of a wind farm project, a suitable location must be selected with consistent and appropriate wind speeds available to rotate turbine blades [7]. The developers of the wind farms should then take proper steps to ensure that the landowner, community, and tangata whenua are consulted to discuss the effects on the people and land, providing a socially sustainable project.

The construction and operation of wind farms is a large-scale industrial construction process that directly affects the environment. After consultation and consents have concluded, construction will begin. Initial construction will begin by preparing the selected land for the turbines, internal roadways, turbine platforms, and foundations that will need to be erected in preparation for the turbines. NZ's wind turbines must be transported to the site via boat and truck before deployment, thus adding another environmental consideration. To assist with understanding the impact on the land, an environmental impacts assessment should be completed to estimate the environmental cost and ways to reduce the impact of development.

The final sustainability consideration to make is the economic impacts of the wind farm during its operational lifetime. NZWEA states this depends on the wind farm developer, but largely positive economic growth has been maintained, as seen in the continued development of wind farms. Deloitte's study on the economics of wind development in NZ [8] states a decrease in key cost drivers in NZ. This is in line with global trends for wind turbines, while the favourable high quality and high average wind speed allow for a high energy yield. Both contributing factors promote positive economic sustainability.

2.2. Parliamentary Commissioner of the Environment

The Parliamentary Commissioner for the Environment (PCE) is one of three independent parliamentary officers that report directly to the speaker of the house. The primary role of the PCE is to investigate environmental concerns independently from the government and report the findings [9]. Wind power, people, and place [10] was produced by the PCE, which investigates the effects of commercial wind farms in NZ.

A significant focus of this report was investigating the community relationship between windfarm developers and local communities. Communities with higher engagement from wind farm developers in the initial consultation stage were more agreeable to the idea of development in their local community. However, wind farms' location, design, and size remain a primary concern for communities to preserve their landscape and environment while wanting to continue achieving sustainable development goals (SDGs). The involvement of local councils allows for higher engagement from the community during the consent and consulting processes. Hutt City Council (HCC) refused to consent to 47 wind turbines at Baring Head on cultural significance to tangata whenua, landscape, and geological unsuitability showcases a positive example of community engagement.

The PCE voices concerns as an environmental officer for considering all wind power as an energy source with no detrimental effects on the local environment. Reduced cost and accumulated knowledge from overseas wind farm developers may inflate the wind farm market reaching into over development and poorly executed implementations. The development of poorly planned wind farms may ruin the natural and rural character of the environment alongside the landscape. Typical wind farms are placed in high wind areas summiting hills and ridgelines, obscuring rural areas' aesthetic appeal. Summaries from the Wind power, people and place conclude that wind energy can be harnessed without harming ecosystems despite limited Limited coverage in the report on the direct effects of unwanted by-products of wind farms such as excessive noise, telecommunication, and impact on the aviary population despite concluding that no damage to ecosystems occur.

The PCE's economic sustainability issues focus on wind power development drivers in NZ. One of the main factors is NZ's position in atmospheric circulatory zones where wind speeds are above average. Suppose wind speeds are the sole economic driver of wind farm development. In that case, NZ consistently offers suitable locations with speeds of 5 metres a second and above, reaching the economically viable goal of 8 metres a second. The consistent wind speed allows farms to supply a constant stream of energy to the NZ national grid reducing reliance on other more expensive energy sources. Corroborating with Deloitte's economics of wind development [8], the PCE reiterates the reducing cost of wind turbines making the renewable energy solution a more economically viable solution, particularly with the rising price of electricity.

3. Code of Sustainability

This section uses the NZWEA best practice for wind farm development framework and PCE's Wind power, people, and place report to develop a code of sustainability. The best practice identified in the literature review will help shape the principles most applicable for wind farm development in NZ, focusing on the Resource Management Act (RMA) [11] and tangata whenua. Best practice sustainability principles identified will allow future developments to apply these principles, promoting a more environmentally, economically, and socially sustainable future.

3.1. Principle 1: Consultation of the Local Community and Tangata Whenua

In the initial planning stages of a wind farm, a case-by-case assessment of the effect on the local environment and community, including consultation with local iwi regarding tangata whenua. The assessment allows communities to voice concerns and grievances to

developers early in the proposal stages of development. Aitken et al. [12] show that a substantial increase in trust from communities towards developers and developments is gained by taking a proactive approach in wind farms' planning and pre-planning stages. Countries with more mature wind farm developments, such as Denmark and UK, have noted the positive effects of smaller community engagements and partial ownership of developments[13].

3.2. Principle 2: Environmental Engineering Consultation

Throughout the wind farm's operational lifetime, environmental engineering consultation ensures that developers take appropriate steps to avoid or reduce any negative impacts on the local environment. Wind farms are a source of green energy, positively contributing to the environment by reducing the reliance on conventional energy production approaches. Chipindula et al. [14] find that onshore wind farm developments, after operating for 6 to 14 months, have offset the initial productions environmental impacts. However, during the development to decommissioning the wind farm, appropriate steps should be taken to ensure that rural aesthetics, ridgelines, and waterways are protected. Developers should externally contract environmental engineers to maintain independence when conducting the assessment.

3.3. Principle 3: Utilisation of Wind Farm Land

As largely vertical structures, wind turbines utilise minimal land beneath the turbine proportional to the total area designated for wind farms. As most of the land is not being utilised, steps should be taken to ensure that the land is productively used to benefit site owners and local communities. Productive use of wind farm land examples involves agricultural or aquacultural utilisation and public recreation areas prompting further financial yield or community engagement. Members of the community other than the site owner typically receive few benefits from wind farms despite the perceived negative visual impact on the landscape. Such reimbursements should be made to local communities as compensation.

3.4. Principle 4: Compliance with Local Laws and Regulations

The operational life cycle should comply with all local laws and regulations from the initial planning stages to the wind farm's decommissioning. New Zealand based windfarms need to abide by broader government regulations and council consent conditions. The RMA and Treaty of Waitangi need to be heavily referenced throughout the wind farm lifecycle as two of the most important documents to consider. Compliance with the RMA and Treaty of Waitangi promotes safe practices for social and environmental sustainability in the community as best practices are adhered to.

3.5. Principle 5: Economically Viable Contribution

Wind farms must make a positive economic impact on the communities the wind farm is located in. The positive economic effects of wind farms can be measured in many formats. Metrics for analysing the positive economic impacts of wind farms include new jobs, tourism, increased cash flow into the community and site owners. Greene et al. reviewed the socioeconomic effects of a wind farm in Weatherford, Oklahoma [15], concluding that increased tax revenue from goods and services purchased locally from communities should be measured to fully understand the economic contribution of wind farm development and operation. Incorporating this claim with NZWEA and the PCE economic impacts will develop a fuller understanding of the financial contribution.

4. Case study discussion

Meridian Energy's West Wind farm is located on Terawhiti Station and Makara coastline near NZ's capital city of Wellington. The wind farm was constructed between 2007 and

2009, erecting 62 wind turbines capable of generating up to 142.6 megawatts of electricity [16]. Siemens 2.3-megawatt wind turbines were used, with a tower height of 67 metres and a total height of 111 metres. The construction of a temporary wharf at Oteranga Bay allowed turbine parts to be directly shipped to the West Wind site avoiding central Wellington streets. To transport the turbine parts from the wharf to the construction site, the development of 33 kilometres of roads proceeded. Developing West Wind came with unique challenges requiring innovative solutions that created a range of sustainability issues. The following sections will apply each principle from section 3 into context with West Wind farm's development and continued operation.

4.1. Principle 1: Consultation of the Local Community and Tangata Whenua

Consultation of the local community and tangata whenua did not occur before the application for the West Wind farm in line with their company policy. After lodging, the application Meridian did take steps to contact key stakeholders and community groups. However, opposition against the wind farm development from Makara residents was actively seen during the consenting and lodging of development plans through Wellington City Council (WCC). The total number of submissions received for consent from community members was 3,757, with 800 opposing the proposal, mainly Makara community members. Oppositions continued through the development of West Wind by the local community members voicing their concerns on the relative distance from residence to turbine [17].

Issues of significance to Māori were identified in the assessment period, and under the RMA, considerations for tangata whenua must be made. However, consultation with local iwi regarding the construction is not mentioned by Meridian or in the PCE case study of West Wind farm. Earlier consultation with local community members would have helped relationships between residents and developers. The overwhelming support from WCC and GWRC for the farm despite concerns raised by residents has reduced trust in the councils and Meridian significantly.

4.2. Principle 2: Environmental Engineering Consultation

Meridian did not undertake consultation with an environmental engineer during the development stages of project West Wind. An impact assessment covered many potential development issues, including ecological effects, water quality, noise, traffic, and natural and rural character effects. Although considerations had been made for potential impacts, an independent review from an external source would have provided a more detailed and accurate assessment of the environmental sustainability issues.

4.3. Principle 3: Utilisation of Wind Farm Land

West Wind farmland area has been successfully utilised for livestock farming shortly after early European settlement began in NZ. Since the installation of the wind turbines, the livestock occupation of the land has continued with negligible effects on total available land use and livestock wellbeing. Alongside the farming, recreational areas, including mountain bike and walking tracks, are open to visitors. The recreational areas were created with Makara community liaison groups utilising the old Post Office building to improve community relations and involvement.

4.4. Principle 4: Compliance with Local Law and Regulation

Meridian's development of the West Wind farm required consent and consultation from WCC and Greater Wellington Regional Council (GWRCC). Consents were granted from WCC for 1.7 million cubic metres of turbine platforms and roads and the temporary wharf structure for transferring the turbines from ship to land. The regulations imposed nationwide by the RMA legislation were strictly adhered to, with many references to the document throughout the development process. Due to the size of the West Wind farm, a case-

by-case assessment had to be conducted on the proposed development. Applicable sections of the RMA included but were not limited to the use of coastal marine area, regional and district plans, environmental protection agency consultation and Mana Whakahono a Rohe.

4.5. Principle 5: Economically Viable Contribution

As section 4.3 mentioned, the land is being utilised for livestock farming, contributing both to the utilisation of land and the continued economic contribution from developing the land. Recreational areas add additional financial yield with tourists and residents of Wellington city visiting the site for the diverse landscape and unique opportunity to get close to industrial wind turbines. The owner of Terawhiti Station receives compensation in rent for allowing Meridian to use the land. However, despite the largely positive financial burdens, local residents of Makara received no payment in any form for the altercations to the landscape [18].

5. Conclusion and recommendations

The organisations developing wind farms in NZ in the future should incorporate the principles produced and contextualised in sections 3 and 4. The sustainability principles promote good practices from wind farm developers, helping achieve success in economic, environmental, and social domains of wind farm construction. In future developments, attentions should be given to:

- Undertaking consultation with communities and iwi early in the planning stages via public gatherings and open days/QA sessions to improve community perceptions of wind farm development;
- Increased input from councils and communities into the placement of wind farms to reduce negative rural and environmental aesthetic impacts; and
- Utilising the land area occupied by the windfarm for additional purposes to maximise land productivity and usage within environmentally sustainable constraints.

These bullet points aim to improve the social, environmental, and economic yield of wind farms seeking to improve the perception of wind farms to the local and broader communities in NZ. The development of wind farms should always abide by local regulations and national legislation to ensure the safety and continued growth in the wind energy sector.

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