

How Profitable are Wind Turbine Projects? An Empirical Analysis of a 3.5 MW Wind Farm In Ireland

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Abstract— With many electricity markets worldwide deregulated or in the process of deregulation, the opportunity for smaller independent generators to provide power to their local power system has increased. For smaller independent wind developers assessing the feasibility of a large scale wind farm project is vitally important due to significant risk associated with the investment. This paper presents a longitudinal case study of a 3.5 MW wind farm situated in the North East of Ireland utilising multiple sources of empirical data obtained over a three year period following commissioning. The findings suggest that an average yearly capacity factor of 34% was recorded from the turbines providing for a simple payback period of 6.7 years. It would appear from this case study that site selection, electricity market conditions, the quality of the control system and the competencies of the design/installation/commissioning company all contributed to the satisfactory results.

Keywords- Wind farm, Empirical Data, Net Present Value, Capacity Factor, Single Energy Market

I. INTRODUCTION

The relentless push for business growth has put pressure on natural and human resources. For example the supply of oil, coal and gas would appear to be at, or approaching, the end period of their life-cycle. In addition to this, it is argued by many scientists that the burning of fossil fuels in power generating plants is contributing to environmental degradation, which over time, could jeopardise our wealth, and even our existence, Catalin and Nicoleta, 2011 [1]. This fragile relationship between the economy and the environment has been largely ignored as business growth and shareholder profits took precedence over the natural environment. In more recent times research papers, reports and international conferences such as Kyoto, 1997 [2] and Doha, 2012 [3] have drawn attention to an imminent environmental, economical, and human crisis. From these studies, a new model of business management has emerged, namely sustainable development, which links the economic, environmental, and human spheres. The wind energy industry grew out of this shift in business thinking, as wind turbines were seen as an alternative to fossil fuel burning plants for power generation. However, caution needs to be applied as there appears to be minimal empirical data with which to compare actual payback periods with predicted payback periods. One such study by Kealy, 2014 [4] identified a payback period of twenty-three years, a very disappointing result for potential wind energy investors.

II. LITERATURE REVIEW

Ireland is committed to reducing its dependence on fossil fuels in line with European Union directives, Department of Communications, Energy and Natural Resources, DCENR, 2014 [5]. The Irish government has initiated a policy whereby 40% of its electricity is intended to be generated by renewable sources by the year 2020, SEAI, 2013 [6]. Of this figure, it is envisaged that a significant portion will come from wind

energy which has prompted increased interest in wind farm development. If this wind energy plan materialises, Ireland will become one of the world's largest power-from-wind producers as a percentage of total supply. While this paper analyses the financial aspects of wind farm design, it is important to remember that there are other environmental aspects associated with such a design, not discussed here. Some of these aspects are discussed in a study of a wind farm in Greece by Abeliotis and Pactiti, 2014 [7] who concluded that wind power is environmentally preferable compared to the current Greece generation mix, mainly fossil-fuel driven plant but wind power is not completely environmentally impact-free, since they consume raw materials and energy for their manufacturing, transportation, installation, maintenance, dismantling, and disposal.

As part of Ireland's deregulated Single Electricity Market (SEM), private wind developers can construct and provide power to their local power system. However, caution needs to be applied when predictions are made with regard to potential energy output from these machines which are in their infancy stage in the overall life cycle of the product. There appears to be a shortage of publicly available empirical research to evaluate turbine performance based on data obtained from actual wind turbines installations, although there is a plethora of research modelling estimated values. One such estimated wind energy potential was investigated using locally accessed wind data for a potential site in Konya, Turkey [8]. The one-year wind data was statistically analysed using computer software. A predicted simple payback period of 6.44 years for a 6 MW wind farm was calculated by Kose *et al*, 2014 [8]. It is hoped that this payback period would attract local investors to invest in wind energy technology. In terms of actual data, an empirical study by Kealy, 2014 [4] investigated the financial performance of a 10 kW rated small-scale wind turbine installation in Ireland over the period from 2010 to 2013. The project had a capital cost of €26,620 and the turbine energy

output was 7,260 kWh units per annum. This gave a capacity factor of just 8.3%. Considering that the client had an annual energy usage of approximately 76,338 kWh's, the investment did not put a significant dent in his electricity usage and the results appear disappointing. The payback period of this investment was approximately twenty-three years. Research by Henaghan, 2013 [9] analysing the capacity factor of Irish wind energy found that some companies were overestimating the energy output from these projects. The findings were based on data from 77 wind farms in both the Republic of Ireland and Northern Ireland in the period 2008 – 2012. Of the wind farms surveyed, the highest recorded capacity factor (CF) was 38.48%, the lowest CF was 19.36% and the average CF was 27.9%. This data was extrapolated from a Single Electricity Market Operator (SEMO) source.

The success or failure of wind turbine investments ultimately depends upon many factors. Therefore for smaller independent wind developers assessing the feasibility of a large scale wind farm project is a significant undertaking due to the inherent risk associated with the investment. The aim of this paper is to present a longitudinal case study of a 3.5 MW wind farm situated in the North East of Ireland utilising empirical data obtained over a three year period (2010/2011/2012) following commissioning. The findings should be of benefit to wind developers assessing the feasibility of similar projects.

III. METHODOLOGY

A. Case Study

This longitudinal case study research project utilized multiple sources of data requested and obtained from the owners of the company involved in the production and sale of wind generated electricity for the three year period, 2010/2011/2012. The data included wind speed, energy output, loan repayments and turbine availability of each turbine in the wind farm installation. The case study methodology was used as an in-depth analysis of the financial benefits was explored to assist future potential investors in the wind energy industry. Three years data was utilised in the assessment of the project. A number of site visits took place during which observations and measurements were recorded. Also, site meetings were organized with the project owners where financial reports and power/energy output readings were analysed. The cost of the project and the financing structure were discussed with the owners and results are reported in Table 3 and Table 4 respectively. Based on average empirical data recorded over the three year period, a unit price of 8.2 cent per kWh unit of energy and a capacity factor of 34% were used and the results are reported in the 'Results' section. The turbine was available for 97% of the time, and the turbine efficiency was also 97%. Although it is not possible to generalize all wind farms based on one case study, these findings should help to augment the gap in knowledge in wind farm empirical research.

B. Wind Farm site and Plant

The wind farm on which this research is based on is situated in the North East of Ireland. Prior to the investment

decision being made, preliminary tests were carried out to determine the suitability of the site some of which are now briefly described. It was advantageous that there was no forestry or dwellings located on site. Wind data analysis was carried out by installing a portable anemometer. An environmental impact assessment took place, which included analysing the effects of the wind turbines to fauna and flora. Subsequently, a decision was made to progress with the investment. The wind farm was built in two phases with an estimate life span of twenty years. Phase one consisted of two Vestas V52 850 kW wind turbines. Phase two consisted of the installation of two Enercon E44 wind turbines, each with an output of 900 kW. Phase 1 had a pre-connection predicted capacity factor of 40.29% and phase 2 had a predicted capacity factor of 36.24%. The total power output of the wind farm is 3.5 MW. A picture of the site is shown in Figure 1 and the electrical layout is shown in Figure 2.

The most commonly used generator is the induction generator, of which the types include cage, wound-rotor, and doubly-fed-induction-generator (DFIG). Each of the turbines assessed in this research paper are of the Double-Fed-Induction-Generator (DFIG) type. At the bottom of each turbine tower, a 690V/10kV transformer is installed, the output of which are coupled together and fed in underground cables to an on-site switch-room (Figure 2). The switch-room is located 4 km from the 38 kV sub-station.



Figure 1 Picture of Wind Farm Site

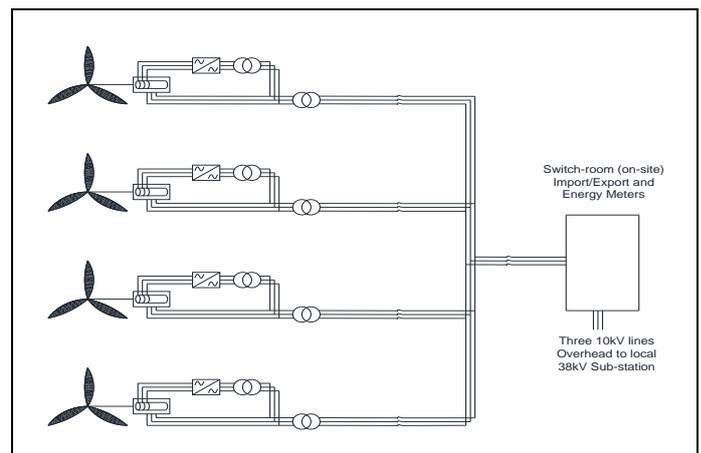


Figure 2 Layout and Electrical Connections of Four Turbines

C. 38kV Local Substation

A major upgrade of the 38 kV Electricity Supply Board sub-station was undertaken to accommodate the 3.5 MW wind farm project (and also a new 3 MW turbine in the planning

stage). This upgrade included replacing an existing 2 MVA transformer with a 10 MVA transformer. A single line diagram of the 38 kV Substation is provided in Figure 3 with Wind Farm connection to the bottom right of Figure 3.

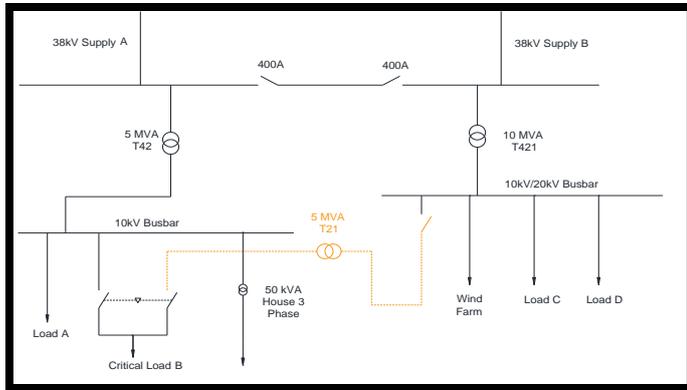


Figure 3 Single Line Diagram for local 38kV Substation

IV. OVERVIEW OF THE ASSOCIATED PLANT

The control strategy to maximise the wind energy captured in a variable speed wind turbine with an internal induction generator at low to medium speeds is a very important aspect to the outcomes in wind energy projects, Iyasere *et al*, 2012 [10]. In a research paper, the authors, Iyasere *et al*, 2012 [10] propose that the tip-speed ratio is controlled via the rotor angular speed, to an optimum point at which the power coefficient is at a maximum for a particular blade pitch angle and wind speed. The control systems used for the variable speed wind turbines in this research are also modern control systems, described in this section. The internal connections for both types of wind turbines in this project are shown in Figure 4.

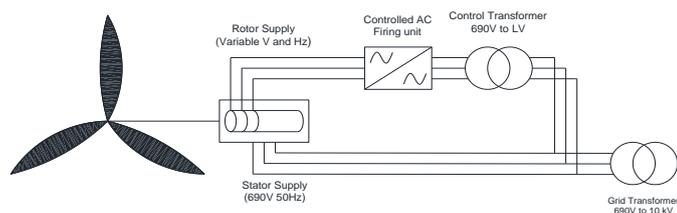


Figure 4 Control System for each DFIG

A. Design of the VESTAS V52 – 850kW Wind Turbine

The Vestas V52 – 850 kW has a rotor diameter of 52 metres and operates using the OptiSpeed™ concept. This feature enables the rotor to operate with variable speed (Revolutions Per Minute). These are also equipped with OptiTip®, the special pitch regulating system. This allows the angle of the blades to be constantly regulated so that they are always pitched at the optimal angle for current wind conditions. This optimises power production and noise levels. The main shaft transmits the power from the rotating turbine blades to the

generator through the gearbox as shown in Figure 4. The generator is a special asynchronous four-pole generator with a wound-rotor. OptiSpeed™ is also named Vestas Converter System (VCS) and this system ensures a steady and stable electric power from the turbine. The VCS consists of:

- An effective asynchronous generator with wound rotor and slip-rings (Rotor supply in Figure 4)
- A power converter with Insulated Gate Bipolar Transistor (IGBT) switches (Firing unit in Figure 4)
- Contactors and protection (Overload and Short-circuit protection, not shown in Figure 4)

The VCS enables variable speed operation in a range of approximately 60% of nominal Revolutions Per Minute (RPM). It controls the current in the rotor circuit in the generator via slip-rings. This gives precise control of the reactive power and gives an accurate and precise connection between the generator and the National Grid. The generator stator is coupled directly to the 690 V supply. The wind turbine controller continuously collects data to control the performance of the turbine. Data continuously collected includes:

- Rotor and Generator speed
- Wind speed
- Hydraulic pressure
- Temperatures
- Power and Energy production
- Pitch

The nameplate on the Vestas ground controller is shown in Table 1.

Table 1 Vestas Nameplate on Ground Controller in tower

Vestas Wind Systems	
Wind Turbine Type	V52 - 850 kW
Controller Type	VMP - 850 kW -690 V - 50 Hz
Voltage	3 × 690 Volts +10/-10%
Frequency	50 Hz +1/-3 Hz
Current Cosθ = 1	711 Amps
Current Cosθ = 0.95	749 Amps
Max Short-Circuit Current	I _k = 15 kAmps

The generator is coupled in Star mode if the total power output is low and Delta mode if there is a high power output from the generator. The VCS frequency converter is a four-quadrant converter which can provide a current in any direction and frequency on the grid side (grid inverter) and on the rotor side (rotor inverter). The converter contains Insulate Gate Bipolar Transistor's (IGBT) and produces harmonic currents on the grid. To reduce the effect of the harmonics, capacitors and Electromagnetic Compatibility (EMC) filters are installed which reduce the high frequency currents.

B. Design of the ENERCON 90 kW Wind Turbine

The ENERCON E-44 is also of the DFIG type. The specification for the ENERCON 900 kW turbine is shown in Table 2.

Table 2 ENERCON 900 kW Specifications

ENERCON E-44/900 kW	
Rated Power	900 kW
Rotor Diameter	44 metres
Hub height	45m/55m
Turbine Concept	Gearless, Variable Speed, Single blade adjustment
Rotor Type	Upwind Rotor with active pitch control
No. Of blades	3
Swept area	1,521 m sq
Rotational speed	Variable 12 - 34 RPM
Generator	ENERCON direct-drive annular generator
Grid feeding	ENERCON Inverter
Cut-out wind speed	28 - 34 m/s
Remote monitoring	ENERCON SCADA

C. Electricity Market

The Single Energy Market (SEM) is the wholesale market for the island of Ireland, regulated jointly by the Commission for Energy Regulation (<http://www.cer.ie>) and its counterpart in Belfast, the Utility Regulator (<http://www.uregni.gov.uk/>). It is structured as a compulsory pool market with capacity payments. Within the market, all price making generators must bid their short run costs into the pool. Electricity suppliers purchase electricity from the pool to cover their consumer's demand for each half hour period throughout the day. Once generators have submit their bids to the Single Electricity Market Operator (SEMO), an initial software run is conducted to determine a Market Schedule which forecasts the System Marginal Price (SMP) for each half hour trading period. The SMP, calculated by the Market Scheduling and Pricing (MSP) software is set by the most expensive generator required to meet supplier demand in a half hour trading period [11]. All generators who produce electricity in a trading period receive the SEM pool price for that period, which for most generators is greater than their short term cost of producing electricity. As wind generators do not consume fuel they have no short term costs and hence can bid a zero price to the SEM. As price takers in the SEM, they receive the SMP set by the most expensive generator for their output in that half hour trading period [12].

D. Renewable Energy Generation Incentives

As part of Ireland's efforts to achieve 40% of electrical energy produced from renewable sources by 2020, the

government has incentivised the production of renewable electricity to encourage entrepreneurs to invest in renewable energy generation. One such support method is the REFIT 2, Renewable Energy Feed In Tariff support scheme [13]. The cost of the REFIT support scheme is covered by a Public Service Obligation (PSO) levy, which also supports other market interventions such as peat generation and the provision of peaking plant. These PSO costs are levied on all customers. Any renewable generator who wants to benefit from the government REFIT subsidiary scheme needs to have a Power Purchase Agreement (PPA) with a licensed supplier. The REFIT 2 scheme operates by guaranteeing a minimum price for new renewable generators for electrical energy exported to the grid for a period of fifteen years. A base price per MWh of €66.35 was set for onshore wind projects above 5 MW and €68.68 below 5MW, these prices are index linked to the consumer price index (CPI) on an upward only basis. In addition to this a balancing payment of €9.90 per MWh will be made to the supplier for any electricity exported onto the grid, this balancing payment is not index linked. If the market price is equal to or greater than the sum of both the base price and the balancing payment no REFIT is payable to the supplier, and if the market price is less than the sum of both, the REFIT payment will be the difference between the two. The main difference between REFIT 1 and REFIT 2 is that the balancing payment is not paid out if the market price is above the sum of both the base payment and the balancing payment in REFIT 2, whereas in REFIT 1 a balancing payment of 15% of the value of the base payment is paid out even if the market price is above the sum of the base and balancing payments combined. A policy document by Doherty and O'Malley, 2011 [14] highlighted some inefficiency in the Irish REFIT scheme. Research by Boomsma *et al*, 2012 [15] assessed two of the most extensively employed renewable energy support schemes operating in Norway, namely feed-in-tariffs and renewable energy certificate trading. The authors carried out a Nordic case study based on wind power and found that the feed-in-tariff encourages earlier investment in the wind industry but renewable energy certificate trading creates incentives for larger projects.

E. Business Expansion Scheme (BES)

This scheme, superseded by the Employment and Investment Incentive Scheme (EIIS), is an investor incentive scheme whereby relief from income tax is available by way of a reduction from income to individuals who invest long-term risk capital in ordinary shares of unquoted small and medium-sized (SME's) companies resident in Ireland [16]. The scheme allows an individual investor to obtain income tax relief on investments up to a maximum of €150,000 per annum in each tax year up to 2020. Relief is initially available to an individual at up to 30%. Up to a further 11% tax relief is available where it has been proven that employment levels have increased at the company at the end of the holding period or where evidence is provided that the company used the capital raised for expenditure on research and development (<http://www.revenue.ie>). This scheme is used to partly finance the wind farm project in this research.

V. RESULTS AND DISCUSSION

A. Cost of Project

There is no promoter equity given for the cost of the project. It is fully funded by the two owners, with financial assistance from the Business Expansion Scheme (BES) which provided €1,840,250 in capital at the beginning of the project. The money is returned in year 5 with an extra 10% on redemption. Most of the remaining cost, €3,565,551, is provided by a long-term, 15-year, bank loan. The loan mechanism process is an amortized type whereby the owners make regular repayments which include both interest and principle amounts and in doing so reduces the amount of money owed, principle, on the loan over time. At the beginning of the loan repayments, the interest and principle monetary values are approximately equal i.e. €170,000 per annum. The interest repayments subsequently decrease as more and more of the principle is paid off over time. There is no corporation tax to be paid on the investment for the first eight years. The capital costs include turbines, unit transformer, crane, non-buoyant foundation, protection equipment, grid-code compliance devices and testing.

Table 3 Capital Cost of the 3.5 MW Wind Turbine Project

Capital Cost (Per MW)	€1,150,000
ESB Connection Cost (Per MW)	€200,000
Civil Works	€450,000
Roads Contribution	€70,000
Initial Development Costs	€157,350
Total Capital Cost of Project	€5,402,350

B. Funding for Project

Table 4 Total Funding for 3.5 MW Wind Farm

Business Expansion Scheme (BES)	€1,840,250
Monies provided by Project owners	€157,350
Bank Loan	€3,565,551
Tax Exemption	-€160,801
Total Finance	€5,402,350

C. Revenue Generated

The turbine produces revenue of €804,282 per annum as shown in Table 5. This value is based on a unit (kWh) price of €0.082. This is not a fixed rate and may either increase or decrease depending on supply/demand market conditions. Whereas a sensitivity analysis is not carried out in this research, it is worth noting that the revenue generated from such a wind farm development is likely to fluctuate on a daily basis.

D. Financial Analysis

The four turbines in the wind farm arrangement produce an average combined energy output of 9,808,318 kWh units of energy per year. This is calculated by multiplying the upper

six elements in Table 5. This yearly energy output is now used in the following financial analysis of the investment.

Turbine Output (kW)	3500
Hours in Day	24
Days in Year	365
Turbine Availability	0.97
Turbine Efficiency	0.97
Capacity Factor	0.34
Price Per kWh	€0.082
Yearly Revenue	€804,282

Table 5 Revenue Generated on a Yearly Basis

Net Present Value (NPV); the NPV investment appraisal method considers all of the costs and benefits of the turbine installation, and makes a logical allowance for the timing of these costs and benefits. The time factor is an important factor as the investors will not see €10,000 received now as equivalent in value to €10,000 receivable in a years' time. The three reasons for this are; (i) Interest lost, (ii) Risk, (iii) Effects of Inflation. The NPV method makes a direct comparison between the sum of the inflows over time and the immediate investment. The cash benefits over time are discounted, depending on the interest rate and the period (year) in which the benefits arise. The discount factor is 6%. The Net Present Value (NPV) for the project is calculated as €2,043,752. This summates all the costs and benefits over the twenty-year period of the project. When the NPV value is positive, it indicates that the risks associated with the investment is worth taking.

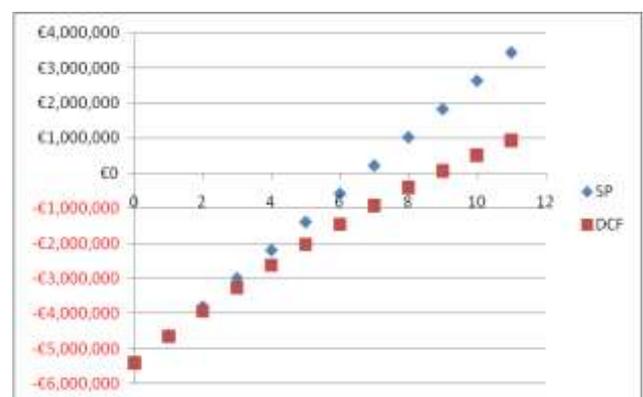


Figure 5 (SP = Simple Payback, DCF = Discounted Cash Flow)

The Payback Period (also called Simple Payback, SP data in Figure 5) of the project is calculated as $(€5,402,350)/(€804,282) = 6.7$ years. This is the length of time it takes for the initial investment to be repaid out of the net cash inflows from the turbine installation. It is a much improved result compared to the small-scale wind turbine results, Kealy, 2014 [4] discussed previously which had a payback period (Simple Payback) of 23 years. The advantages of the PP method are that it is quick and easy to calculate and is easily understood by the personnel making the investment decision. If the financial benefits of the investment are discounted, due to the time factor as discussed in the previous

chapter, then the payback period is between 8 years and 9 years as demonstrated in Figure 5 (DCF, Discounted Cash Flow data points). This simple payback calculation is slightly inferior to the 5.2 years calculated by Tran and Chen, 2013 [17] on a rural area of Vietnam. However, the hub height in the research by Tran and Chen [17] was 80 metres high, significantly higher than the height of the turbines assessed in this case study.

VI. CONCLUSIONS

Results show that this was a good investment. It was a major improvement on the 10 kW small-scale wind turbine discussed by Kealy, 2014 [4]. There may be a number of factors affecting this result. Firstly, there is a highly efficient control system on each of these large turbines. This allows the system to maximise its output, even in low wind conditions. The Vestas Converter System (VCS) ensures a steady and stable electric power from the turbine. This is achieved by regulation the pitch of the blades and controlling the current in the rotor circuit of the generator.

Secondly, there were extensive preliminary on-site tests carried out before the project went ahead. These involved an environmental impact assessment and also wind speed analysis on the site. This ensured the suitability of the site, gaining prior knowledge that it is noted as a 'good' site, and helped to minimise the risks associated with the investment.

Thirdly, the design, installation, and commissioning engineers were experts in the wind industry and this manifested itself in all aspects of the project. The risk associated with the investment for the wind farm installation in this research appears to be a risk worth taking. Financial results indicate a healthy bank balance and good income is achieved from the four turbines in the project. A simple payback period (PP) of less than seven years is acceptable to the project owners and to confirm this, the wind farm owners are in the planning stage for a new 3MW single turbine close to the existing site used in this research.

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