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# Wind Power Potential Assessment for Three Locations in New Zealand

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This paper proposes and evaluates an optimized system of offshore wind turbines operating as a renewable energy generating unit in New Zealand. A comprehensive simulation model has been set up, using several available commercial software packages to test performance, capacity and efficiency of the proposed system. Available wind records have been used to select three coastal regions which are suitable for wind energy generation and conduct simulation model runs at three locations. Findings so far have been firstly that horizontal axis wind turbines are the most suitable for offshore installation; secondly that a direct current microgrid appears suitable for linking to the onshore electricity supply network; thirdly, many coastal sites can be ruled out because generating capacity is too low or because site factors preclude installation; and fourthly there are some sites where simulation results indicate good potential for offshore wind energy and other site factors do not preclude development. Evaluation of the economic feasibility and returns is now in progress.

## 1. Introduction

Wind energy is one of the renewable energy sources already being used to meet the world's massive demand for electricity and reduce use of its fossil fuels Most existing wind farms have been built on land (onshore). The use of offshore wind energy commenced in 1990s, and its potential has been estimated as greater than onshore (Esteban et al., 2011). European countries commenced large offshore wind projects 2003 onwards (Kaldellis et al., 2013). Investment in offshore wind energy is forecast to increase until at least 2030 (Moccia et al., 2011).Presently, New Zealand has several onshore wind energy installations ranging from lower than 1MW up to 68 MW capacity, on elevated terrain inland and also close to the coast. But no offshore wind energy installations have been proposed or installed as yet. The effects of configuration parameters on the performance of wind turbines have been thoroughly investigated onshore (Esteban et al., 2011), and the findings apply equally to turbines installed offshore. However, to ensure their better operation in an offshore environment, some technical challenges remain to be resolved. These are improving system stability, simplifying the operational complexity of large arrays, and ensuring reliability of power cable linkages to onshore supply networks (Jose et al., 2016). What is novel about the project described in this paper, is that it investigates the technical feasibility of boosting New Zealand's renewable power output by offshore wind turbine installation. It evaluates several design features which may enable large turbine arrays to supply power more efficiently. It contributes new knowledge about places on the New Zealand coast which have different potentials for extra renewable energy generation. What remains to be done, is to provide economic analysis of the costs and returns entailed, if wind turbines are to be installed offshore at the various locations.

## 2. Methods

Parameters for offshore wind turbines issued on IEA Wind TCP Task 37-May 2019 are used for the simulation model (Bortolotti et al. 2019). It is set up by using several available commercial software packages. They are:

1) QBlade: QBlade software is used to examine parameters for design of turbines (Marten et al., 2013).

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2) RETScreen: is a feasibility study tool and is freely downloadable software developed by Ministry of Natural Resources, Canada for evaluating both financial and environmental costs and benefits of different renewable energy technologies for any location in the world. (Sinha et al., 2014).
3) SIMULINK: is a block diagram environment for multidomain simulation and Model-Based Design. It supports system-level design, simulation, automatic code generation, and continuous test and verification of embedded systems (Giordano and Levesque, 2015).

### 2.1 Selection of turbine

The wind turbine proposed for evaluation is Siemens SWT3.6-107-80m, as a result of designing an option matrix to quantify what the best device will be. Each characteristic is given an associated weighting due to its relevance.
Characteristics in the option matrix were:

- HAWT above sea level because preliminary evaluation shows horizontal axis turbines will generate more power than vertical axis turbines.
- Rotor diameter because generating capacity increases with diameter for HAWT.
- Number of blades, because with an increasing number of blades, solidity increases. So, turbines with different number of blades are compared to see which one will maximise HAWT power.
- Cut-in and cut-out wind speeds are included because of the effect of wind speed on produced power.
- Height above sea surface (for wind turbine) because rotor blades must clear sea surface. Also, because air friction and turbulence decrease at height, altering wind turbines' efficiency. Finding an optimal hub height at which wind turbines can sit, will maximise efficiency.

As a result of evaluating option matrices for numerous turbines, the turbine proposed for evaluation is Siemens SWT3.6-107-80m. This turbine of Siemens, SWT-3.6-107 Offshore, is a production of Siemens Wind Power A/S, a manufacturer from Denmark taken over by Siemens Gamesa Renewable Energy in 2017.The energy yield can be obtained from RETScreen software. The software requires the wind turbine wind power curve, the annual average wind speed, the rotor swept area, the mean temperature and pressure, hub height, etc. The wind turbine-related parameters are summarized in Table 1.

*Table 1:SWT-3.6-107 offshore wind turbine parameters*

| Item | Value |
|---|---|
| Model | Siemens SWT-3.6-107 Offshore 3.6 MW |
| Rated power (kW) | 3,600 |
| Rotor diameter (m) | 107 |
| Hub height (m) | 80 |
| Swept area of rotor (m2) | 8,992 |
| Cut-in-wind-speed (m/s) | 4 |
| Rated wind speed (m/s) | 15 |
| Cut-out-wind speed (m/s) | 25 |
| Rotor Speed (rpm) | 13 |

### 2.2 Simulation of performance, capacity and efficiency

SIMULINK is used to simulate the wind power curve of the SWT-3.6-107 Offshore wind turbine (Figure 1) which shows that the wind turbine starts generating power at a cut-in-speed of 4 m/s and reaches its rated capacity at 15 m/s and continues to produce rated power up to a wind speed of 25 m/s.

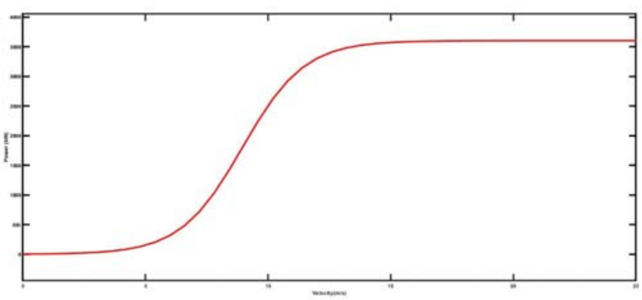

*Figure 1: Output power of SWT 3.6-107 offshore wind turbine (Simulink simulation)*

### 2.3 Selecting components for a microgrid system design

SIMULINK is used to design components for a wind energy generation system with Siemens SWT-3.6-107 wind turbines.

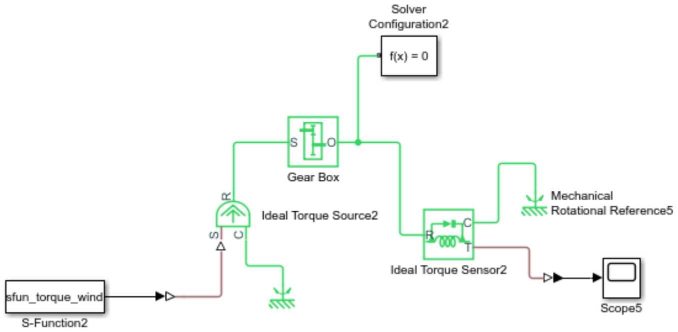


*Figure 2: Simulink model of wind turbine generation system*

The design includes a microgrid system for linking offshore wind turbines (Siemens SWT 3.6-107) to an on-shore grid, as shown in Figure 2 which is a SIMULINK block diagram. A DC microgrid system is being investigated because it has several advantages compared with AC supply. These are:

1) Better controllability and power management
2) Reduction in transmission losses
3) Greater reliability for preventing power outages.

## 3. Results

### 3.1 Sites which are suitable for wind generation

Westerly wind patterns prevail in most parts of New Zealand. NIWA recording sites in 2014 summarize every hourly measurement, illustrating patterns of turbulence and calm in different places shown in Figure 3.

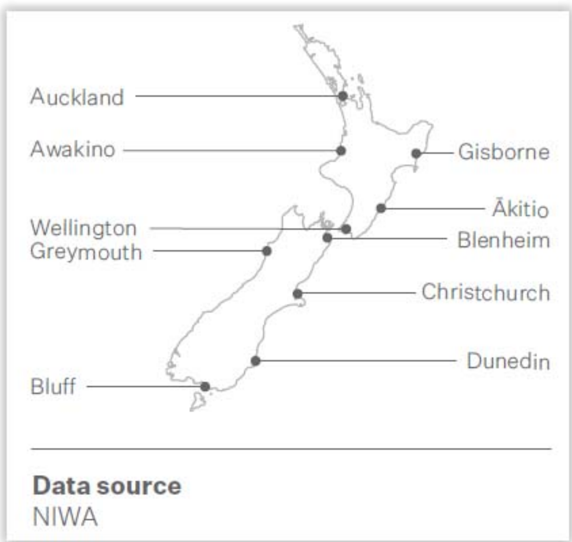


*Figure 3: NIWA recording sites, selected to show typical wind patterns in 2014 (McDowell and Denne,2019)*

For each site selected, scatter charts (Figure 4) show how often and how strongly winds blow from different directions during 2014. The centre of each plot represents calm conditions. Wind strength is shown by the distance from the chart centre, in 1 metre-per-second steps. The further a tick is from the calm centre, the stronger the wind. Wind direction is determined by angle from the centre. Northerly winds are at a 12 o'clock position; easterlies at 3 o' clock. The duration for which wind blew from a particular direction at a certain strength is shown by below periodic time symbols in Figure 4.

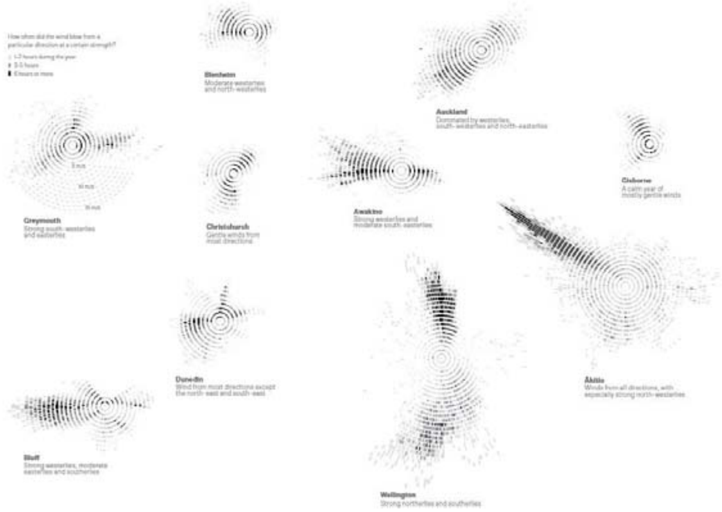


*Figure 4: Wind Patterns in New Zealand (McDowell and Denne,2019)*

The results of reviewing information about wind speeds and directions on the New Zealand coastline are that the west coast of North Island, south-east coast of North Island, and south coast of South Island are coasts with great potential to generate electricity from wind energy. From bathymetric maps showing depth to seabed, also from known information about storminess of these coasts, it can also be concluded that cost of constructing and maintaining towers in harbours will be less than on stormy open coasts.

### 3.2 Site short-listed for simulation

Global Wind Atlas data sourced from RETScreen software is used to identify which of the harbour/estuary sites in Table 2, also have good wind runs (expressed as mean annual wind speed). The latitude, longitude and wind run of sites which appear to have potential for generation are summarized in Table 3.

*Table 2: The geographical coordinates and wind run of New Zealand harbours and estuaries*

| Location | Latitude (deg) | Longitude (deg) | Annual Wind Speed (m/s) |
|---|---|---|---|
| Bluff | -46.4°N | 168.3°E | 10.7 |
| Whanganui Inlet | -40.0°N | 175.0°E | 5.3 |
| Hokianga | -35.1°N | 173.3°E | 4.5 |
| Kawhia | -37.8°N | 175.3°E | 4.7 |
| Manukau | -37.0°N | 174.8°E | 5 |
| Kaipara | -36.8°N | 174.8°E | 6.4 |
| Aotea | -37.8°N | 175.3°E | 4.7 |
| Parengarenga | -34.5°N | 172.9°E | 8.5 |
| Tauranga | -37.7°N | 176.2°E | 4.1 |
| Rangaunu | -34.9°N | 173.3°E | 4.5 |
| Whangarei | -35.7°N | 174.3°E | 6.5 |
| Otago | -45.8°N | 170.6°E | 5.9 |
| Lyttelton | -43.6°N | 172.7°E | 4.2 |
| Akaroa | -43.8°N | 173.0°E | 4.2 |
| Wellington | -41.3°N | 174.8°E | 7.3 |
| Firth of Thames | -37.0°N | 175.4°E | 5.7 |

Many sites can be ruled out because wind run is not good (Hokianga, Kawhia, Aotea, Tauranga, Lyttelton, Akaroa). Some harbours in Table 2 can be ruled out, because they have commercial ports. Here turbine monopiles will be navigation hazards (except if the deep-water channel extends upstream beyond wharf). Commercial ports ruled out are Whangarei, Waitemata (Auckland), Manukau (Auckland), Tauranga (south entrance), Port Nicholson (Wellington from wharf to entrance), Lyttelton (Christchurch), Otago (Dunedin), Bluff (from wharf to entrance).

Some estuaries have also ruled out because they contain marine reserves or they are next to national parks etc. (Port Pegasus, Paterson Inlet, Akaroa, parts of Golden Bay, Whanganui Inlet). Here Department of Conservation will not allow resource consent.

Finally, a few estuaries with deep entrance channels have to be ruled out because their shores are inhabited by tangata whenua (Maori) who say that the estuaries are taonga (valuable possessions) for fishing, gathering shellfish etc. Or that the shores are wahi tapu (sacred places) which must not be disturbed. Examples are Parengarenga and Rangaunu. Maybe also Hokianga, Aotea and Kawhia. Table 3 shows the sites which appear to meet criteria in all respects.

*Table 3: The geographical coordinates and wind run of the New Zealand sites which are being used for modelling a microgrid system for offshore wind energy generation*

| Location | Latitude (deg) | Longitude(deg) | Annual Wind Speed(m/s) |
|---|---|---|---|
| Bluff | -46.4°N | 168.3°E | 10.7 |
| Whangarei | -35.7°N | 174.3°E | 6.5 |
| Wellington | -41.3°N | 174.8°E | 7.3 |

### 3.3 Examples of Energy Yield Estimation for selected sites

When evaluating these and other sites, various types of turbine design-related losses like array, airfoil soiling, icing and miscellaneous can be considered in the estimation of energy yield. Array losses for a single turbine installation are 0% while a well-designed cluster of less than 8 to 10 turbines should keep array losses below 5 %. Airfoil soiling and/or icing losses typically range from 1 to 10 % (Babcock and Conover, 1994). Some examples of RETScreen loss estimates for short-listed sites are given in Table 4.

*Table 4: Wind energy related coefficients used in energy yield estimation*

| Wind energy related coefficients | Bluff | Wellington | Whangarei |
|---|---|---|---|
| Array losses (%) | 0 | 0 | 0 |
| Airfoil soiling and/or icing losses (%) | 2 | 2 | 2 |
| Miscellaneous losses (%) | 6 | 6 | 6 |
| Pressure adjustment coefficient | 0.997 | 0.989 | 0.995 |
| Temperature adjustment coefficient | 1.018 | 1.006 | 0.998 |
| Wind shear exponent | 0.14 | 0.14 | 0.14 |

RETScreen initially calculates the gross energy production for one (proxy) wind turbine, which is the total annual energy produced by the wind energy equipment, before any losses, at the wind speed, atmospheric pressure and temperature conditions at the site. Next, the model calculates and applies the pressure adjustment coefficient, which is proportional to the average atmospheric pressure at the site. The coefficient should fall between 0.59 at an altitude of 4,000 m and 1.02 at an altitude of 0 m. Then the model calculates the temperature adjustment coefficient, which is inversely proportional to the average temperature at the site. Typically, the coefficient falls between 0.98 and 1.15 for temperature ranging from 20°C to -20°C. A value of 0.14 for wind shear exponent is recommended as a good approximation when wind shear at the site is yet to be determined (Babcock and Conover, 1994).

*Table 5: Summary of energy yield and related output from SWT-3.6-107 Offshore wind turbine*

| Summary of energy yield and related output from SWT-3.6-107 Offshore wind turbine | Bluff | Wellington | Whangarei |
|---|---|---|---|
| Annual mean wind speed (m/s) | 10.7 | 7.3 | 6.5 |
| Specific yield ($kWh/m^2$) | 2,034 | 1,630 | 1,418 |
| Gross energy yield (MWh/y) | 19,969 | 16,306 | 14,218 |
| Unadjusted energy delivered (MWh/y) | 20,259 | 16,232 | 14,129 |

The wind energy yield and other relevant output parameters from the model are summarized in Table 5. The specific energy yield, annual gross energy yield (which is calculated by applying pressure and temperature coefficients to unadjusted energy delivered) and the unadjusted energy delivered (or produced energy at standard conditions of temperature and atmospheric pressure) are highest at Bluff, intermediate at Wellington, and lowest at Whangarei. The yields demonstrate that all three sites could produce a satisfactory amount of energy for supply to a grid. If project objectives are solely substitution of renewable energy for carbon-sourced energy with corresponding reduction in greenhouse gas emissions, Bluff (a port with an aluminum smelter requiring enormous electricity supply) clearly is the best site. If project objectives include minimum development cost and maximum profit from electricity sale, other factors such as local difference in construction cost or local difference in wholesale power price could tip the balance in favour of Wellington (a city with large electricity demand from residential housing) or Whangarei (a medium-sized town although with high electricity demand from several energy-intensive industries). A cost-benefit analysis, confirming whether Bluff remains the best site once economic considerations are added to renewable energy objectives, is planned as a final phase of site evaluation.

## 4. Conclusions

The main conclusions from work conducted so far, are firstly that simulation shows horizontal axis wind turbines (HAWT) are the most suitable for offshore installation, in terms of their design characteristics and rated power curves. Secondly, for linking an offshore turbine array to the onshore electricity supply network, a direct current (DC) microgrid appears suitable because of its better controllability, reduced transmission loss, and greater reliability when compared with alternating current (AC) cables. Thirdly many coastal sites can be ruled out because simulation results show generating capacity is too low (not enough wind run) or because other site factors (such as shipping channels) preclude installation. Fourthly there are some sites where simulation results indicate good potential for offshore wind energy and other site factors do not preclude development.

Results indicate Bluff harbour has slightly better potential for offshore wind energy generation than Wellington or Whangarei. Bluff harbour has better wind run (Table 3) and can export the most electricity to an on-shore supply grid (Table 5).

Findings expected from future research are:

- Cost of erecting and operating offshore wind turbines at the selected sites.
- Value of extra electricity generated by offshore wind turbines.
- Whether there is an economic benefit from the extra electricity generated.
- Whether the economic benefit is sufficient to warrant constructing an offshore microgrid system linking wind turbines to an on-shore supply grid.

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