

# Implementation of wind turbines on Scotland Island

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**Abstract** – Implementing a renewable energy system required several steps, involving discussions between advantages and disadvantages. First, a place and a type of energy must be chosen. In addition, the system specification, topology and components must be researched and discussed. Finally, an evaluation of the system performance is needed to complete the project and assess its economical and practical feasibility.

**Index Terms**—Isolated Island, Research, Renewable Energy System, Scotland Island, Wind Energy.

## I. INTRODUCTION

As renewable energy systems reveals more and more advantages to the world and its bright future, its popularity has significantly risen. The implementation of renewable energy systems for isolated island was discussed in this report, using evidence of its obvious economic and environmental advantages.

## II. IDENTIFY A PLACE AND RENEWABLE ENERGY SOURCE(S)

Several questions needed to be answered in order to find a suitable place and renewable energy source(s) that satisfies and make the project viable. First, who will be in need of renewable energy, and will the advantages outweigh the disadvantages of exploring those energy? One answer came to mind: renewable energy source(s) implemented in small or private islands. The system would be most suitable for small islands such as Scotland Island in Sydney that has a diameter of around 1km. My conjecture has proven to be accurate as several articles from different sources has confirmed my claim. “With rising oil prices, fuel import bills now represent up to 20 percent of annual imports of 34 of the 38 small islands developing states (SIDS)” [1], claims Vanya Walker-Leigh. In fact, the biggest expenses of those islands are importing all kinds of materials. Although it will stop or reduce the amount of fuel imported, setting up and importing the materials for renewable energy system will be costly. It will however save the island money as well as contributing to a clean environment and less pollution, over time. The scenery of those small islands also shouldn’t be affected by the implementation of non-eco-friendly energy source infrastructure. In fact, the implementation of renewable energy systems will reflect a brighter future and will not affect the ecosystem on and around the islands. Furthermore, the high price of importing fuel for electricity uses makes the use of

renewable energy system cost competitive. The wide variety of renewable energy systems made the choice of energy difficult. While wave & tidal, and hydroelectric were some choices that came to mind, I have decided to give up on them as views and scenery might be affected and won’t be a first choice for inhabitants. On the other hand, given how common solar energy is used, I believe that it is one of the first choice. As more and more people choose to install solar panels on their roof for personal use, people should be more accepting towards those changes in scenery. Another energy chosen for the project is wind energy. The Danish island of Samsø was the first island to go from fossil fuel dependent to 100% renewable with wind energy. On top of that, coastal areas are suitable as it is windier there because of the sudden change in the atmospheric pressure. In fact, “there is an enormous amount of energy to be harvested from wind” [2], claims Roger Rassool, a particle physicist at the University of Melbourne. In terms of efficiency, “The most efficient forms of renewable energy geothermal, solar, wind, hydroelectricity and biomass” [3]. Although both solar and wind energy are efficient, I have decided to pursue the project with a wind energy system. The location chosen for this project is Scotland Island, a small island located in Northern Beaches, NSW.

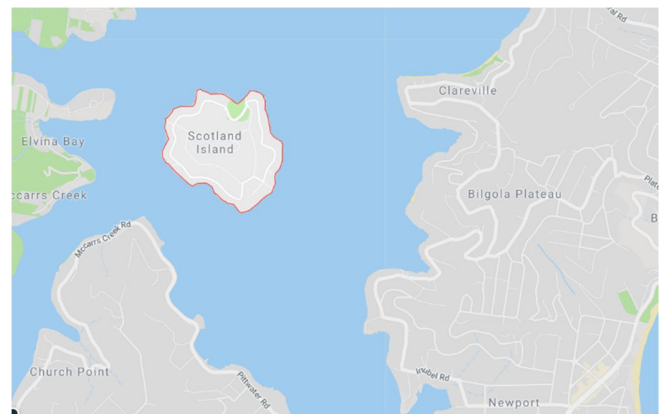


Fig. 1. Scotland Island (Source: Google Maps)

## III. SYSTEM SPECIFICATIONS

The system used will need to satisfy several specifications. Firstly, the aim of this renewable energy system generation will complement other sources of electricity such as fuel, which is

very common to use on islands. It is aimed to provide electricity for one household, acting like a residential generator. Furthermore, it will considerably reduce the use of non-renewable supply of materials and therefore contribute to the reduction of importing those materials. Choosing to complement electricity while not going fully renewable has its advantages. In fact, if a storm is to break own and destroys the newly installed infrastructure, other energy systems such as solar or non-renewable type of system can act as a backup generator in case of emergencies. According to Ausgrid, Daily use of electricity in the Northern Beaches amounts to 16.4 KWh/day. For a whole year, a household in Scotland Island will use around 5,986 KWh/year. In turn, Scotland Island will use around 2,095,100 KWh/year. A large amount of the demand has to be filled with renewable energy systems and the appropriate infrastructure has to be built.

From the wind forecast in Australia, the wind speed for 2019 on Scotland Island has an average of 14.7 km/h.

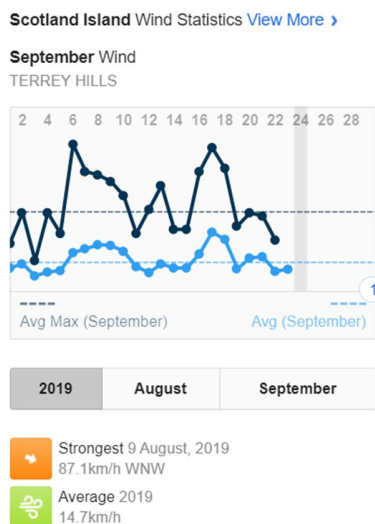


Fig. 2. Average Wind Speed (Source: <https://wind.willyweather.com.au>)

According to the Danish Wind Industry Association, “the average wind speeds are often available from meteorological observations are measured at a height of 10 meters” [4]. The highest point on Scotland Island reaches 100 meters over sea level, making the location suitable to implement the system. Using their wind calculator, the average wind speed at a height of 100 meters will be 17.83 km/h, or 4.95 m/s.

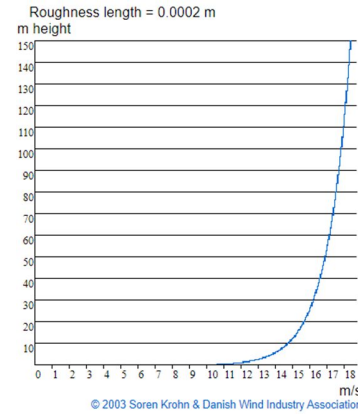


Fig. 3. Average Wind Speed by height



Fig. 4. Average wind speed monthly

From the graph above, it is found that the wind resources since 1999 per month is relatively constant, with an average of 15.7 km/h. Although maximum conversion rate is reached when the wind speed is between 10 and 15 m/s, the wind speed will change over time, making the average not as accurate.

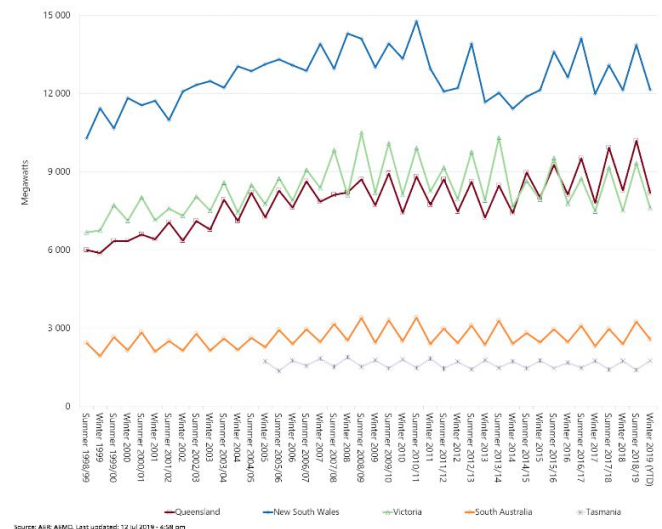


Fig. 5. Electricity usage in Australia per season per state

The graph found from the Australian Energy Regulator is revealing that the demand is higher in winter and in NSW. It is due to the lower temperature and shorter days, using both lights and heater. The use of electricity is further described by the graph below. The average household, on top of using more electricity in winter, will reach its peak consumption in the morning from 8am to 10am and in the evening from 6pm to 10pm.

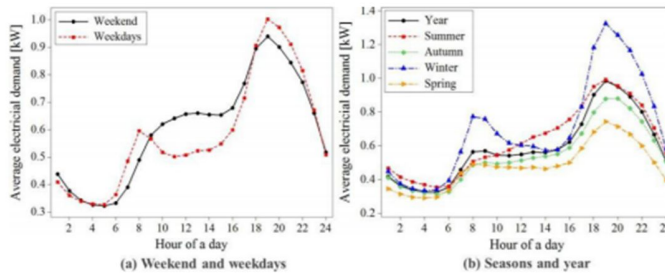


Fig. 6. Electricity Demand per day per hour (Source: ScienceDirect)

One important point is the need of an energy storage system in order to store energy when it is produced or not used. Wind turbines create AC electricity and later convert it to DC before being stored in batteries. This system is only designed to produce and store energy, while transmission to the household is not considered and a third-party company will need to be contacted.

In the case study, the author claims that using a Fuhrländer 250 turbine will grant us “an expected lifetime of 15 years” [5] (2004, Andrew Stiel and Maria Skyllas-Kazacos). In terms of size, the renewable energy systems will only need to provide electricity to around 350 households. As stated above, it will be assisting the existing energy source by providing and reducing the use of non-renewable energy. Thus, the system doesn’t have to be as rigorous in terms of producing the right amount of energy.

#### IV. DESIGN SYSTEM TOPOLOGY

Considering the small size of the different targeted islands (1 km diameter approximately for Scotland Island), the distance from generation to consumption will be relatively small. While solar panels can be installed per household, it is uncommon to have a wind energy system for a household. Constructing onshore might raise environmental issues, ruin the scenery and in turn raise complaints from the local. However, onshore center is preferred as maintenance will be easier and the distance until delivering energy will be shortened. An isolated area on the island will be needed to provide energy for the island as a whole. As isolated islands, the wind tends to be stronger and thus its lack will not be a worry. This renewable energy systems will assist and not replace the existing source and will consequently not be as vast as one might think.

Furthermore, horizontal axis wind turbine will be preferred over vertical axis wind turbine. Even though horizontal axis wind turbine has “higher cost in tower construction to hold the generator, gearbox and the heavy blades” and they also “require additional control mechanism for controlling the direction of

the turbine blades” [6] it has a better efficiency in converting wind to energy. For a medium scale converting energy to electricity for 350 households, a higher efficiency is needed in order to build less and smaller wind turbine with better capacity.

Calculated earlier, an approximate of 15,986 KWh/year will be needed to supply electricity to an average household, and 2,095,100 KWh/year for the whole island. As the wind turbine will be acting as a complement to the AC grid, there will be a need for energy storage system. The aim of this system is to provide at least 70% coverage for the island electricity consumption.

For the topology of this system, several other components will be needed, and more detailed descriptions are provided in this section.

On top of the turbine blades, a tail section is needed to allow the turbine to change its direction and face it towards the direction of the wind. Alternatively, the more modern wind turbines will use a Yaw drive and motor to change the direction of the turbine. It will also need a winch for the generator to be lowered if maintenance is needed.

As AC electricity is generated by the wind turbine, a rectifier is needed to convert AC to DC and store the energy to a battery storage system. The rectifier should be located in a separate control box.

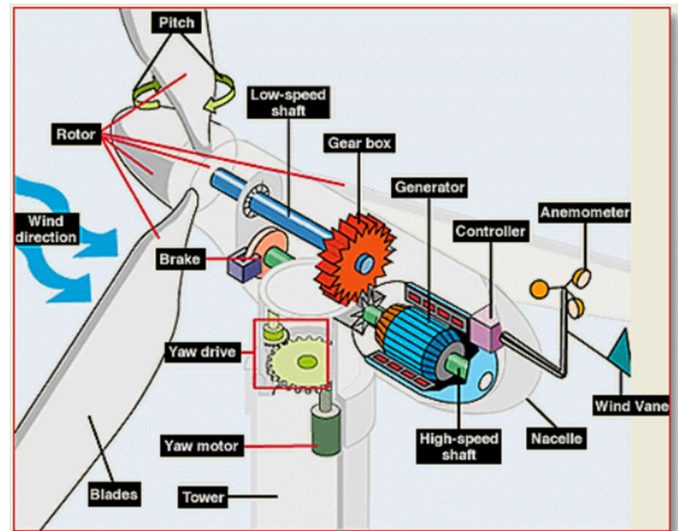


Fig. 7. Wind turbines components (Source: NREL)

In the diagram above, the different components in the wind turbine are listed. While the anemometer records the wind speed, it inputs the data to the controller that starts the machine when a certain wind speed is reached and stops the system when the wind is too strong, avoiding permanent damage. The gearbox plays an important role in the wind turbine and connects the low and high-speed shaft. It supports and allows the high-speed shaft to reach a sufficient speed for the generator to produce electricity.

As mentioned earlier, the system will only produce and store the energy while transmission to each household will be handled by a third-party professional. The wind generator site will need several turbines in order to reach an adequate production of energy.

In the next section, more specific components will be discussed, and which one will be chosen.

## V. DESIGN SYSTEM COMPONENTS

First, the size of the turbine must be determined before choosing which components can satisfy the requirements of the system. After careful calculations (shown in the next section), the size of each rotor will be 25 meters. For the wind turbines to operate without being affected or affecting the population and the environment, the lower part of the rotor must be elevated to at least 20 meters above ground. In this case, the turbines chosen will have a tower as tall as 35 meters. Modular steel tower was chosen over tubular steel tower. Using glass fiber reinforced with polymer were used for the nacelle and the rotor blades, to decrease the weight of the two components. WindObserver75 was selected for the anemometer, observing and analyzing wind speed up to 75 m/s. A yaw drive and motor are needed to move the direction of the turbine to face it towards the wind, thus accumulating and generating maximum power. The Yaw gear Brevini Z11AW83V9 was chosen in this case. Found from a datasheet of a wind turbine of similar size, a 690V three phase asynchronous generator is needed to generate enough power for the system. In addition, a gearbox is necessary to connect the low-speed and high-speed steel shaft. Following the reasoning behind the datasheet of a turbine of similar size, a 1:50 planetary gearbox was implemented in each turbine. Finally, battery storage system will be using lithium-ion battery next to the generators to store the electricity generated.

The costs of each components are listed in the financial spreadsheet, with a cost totaling AUD\$2,753,072. The reasoning between the choices and costs are discussed in the next section.

### A. Tower

Modular Steel Tower (58 tons)	\$ 92,800
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### B. Rotors and Blades

Glass Fiber reinforced polymer	\$ 13,516
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### C. Nacelle

Glass Fiber Nacelle (18 tons)	\$ 73,728
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### D. Anemometer

WindObserver75	\$ 3,779
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### E. Yaw drive and motor

Yaw gear Brevini Z11AW83V9	\$ 18,440
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### F. Generator

690V Three Phase Asynchronous Generator	\$ 96,112
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### G. Gearbox

Planetary 1:50 Gearbox	\$ 1,620
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### H. Battery storage

Lithium-ion battery	\$ 1,000,000
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### I. High and low-speed shaft

Steel shaft	\$ 53,999
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### J. Installation and transportation

Installation and Transportation	\$ 1,400,000
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### K. TOTAL

TOTAL	\$ 2,753,993
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## VI. EVALUATION OF THE SYSTEM PERFORMANCE

To satisfy the needs of the population of Scotland Island, several calculations had to be processed. In fact, finding the right size of the blades of the turbines and how many wind turbines was needed was crucial to the development of this project. According to the European Wind Energy Association, "An average onshore wind turbine with a capacity of 2.5–3 MW can produce more than 6 million kWh in a year – enough to supply 1,500 average EU households with electricity" [7]. Finding the ratio between the capacity to the production of energy, we can determine the size of the wind blades. To find how much power a certain rated wind turbine produce every year, we do:  $365 \times 24 \times (\text{wind turbine rating}) \times (\text{efficiency})$ . As 3MW rated wind turbine produces around 6 million KWh, the efficiency was found to be 0.22. After several trials and errors, we have come to find the appropriate rating of the wanted wind turbines and its number. It was settled that the system required four 200KW rated wind turbine. Using the equation above, each individual turbine will produce 438,000 KWh. Thus, the four turbines will be more than enough to cover more than 80% of Scotland Island yearly electricity consumption (1,752,000 KWh out of 2,095,100 KWh). Comparing different 200 KW rated wind turbines, the average rotor diameter was 25–30m.

On the other hand, the modular steel tower was preferred over the tubular steel tower. The important reason behind the choice is that Modular steel towers are "is light and reduces transport movements to 10% in comparison to concrete tower solutions" [8]. Another important reason is its adaptability: it has "the ability to build ever higher towers" [9]. The price for a ton of steel amounts to 400 dollars, while the weight of a tower is around 58 tons out a total of 85 tons for the turbine. As four wind turbines are required, the cost for the manufacturing of the tower will reach AUD\$92,800.

Both rotors and nacelles were built using glass fiber reinforced by polymer, for its durability and lightness. Other composites were also available such as glass fiber reinforced epoxy and carbon fiber epoxy. With a price of AUD\$1,024 per ton for glass fiber reinforced polymer and the weight of the nacelle (18 tons) and the three blades (3.3 tons), the cost will amount to AUD\$87,244.

Three models were available for the anemometer. WindObserver70, WindObserver75 and WindObserver90. Comparing the prices, WindObserver75 was chosen as little differences in price between the 70 model and the 75. As the 75 model is much cheaper than the 90 model, the 75 model was selected for a price of AUD\$3,778. The only difference between models are the resistance to the wind. For example, WindObserver90 can handle winds up to 90 m/s while WindObserver75 can handle winds up to 75 m/s.

Given the availability of the Yaw gear Brevini Z11AW83V9 with four available models, it was chosen to be implemented for a cost of AUD\$18,400 for the four models. Its availability was the advantage as other yaw gears lacked specifications and details.



Following the datasheet of a wind turbine of similar size [10], a 690V Three Phase Asynchronous Generator and a planetary 1:50 gearbox were selected. As very little information was available that explains the cost of each and the type of each of these components, a 25m diameter turbine was chosen as reference. The corresponding price of each component amounts to AUD\$96,112 and AUD\$1,620 respectively for the four turbines combined.

The lithium-ion battery's price was derived from the curve per kWh. The following graph reveals the price to store 1 kWh will cost around AUD\$200.

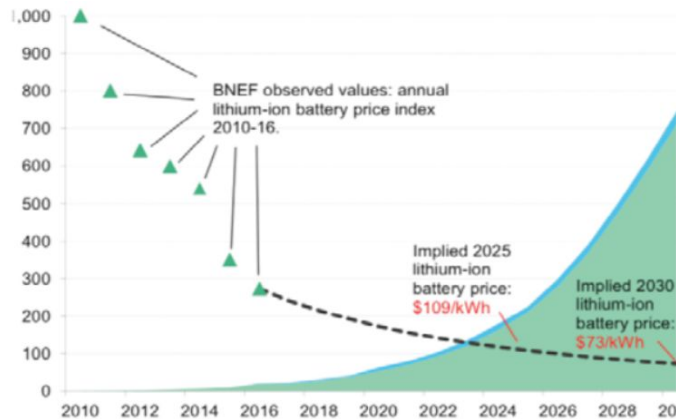


Fig. 8. Price of battery storage per kWh (Source: BNEF)

According to Windustry, “Most of the commercial-scale turbines installed today are 2 MW in size and cost roughly \$3-\$4 million installed” [11]. Proportionally, the installation of the four 500kW wind turbine will have an overall installation of AUD\$1,400,000.

Listed in the different cost and proportion of each component, the price of the high speed and low speed shafts are about 2% the price of the overall system cost. Taking 2% from AUD\$2,753,993 will result in the price of the shafts of all four turbines of AUD\$53,999.

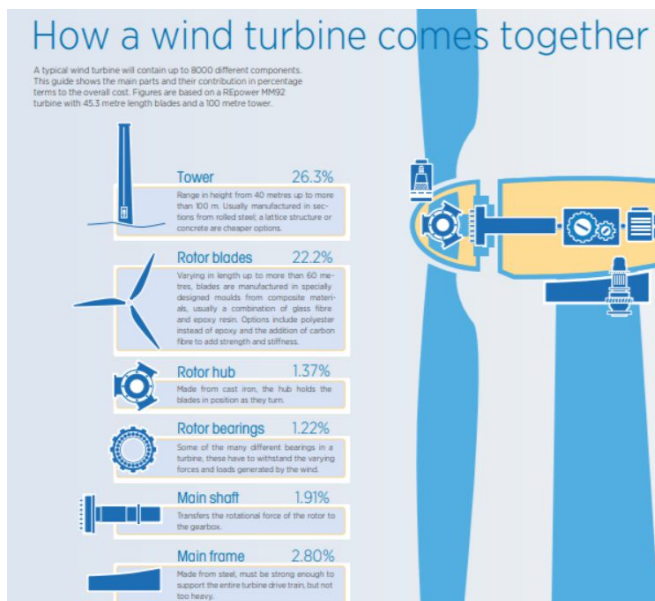


Fig. 9. Percentage of cost for turbine components (Source: Windustry)

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