A comparison analysis of the life cycle cost of onshore wind farms to offshore wind farms

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Acknowledgements

The author would like to take this opportunity to thank all those who contributed in aiding the research of this chosen topic

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List of Abbreviations

DWIA – Danish Wind Industry Association

ESB – Electric Supply Board

EWEA – European Wind Energy Association

GWEC – Global Wind Energy Council

LCC – Life Cycle Costing

O&M – Operation and Maintenance

RICS - Royal Institute of Chartered Surveyors

WEC – Wind Energy Council

WLCC – Whole Life Cycle Costing

Declaration

I hereby declare that this thesis is my own work and effort. Where other sources of information have been used, they have been acknowledged.

Signed,

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Gavin McQuaid

Abstract

The aim of this thesis was to critically asses the financial and practical credentials of onshore wind farms in comparison to offshore wind farms, and to determine the life cycle cost of the two chosen wind energy production systems over the life of the project.

After compiling a LCC analysis of the two options of wind energy production established that a 5MW offshore wind farm cost €5,864,858.03 more than an onshore wind farm of the same capacity. The O&M cost of running the offshore wind farm was again significantly higher than that of the onshore alternative, with it costing an additional €2,059,302.47 over a 20 year period to run an offshore wind farm.

An offshore wind farms has a greater annual energy production rate than an onshore wind farm of the same capacity. With a 5MW offshore wind farm producing 21900000kWh per annum, whereas a 5MW onshore wind farm produced 13140000kWh per annum. In turn this resulted in a 40% increase in annual income in the offshore option over the onshore option.

Chapter One – Introduction

1.1 Dissertation Background

Quantity Surveyors are expected to evaluate and appraise building systems and construction options, in order to assess which delivers greater value for money for the client. The author has decided to investigate the costs of constructing a Wind Farm. The Author will look at both onshore and offshore wind farms and compare the life cycle costs of both options. The author felt it was important to do this in accordance with the Royal Institute of Chartered Surveyors (RICS) guide to Life Cycle Costing.

1.2 Topic Rationale

Wind power is developing rapidly at both European and global levels. Over the past 20 years, the global installed capacity of wind power has increased from around 2.5 GW in 1992 to more than 238 GW at the end of 2011; an average annual growth of more than 25 per cent. From this 238 GW, Ireland is responsible for 1,428 megawatts. (GWEC) That figure is enough power to supply the equivalent of 918,000 domestic homes nationally (eirgrid.com).

And with Investment in Wind Power Generation set to keep increasing according to EWEA, 2009. A greater amount of this investment will be going into the construction of offshore wind power plants, the author felt that it would be a worthwhile topic to research the life cycle cost of both options. There are already 170 wind power plants in Ireland over 27 counties with only one of these being offshore, the natural direction of the Wind industry is towards offshore wind farms. As a result of this the author felt a greater amount of this investment will be going into the construction of offshore wind farm. This view was backed up by the findings off the EWEA, 2009 which state by the year 2030 the split between onshore and offshore wind farms will be almost 50-50. The author felt that it would be a worthwhile topic to research the life cycle cost of both onshore and offshore wind farm.

1.3 Aim

The author intends to critically assess the financial and practical credentials of wind turbines used in onshore wind farms in comparison to those used on offshore wind farms, and to determine the life cycle cost of the two chosen turbines over the life time of the project.

The author intends to critically analyse how a life cycle analyse is carried out for both, using two case studies to compare and contrast onshore and offshore wind farms and how Life Cycle Analysis was carried out on both projects.

1.4 Objectives

The main objectives of the dissertation are as follows:

i. To examine the concept of both offshore and onshore wind farms, in relation to how each method is constructed and to provide a practical assessment of their use.
ii. To examine the economics of wind energy production.
iii. To investigate the methods used for Life Cycle Costing, and whether it is effective as an option appraisal tool.
iv. To investigate two Irish based wind farms, by way of case studies and to analyse the different costs associated within the projects life.
v. To carry out a detailed life cycle cost analysis of both a 5MW offshore wind farm and 5MW onshore wind farm and compare the results.
vi. To conduct all research from a Quantity Surveyors perspective, providing detailed cost analysis.

1.5 Chapter Outlines

1.5.1 Chapter One – Introduction

This chapter provides an introduction to the thesis for the reader. The background to the thesis is discussed, along with the reasoning behind the author's decision to investigate the topic in detail. The author also outlines the aims and objectives of the thesis, and provides an outline of each of the chapters.

1.5.2 Chapter Two – Wind Farm Design Onshore Vs Offshore

The literature review is split into three sections. Chapter two contains information regarding both onshore and offshore wind farms. This section will include an introduction and background to the two different types of wind power plants. The section also discusses the construction process involved, advantages and disadvantages for each method of wind energy production.

1.5.3 Chapter Three - The Economics of Wind Energy

The chapter discusses the Economics of Wind. The Key factors which influence the feasibility of a wind development are established and appraised between the different sources.

1.5.4 Chapter Four – Life Cycle Costing

Chapter four deals with Life Cycle Costing, It outlines an introduction and history behind LCC. This section also provides the uses, factors affecting, and data requirements for LCC. To conclude the chapter the risk techniques and methods used to perform a Life Cycle Costing are reviewed.

1.5.5 Chapter Five – Research Methodology

In this chapter the author wanted to highlight, to the reader, the research methods used in order to achieve the aims and objectives of the thesis. Detailed descriptions of the various methods used were discussed, along with a thorough account of the interviews undertaken by the author and their purpose is also given.

1.5.6 Chapter Six – Case Studies

This chapter provides a detailed account of two particular farms, one onshore and the other offshore. It details the difficulties involved when using both methods of wind power production. Although they are similar, the different construction and running

costs of each power plant are also discussed and calculated within this chapter. These findings are brought forward to chapter seven.

1.5.7 Chapter Seven – Life Cycle Analysis

In this chapter the calculation from chapter four are used to evaluate a LCC analysis for both onshore and offshore wind power plant construction on the basis of the two case studies. The author determines which type of wind power production has the best economical saving by the way of LCC analysis.

1.5.8 Chapter Eight – Conclusions and Recommendations

The purpose of this chapter is to discuss the main findings of the research. An overall conclusion is ascertained through the thesis objectives. The limitation of the research and the recommendations for further research are also highlighted in this chapter.

Chapter 2 - Wind Farm Design Onshore Vs Offshore

2.1 Introduction

In this chapter the author will be investigating the factors affecting the selection of the sites for both onshore and offshore wind farms. Although some of the factors affect both onshore and offshore the author shall try to differentiate between the factors that affect each more significantly than the other. The author shall be investigating the installation of both methods along with the advantages and disadvantages of both onshore and offshore wind farms.

2.2 Onshore

2.2.1 Factors affecting Onshore Wind Farm Design:

Once a site has been identified and a decision to invest in development has been taken, the wind farm design process begins. The main aim is to maximise energy production, minimise capital and operating costs, and to remain within the constraints imposed by the selected site. The factors that are most likely to affect turbine location are:

- optimisation of energy production
- visual influence
- noise
- turbine loads

2.2.2 Optimisation of Energy Production

"The aim of this process is to maximise the energy production of the wind farm whilst minimising the infrastructure and operating costs." (EWEA, 2009a)

This process is also known as "mirco-siting". The economics of each project is more likely to be sensitive to changes in energy production more so than infrastructure and operating costs. Therefore it is appropriate to use energy production as the dominant layout design parameter. The most efficient way of optimising the energy production of a wind farm is to use a WFDT. Especially for larger wind farms it is difficult to manually derive the most productive layout. For such sites the use of a WFDT may result in substantial gains in predicted energy production. "Even a 1 per cent gain in energy production from improved micro-siting is worthwhile as it may be achieved with no increase in capital costs" (EWEA, 2009a) but will increase the potential energy production of the wind farm.

2.2.3 Visual Influence

Visual influence refers to the visibility of the wind turbines within a wind power plant from the surrounding area. "In many countries the visual influence of a wind farm on the landscape is an important issue, especially in regions with a high population density" (EWEA, 2009a). The layout and visual influence of a wind farm like any other construction project is of great importance especially when seeking planning permission for the project. A visibility footprint most be calculated to identify from where the wind farm may be visible. When applying for planning permission it is usually necessary to agree a number of cases where:

- Locations from which 50% of turbine hubs can be seen
- Locations from which at least one hub can be seen
- Locations from which at least one blade tip can be seen.

(EWEA, 2009a)

There are other factors that affect the visual influence of a wind farm. The decision to use large or small turbines is one of these factors. "Larger turbines rotate more slowly than smaller ones, and a wind farm of fewer larger turbines is usually preferable to a wind farm of many smaller ones." (EWEA, 2009a)

2.2.4 Noise

The noise generated from a wind farm can be a limiting factor for the capacity that can be installed on a site, especially in densely populated countries. Although the noise produced by wind turbines has been significantly reduced in recent years it is still a major factor on the design of a wind farm. This is for two main reasons:

- Wind turbines are often located in rural areas, where background noise levels can be very low. The critical times are when the wind speed is at the lower end of the turbine operating range, as wind-induced noise is at its lowest.
- The main noise sources are elevated, and so are not screened by topography or obstacles.

(EWEA, 2009a)

The planning authorities will require the wind farm to conform to noise limits, if it can be shown that this is not being done there may be penalties enforced.

2.2.5 Turbine Loads

A key element of the layout design is the minimum turbine spacing used. In order to ensure that the turbines are not being used outside their design conditions, the minimum acceptable turbine spacing should be obtained from the turbine supplier and adhered to. The appropriate spacing for turbines is strongly dependant on the nature of the terrain and the wind rose for a site. Separately from the issue of turbine spacing, turbine loads are affected by:

- Natural turbulence caused by obstructions, topography, surface roughness and thermal effects
- Extreme winds.

2.2.6 Installation:

A wind farm may be a single machine or it may be a large number of machines. The design approach and the construction method will, however, be almost identical whatever the size of project envisaged. “The record of the wind industry in the construction of wind farms is generally good. Few wind farms are delivered either late or over budget” (EWEA, 2009a)

Newcomers to the wind industry tend to think of a wind farm as a power station. There are, however, some important differences between these two types of power generation. A conventional power station is one large machine, which will not generate power until its construction is complete. It will often need a substantial and complicated civil structure, and construction risk will be an important part of the project assessment. However, the construction of a wind farm is more akin to the purchase of a fleet of trucks than it is to the construction of a power station. The turbines will be purchased at a fixed cost agreed in advance and a delivery schedule will be established exactly as it would be for a fleet of trucks. In a similar way the electrical infrastructure can be specified well in advance - again probably at a fixed price. There may be some variable costs associated with the civil works but this cost variation will be very small compared to the cost of the project as a whole. The construction time is also very short compared to a conventional power plant. A 10 MW wind farm can easily be built within a couple of months.

2.2.7 Advantages of Onshore Wind Farms:

1. **No Pollution and Global Warming Effects** – Wind Turbines do not lead to pollution which is one of the biggest advantages of Wind Energy. Note there are costs associated with the equipment used to build and transport Wind Equipment but the running of Wind Energy leads to no pollution
2. **Low Costs** – The Costs of Wind Energy has reached the level of Gas powered Energy and can be generated at extremely low rates of around 7-8c/kWh in favourable conditions onshore.
3. **Big Industrial Base** - Wind Energy has become a mainstream source of energy and a large industrial base already exists .This allows a rapid deployment of Wind Power in most places in the world. The number of Wind Turbine Producers is increasing with a number of Asian firms entering the industry.
4. **Fuel Cost** - Wind Energy does not require any fuel like most other sources of renewable energy. This is a huge advantage over other fossil fuels whose costs are increasing at a drastic rate every year. Electricity prices are increasingly rapidly in most parts of the world much faster than general inflation. Price shocks due to high fuel costs are a big risk with fossil fuel energy these days

2.2.8 Disadvantages of Onshore Wind Farms

1. **Wind Speeds** – wind is not predictable, some days there may be very low levels of wind or even none at all.
2. **Scenery** – There is a view within the general public that covering the landscape with wind turbines is unsightly and is having a bad effect on the views of these areas. Recently there has been uproar over a planned wind development in a west Yorkshire moor near the home of the Bronte sisters. There has been a test mast placed in the location. This area is said to be “the inspiration for Emily Bronte’s novel *Wuthering Heights,* depending on how much wind the mast at Thornton Moor detects, the landscape could shortly have a new addition: four large wind turbines. Local campaigners say that will be a disaster for local tourism and national heritage alike.” (http://www.ft.com/intl/cms/s/0/07b5968a-8401-11e1-82ca-00144feab49a.html#axzz1sCBjtUQz)

3. **Noise** - Wind Turbines emit a slight whirring noise which has led to problems with people living nearby. Some farmers have also complained that the livestock like sheep get affected by the moving of the Wind Blades.
4. **Can Harm Wildlife** - Wind Farms on Land frequently cause deaths and injuries to birds though newer wind turbines don’t cause too much problems.

2.3 Offshore

2.3.1 Factors Affecting Offshore Design:

2.3.2 Site Selection

The site selection is the most important decision in the development of an offshore wind farm. “it is best accomplished through a short-listing process that draws together all known information on the site options, with selection decisions driven by feasibility, economics and programme, taking accounts of information on consenting issues, grid connection and other technical issues” (EWEA, 2009a)

2.3.3 Wind Turbine Selection

Selecting the type of wind turbine to be used in the project at the earliest stage of the design process is necessary so that the correct support structures/foundations, type of electrical system and grid connection can be chosen. “Offshore projects require use of the larger wind turbines on the market, meaning that there is often limited choice, securing the wind turbine model may be necessary to start up the project programme” (EWEA, 2009a)

2.3.4 Layout

The process of designing the layout for an offshore wind farm is quite similar to that of an onshore wind farm. Whenever the site has been secured for development, the constraints and any known data are evaluated and inputted into the layout design process, which can be seen on the next page.

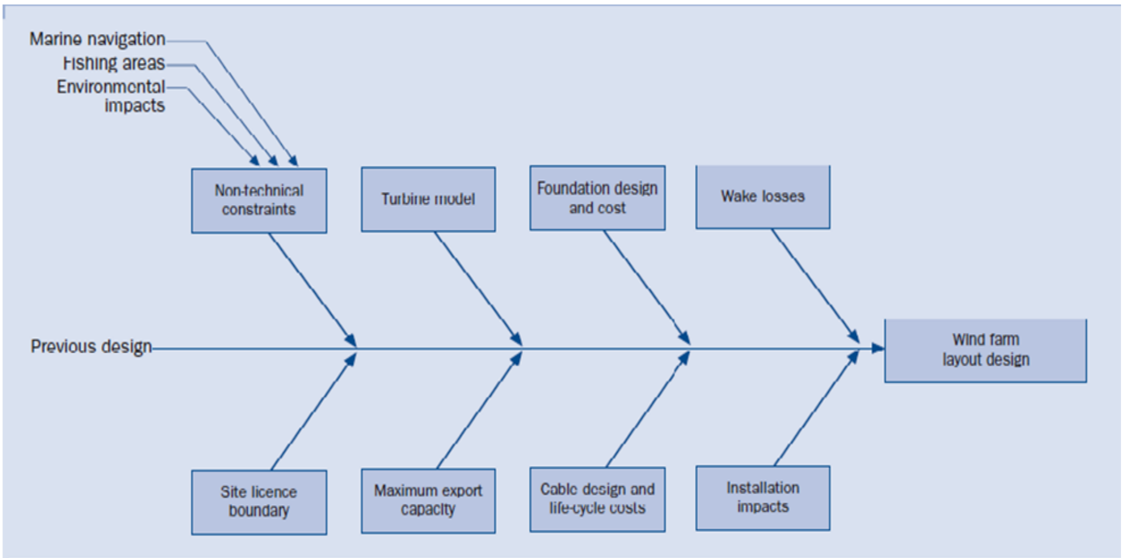


Figure 2.1 Layout Design Process

Source: (http://www.wind-energy-the-facts.org/en/part-i-technology/chapter-5-offshore/wind-farm-design-offshore/layout.html)

"The layout design process evaluates and compares layout options in relation to technical feasibility, overall capital cost and predicted energy production" (EWEA, 2009a)

2.3.5 Offshore Support Structures

"Support structures for offshore wind turbines are highly dynamic, having to cope with combined wind and hydrodynamic, loading and complex dynamic behaviour from the wind turbine" (EWEA, 2009a). There are various types, shapes and sizes of support structures, in the table below you can see examples of the most common types.

Structure	Examples	Use	Notes
Monopile	Ultrunden, SE, Blyth, UK. Arklow Bank Wind Park, Arklow, IRL.	Shallow to medium water depths	• Made from steel tube, typically 4-6m in diameter • installed using driving and/or drilling method
Jacket	Beatrice, UK.	Medium to deep water depths	• Made from steel tubes welded together, typically 0.5-1.5m diameter • anchored by driven of drilled piles
Tripod	Alpha Ventus, DE.	Medium to deep water depth	• Made from steel tubes welded together, typically 0.5-1.5m diameter • anchored by driven of drilled piles
Gravity Base	Vindeby, DK. Tuno Knob, DK.	Shallow to medium water depth	• Made from steel or concrete • relies on weight of structure to resist overturning • seabed may need some careful preparation

Table 2.1 Structure Support Systems Source: (EWEA, 2009a)

The monopile support structure has been chosen for most of the installed offshore wind turbines to date. This is partly because most wind farms have so far been located within 20km of the shore therefore none have been located in deep waters. But as the wind turbines developed become larger, the need to position wind farms in deeper waters will introduce the use of tripod or jacket support structures on a wider scale.

2.3.6 Electrical Systems

An offshore wind farm electrical system consists of six key elements:

1. Wind Turbine Generators
2. Offshore Inter-turbine cables
3. Offshore Substation
4. Transmission cables to shore
5. Onshore Substation
6. Connection to grid.

(EWEA, 2009a)

The following diagram shows the elements of an offshore wind farm electrical system on a single line diagram.

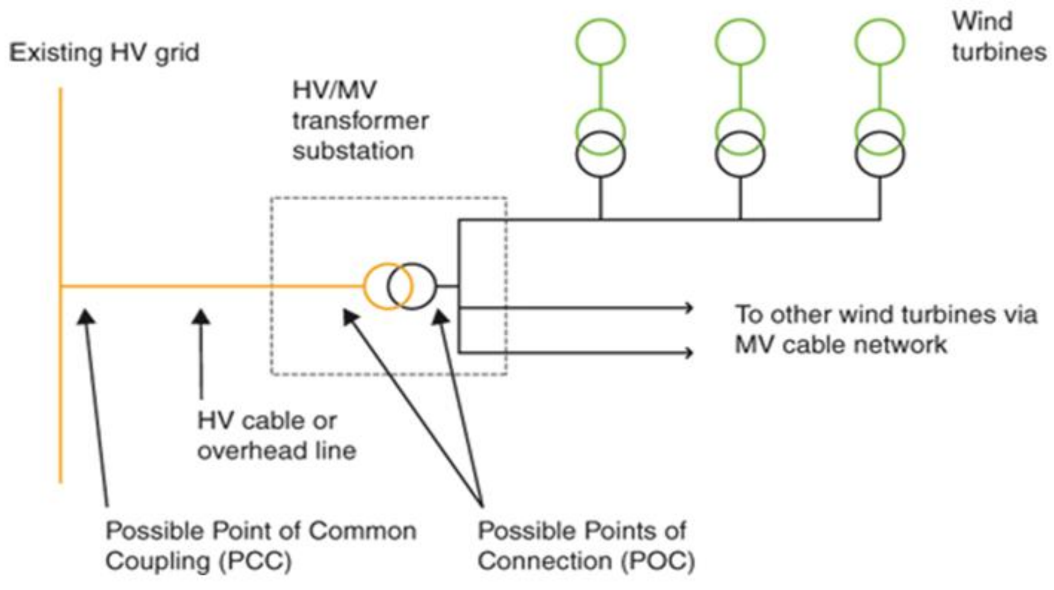


Figure 4.2Wind Farm Electrical System

Source: (http://www.wind-energy-the-facts.org/en/part-i-technology/chapter-5-offshore/wind-farm-design-offshore/electrical-system.html)

The characteristics of the wind turbine generators used and of the network to which the wind farm is to be connected to, as well as regulations imposed upon it, especially through grid codes determine the design of the electrical system to be used. The network operator controls the grid to meet its operational objectives and also requires a degree of control over large generators (which may include offshore wind farms). Additionally, the wind farm must be designed to respond appropriately to grid faults. These demands can be expected for any large wind farm located offshore.

2.3.7 Installation

"The installation of the wind turbines and their support structures is a major factor in the design of offshore wind farms, with the specific challenge of having to perform multiple repeated operations in difficult offshore locations" (EWEA, 2009a)

Figure 2.3 Offshore Installation Process

Source: (EWEA, 2009a)

2.3.8 Advantages of Offshore Wind Farms:

1. **No Noise Pollution -** Offshore Wind Farms are located far off the coast cause no such noise problems for humans or wildlife
2. **No Injuries to Birds** – Offshore Wind Farms do away with this problem entirely as they are located in the Ocean where birds don't fly frequently if at all. There is research being conducted to see if there is an impact on sea life by Cowries.
3. **No loss in scenery -** Though near shore offshore wind farms have come into controversy because of this. Donald Trump has blamed an offshore wind power plant for the shelving of a luxury golf resort in Aberdeenshire. Donald Trump had this to say about the project "All further plans for future development, including the hotel, are now on hold until the Scottish government makes a decision on the application for the European Offshore Wind Deployment Centre. If the north east of Scotland is serious about tourism and creating a global golf destination it cannot allow the coastline to be ruined by an ugly industrial park directly off the shoreline." (http://www.windenergyplanning.com/trump-blames-offshore-wind-farm-for-shelving-of-luxury-golf-resort/)

2.3.9 Disadvantages of Offshore Wind Farms:

1. **Cost** – This is the biggest disadvantage of offshore wind power over onshore wind energy. Note it can cost between 2.5-3.5 times more to generate electricity from offshore wind turbines than the wind farms built on land. There are a number of factors that determine the price such as wind speeds etc. However offshore wind industry is still in a novice state compared to the relatively mature level of the land based wind industry.

Chapter 3 - The Economics of Wind Energy

3.1 Introduction

Due to ongoing improvements in turbine efficiency and higher fuel prices, wind power is increasing in economic competitiveness against conventional power production. There are some key elements used to determine the basic costs of wind energy, according to the EWEA, 2009b these elements are:

- Upfront investment costs, mainly the turbines
- The costs of capital, i.e. the discount rate
- Operation and maintenance (O&M) Costs
- Other project development and planning costs
- Turbine Lifetime
- Electricity Production, the Resource base and energy losses.

Manwell et al., 2010 believes that the availability of wind energy systems is another element which also needs to be taken into account while determining the cost and the economic viability of the wind turbine

According to Redlinger, 2002, "The most important parameters are the turbines electricity production and their investment costs. As electricity production is highly dependent on wind conditions, choosing the right turbine site is critical to achieving economic viability."

When examining the cost of producing energy using a wind turbine, approximately 75% of the total costs are upfront costs for example the cost of the turbine itself, the foundations, electrical equipment and finally connecting the turbine to a grid. As wind is a free resource, there are no fluctuating fuel prices to impact on power generation costs. The EWEA, 2009b states:

"Thus a wind turbine is capital-intensive compared to conventional fossil fuel fired technologies such as a natural gas power plant, where as much as 40-70% of costs are related to fuel and O&M."

3.2 Upfront Investment Costs:

According to Manwell the determination of the capital (or total investment) cost generally involves the cost of the wind turbine(s) and the cost of the remaining installation the initial costs that will be witnessed in a wind energy system development are dominated by the cost of the wind turbine(excluding works). The cost of the wind turbine(s) can be as much as 64-84% of the initial capital costs of the wind energy system, in relation to the country that they are being installed within. There is a degree of variation between countries, ranging from 16 percent of total turbine costs in Denmark to 32 per cent in Portugal. “Costs vary depending on turbine size, as well as the country of installation, distance from grids, land ownership structures and the nature of the soil” (EWEA, 2009b). The cost of the turbine itself depends greatly on the size of the wind turbine chosen for the site. Wind turbine costs can vary significantly, often due to site specific factors which occur during the development (Manwell et al, 2010). According to Manwell et al, 2010 wind turbine costs are often normalised to cost per unit of rotor area or cost per rated kW. “The average turbine installed in Europe has an investment cost of around €1.23million/MW of rated power” (EWEA, 2009b). There are certain other costs that make up the initial investment costs of a wind energy system these include grid connection, foundation, electrical installation, land, financial costs, road construction and consultancy (EWEA, 2009b). Table below displays the Cost Structure of a typical 2 MW wind turbine installed in Europe (2006) and share of the total cost %.

	Investment (€1000/MW)	**Share of Total Cost %**
Turbine (ex works)	928	75.6
Grid Connection	109	8.9
Foundation	80	6.5
Land Rent	48	3.9
Electric Installation	18	1.5
Consultancy	15	1.2
Financial Costs	15	1.2
Road Construction	11	0.9
Control Systems	4	0.3
Total	**1,227**	**100**

Table 5.1 Breakdown of Upfront Investment Costs Source: EWEA, 2009.

Grid connection is the second most expensive of the upfront investment costs, this can be a result of the distance from the turbine to the grid, as you would need to include the cost of developing additional transmission network (Mathew, 2006). Grid Connection can in some cases account for almost half of the auxiliary costs, followed by typically lower share for foundation cost and cost of the electrical installation. These three items may add significant amounts to the total cost of the projects. Cost components such as consultancy and land normally account for only minor shares of the additional costs (EWEA, 2009b).

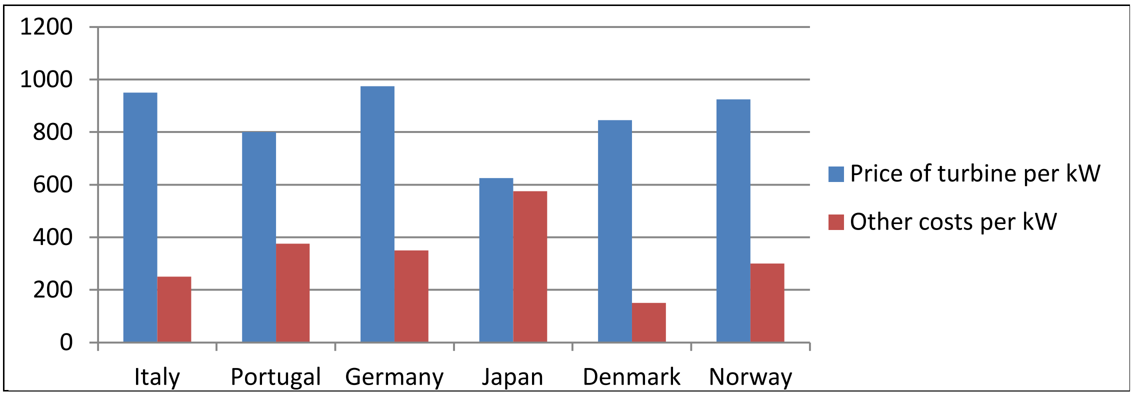


Figure 3.1 Price of turbine and additional costs for foundation and grid connection, calculated per kW for selected countries **Source: (RISO, DTU)**

3.3 Turbine Lifetime

When one is carrying out an economic analysis on a wind energy system, it is quite common practice to connect the design lifetime with the economic lifetime of the wind turbine. The World Energy Council (WEC) states that a maximum period of 20 years would be often assumed for the economic assessment of wind energy system across Europe WEC, 1993(Manwell, 2010). Although the wind turbine may last longer than 20 years, if it is located in a low-turbulence climate (EWEA, 2009b), but it could also have a shorter life span, if there are particles of corrosive or harmful substances in the atmosphere (Mathew, 2006). A modern wind turbine is designed to work for around 120,000 hours (20-25years) during its lifetime. (DWIA)

3.4 Operation and Maintenance Costs

According to the EWEA a wind turbine require service and maintenance (known as operation and maintenance, or O&M), this constitutes a sizeable share of the total annual costs of a wind turbine. In comparison with other power generating technologies, the O&M costs of a wind turbine are quite a bit lower. The operation and maintenance costs are made up of:

- Insurance
- Regular Maintenance
- Repair
- Spare Parts
- Administration

Some of the cost components can be estimated relatively easily. For insurance and regular maintenance, it is possible to obtain standard contracts that will run for the lifespan of the wind turbine. In comparison, costs for repairs and spare parts are much more difficult to predict. Although all cost components tend to increase as the turbine gets older, cost for repairs and spare parts are particularly influenced by the turbine age, starting low at early stages and increasing with age (EWEA, 2009b). As stated by the DWIA, "maintenance costs are generally very low while the turbines are brand new, but they increase somewhat as the turbine ages". Usually for the first two or three years of the wind turbines lifetime, it is still under the manufacturer's warranty, resulting in relatively low O&M costs for these starting years (EWEA, 2009b). In Denmark, older wind turbine with a rated power of 25-150kW, have an annual maintenance costs equating to, on average, around three per cent of the turbine's original investment cost. Newer turbines are significantly larger, which would tend to lower maintenance costs per kW installed power, as large modern machines do not have to be serviced as frequently as their smaller counterparts (DWIA). "Due to the relevant infancy of the industry, there are only a limited number of wind turbines that have reached their life expectancy of 20 years". However, these few wind turbines, are much smaller and more conservative than designs available on the market today. Thus, the estimates for what the O&M costs might be at the end of the turbine's lifetime are still uncertain (EWEA, 2009b). Generally, some elements of O&M costs can be estimated quite easily. Standard contracts for the insurance and general repairs can be sought after by the developer, to cover the turbine for a considerable share of its lifetime. Conversely, estimated costs for

repair and related spare parts are more difficult to predict. The EWEA believe that O&M costs for onshore wind energy are generally estimated to be around 1,200 to 1,500 € per kW of wind power produced over the total lifetime of a turbine (EWEA,2009a).

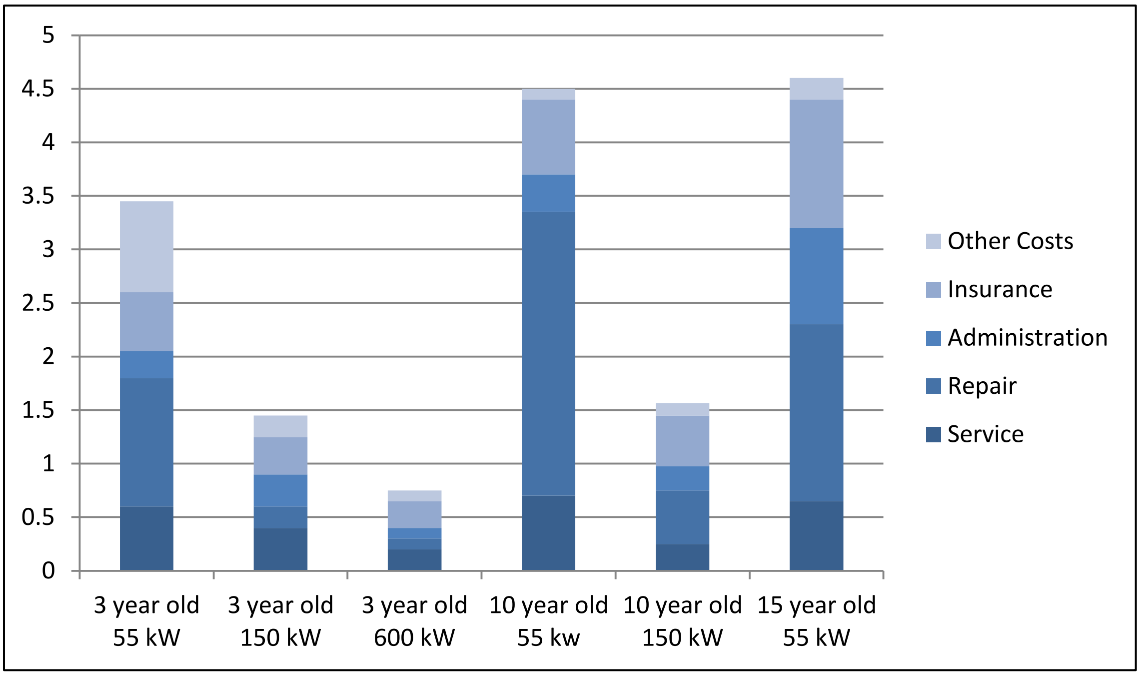


Figure 3.2 Breakdown of O&M Costs

Source: (EWEA, 2009b)

Figure 3.2 above shows the total O&M costs resulting from a Danish study, and how these are distributed between the different O&M categories, depending on the type, size and age of the turbine. So, for a three-year-old 600 kW machine, which was fairly well represented in the study, approximately 35% of total O&M costs covered insurance, 28% regular servicing, 11% administration, 12% repairs and spare parts and 14% other purposes. In general, the study revealed that expenses for insurance, regular servicing and administration were fairly stable over time, while the costs for repairs and spare parts fluctuated considerably. In most cases, other costs were of minor importance (EWEA, 2009b).

3.5 Availability of Wind

"The availability of wind is the fraction of the time that the wind turbine is able to generate electricity" (Manwell et al, 2010,). Nelson, 2009 states that the availability of wind is an important factor in deterring the quantity of energy produced by a wind power system. There will be times during the lifetime of a wind turbine that it will not be able to produce energy. This can happen during times when the turbine requires maintenance or replacement of parts die to damage. Another time when this can occur is when the wind speeds are too high, for example during storms the wind turbine will cut-out for safety purposes. This would not be a regular occurrence, depending on the site. Recent data from both Manwell, 2010 and Nelson, 2009 indicate that the availability is now in the region of 97-99 percent. "Availability of wind on earlier machines was low; however recent figures reached 98%" (Nelson, 2009).

3.6 Electricity Production and Average Wind Speed

"Wind turbines can produce electricity for consumption on or near the site, to sell to the utility or both" (Nelson, 2009). When undertaking an economic analysis of a wind energy system, the local wind resource is one of the most important elements in attaining a successful development. Wind turbines are useless without a powerful wind resource. "The correct micro-siting of each individual wind turbine is therefore crucial for the economics of any wind energy project" (EWEA, 2009b). Wind is an extractive industry, as it takes a portion of the kinetic energy in the wind passing through the swept rotor area, and produces energy. According to the EWEA, wind turbines are usually optimised to extract the maximum share of the energy at wind speeds of around 8m/s (EWEA, 2009b).

3.7 Finance

As a wind energy system is a very capital intensive project in comparison with any fossil fuel-fired technologies, there is a considerable amount of the cost undertaken at the start of the project. As a result of this, the developer will usually have to finance the purchase and installation of the project. The developer will pay a limited down payment, possibly in the region of 20 percent of the costs and borrow the remainder. The finance would normally be borrowed from a bank or investor. In the case of each, the lender will acquire a return on the loan, known as interest. Over the lifetime of the project, the cumulative interest on the project can add up to a significant amount of the total costs. Therefore, the element of financing the project must be considered by the developer when carrying out an economic appraisal of a wind energy system (Manwell, 2010).

Chapter Four - Life Cycle Costing

4.1 Introduction

In this part of this literature review the author is trying to achieve an understanding of already existing published literature on the topic of Life Cycle costing. The main objective of this section is to evaluate the knowledge on life cycle costing at present and to sync it to the main topic of the thesis. This segment of the literature review provides a background of Life Cycle Costing, a technical analysis of the methods of LCC and the limitations, factors affecting LCC and finally the uncertainty and risk assessment in LCC.

4.2 Definitions

The RICS define Whole Life Cycle Costing (WLCC) as "the systematic consideration of all costs and revenues associated with the acquisition, use and maintenance and disposal of an asset" (RICS 2003). Whereas the BS ISO 15686 defines WLC as:

"A tool to assist in assessing the cost performance of construction work, aimed at facilitating choices where there are alternative means of achieving the client's objectives and where those alternatives differ, not only in their initial costs but also in their subsequent operational costs"

Life Cycle Costing (LCC) is defined as "cost of an asset or its parts through its life cycle, while fulfilling the performance requirements" by the BSO ISO 15686-5.

As decision making is at the middle of all our working hours as quantity surveyors, any method used to aid the decision making process, helps to justify our actions. Our capability to forecast the consequences of our decisions helps to decrease uncertainty and forms the basis for ultimate success. LCC is one of these methods, "Life Cycle Costing is a mathematical method used to form or support a decision and is usually employed when deliberating on a selection of options" (Bull, 1993)

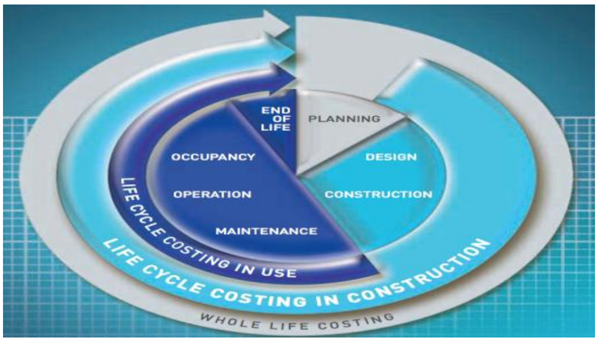


Figure 6.1 LCC in Construction

4.3 Difference between WLCC and LCC

"WLCC is an economic evaluation in which all costs arising from owning operating and maintaining a building over a certain study period or building life cycle are considered to be potentially important in option appraisal, design decisions and cash flow forecasting" (SCSI, 2011). LCC takes into account the costs arising from owning, operating and maintaining an individual building system or component throughout the components life cycle or the estimated life cycle of the building itself. Whereas, WLCC is the systematic accumulation of all the individual LCC calculations of the building system or component that were used in the building, throughout its life cycle or the period being studied.

4.4 Why And At What Stages WLCC Should Be Carried Out?

The focus on WLCC should ideally start at the business justification stage when a conscious informed decision may be taken to increase value in an operational aspect while keeping maintenance as low as possible (SCSI, 2011) The WLCC is at its optimum use for the period of the design stage. This is largely because most options are open to contemplation (Griffin 1993). During this stage the WLCC is the decision making between different projects. It is stated that "80-90% of the cost of running and preserving a building is determined at the design stage" (Kirk and Dell'Isola 1995, RICS 2003)

Ruegg et al (1990) states that "from the perspective of the investor or decision-maker all costs arising from the investment decision are potentially important to that decision and that those costs are the total whole-life costs and not exclusively the capital costs." Below are five points describing making decisions about options:

1. Identify project objectives, options and constraints.
2. Establish basic assumptions.
3. Compile data.
4. Discount cash flows to a comparable time base.
5. Compute total life cycle costs, compare options and make decisions.

(RICS 2007)

In the costing of assets, life cycle costing is essential to effective decision-making. This is stated by Flanagan et al 1983; Bull 1993 in the following ways:

- “Life cycle costing is a whole or total cost approach undertaken in the acquisition of any capital-cost project or asset, rather than merely concentrating on the initial capital cost alone.”
- “Life cycle costing allows for an effective choice to be made between competing proposals of a stated objective. The method will take into account the capital, repairs, running and replacement costs, express these in consistent and comparable terms. It can allow for different solutions of the different variables involved and set up hypotheses to test the confidence of the results achieved.”

However making informed LCC decisions at early stages of a design may be difficult as there might not be enough detailed information to carry out calculations. Typically, LCC analysis may be used during the following four key stages of the life cycle of any constructed asset:

a. Project investment and planning; WLC/LCC strategic options analyses; preconstruction;
b. Design and construction; LCC during construction, at scheme, functional, system and detailed component levels;
c. During occupation; LCC during occupation (cost-in-use); post-construction; and
d. Disposal; LCC at end-of-life/end-of-interest.

(BS ISO 15686-5:2008)

There are many phases in the life cycle of a standard construction project. The British Standard 3811: 1974 adequately describes these phases. Although this assumes engineering terminology it describes the physical assets of a building and associated costs appropriately.

<table>
<tr><th>Life Cycle Phase</th><th>Description</th><th>Associated Costs</th></tr>
<tr><td>Specification</td><td rowspan="2">The formulation of the clients requirements and translating these into an acceptable design</td><td rowspan="2">Initial Costs connected with land purchase, professional fees and construction</td></tr>
<tr><td>Design</td></tr>
<tr><td>Installation</td><td rowspan="2">The construction process up to completion and the handing-over of the project to the client</td><td rowspan="5">Recurring Costs necessary for occupational charges such as rates, insurances, repairs, improvements, fuel, cleaning and estate control

Recurring Costs required for major changes to building in respect of refurbishment and redevelopment.</td></tr>
<tr><td>Commissioning</td></tr>
<tr><td>Maintenance</td><td>The use of the project for its intended purpose</td></tr>
<tr><td>Modification</td><td>Alterations necessary to keep the project in a good standard of repair or to improve to current-day standards</td></tr>
<tr><td>Replacement</td><td>The evaluation of the project for major refurbishment, or the site for redevelopment</td></tr>
</table>

Table 4.1 Phases in the Life Cycle of a Project

Source: Baird, 2008

4.5 Major issues Associated with Life Cycle Costing

Over many years of research, numerous factors have arisen which have proven to affect the application of the LCC. These factors have been categorised by Kishk and Al-Hajj (1999) under the following headings:

- The client
- The industry practices
- Analytical tools employed in the LCC

4.5.1 The Client

The majority of clients using the LCC do not fully understand the process involved. As a result, clients will have a higher chance of making poor decisions in the industry leading to further problems down the line. There are also many aspects of the client which are in disagreement with the principle of the LCC. Some of these may include non financial and intangible aspects (aesthetics). According to Wilkinson (1996) a high majority of intangible aspects are in divergence with principles of the LCC.

4.5.2 The industry practices

It is usual to find both running and capital cost detached from one another. While handing over a dwelling to another, it is common to agree to the lowest cost offered. Literature by Bull, 1993 states that there is no clear definition of the buyer, seller, and their responsibilities towards maintenance and operating costs. The design and cost estimating fees add up to a percentage of the total cost, which in addition leads to cost pessimistic.

4.5.3 Analytical tools

The one major concern with this section is the difficulty in attaining a reasonable amount of information to make an analysis. The reason for this is due to the shortage of historical information (Bull 1993). With the high cost and lack of time needed for information it may be impossible to rearrange other alternatives. “Another difficulty is the need to be able to forecast, a long way ahead in time, many factors such as life cycles, future operating and maintenance costs, and discount and inflation rates.”(Ferry and Flanagan 1991; RICS 2007)

4.6 Data Requirements

4.6.1 Discount Rate

The discount rate is a key variable in discounting future costs. Discounting is used to recognise the time value of money: today's expenditure is more important than tomorrows (Bull, 1993). Discount rates are used to bring future costs to a comparable time base (year 0 - today). Private sector investments generally generate a higher return than public sector investment and thus a higher discount rate is applied in private sector LCC calculations (SCSI, 2011). Ruegg and Marshall (1990) also believe that two separate discount rates for private and public decisions should be used. The private should have a business discount rates for commercial decisions and public discount rates for public decisions.

4.6.2 Escalation Rate

The escalation rate is the rate of increase in the price of a specific commodity. The easiest way to estimate future costs is to inflate costs known today with a relevant escalation rate. Applying escalation rates to energy costs, maintenance costs and replacement costs will produce estimated future (nominal costs) costs. Today's estimated costs are predominantly determined from the cost plan or bill of quantities, depending on what stage the LCC study is been carried out. When assessing the replacement costs of a building component or system in 25 years, a factor should be applied to the estimated cost (today's cost) for demolition and disposal of the existing component. The factored cost is then escalated with a relevant escalation rate to its future value. (SCSI, 2011)

4.6.3 Study Period

The study period is that period of time for which the investor has an interest in the building's life. In a WLCC analysis this may be represented as the estimated physical life of the building or possibly the estimated period of use. In Public Private Partnership's (PPP) the life cycle study period is determined by the hand over date. The

study period may also be determined by the investors expected payback period on their initial investment. (SCIS, 2011)

4.7 Risk Assessment

According to Boussabaine et al. (2004) there are various risk assessment techniques for WLC. These include:

- Sensitivity analysis
- Probability techniques (The confidence index approach, The Monte-Carlo Simulation)

4.7.1 Sensitivity analysis Technique

"The sensitivity analysis is a modelling technique that is used to identify the impact of a change in the value of a single risky independent parameter on the dependent variable" (RICS 2003). There are three steps to this method illustrated by Jovanovic, 1999:

- The assignment of several reasonable values to the input parameter
- The computation of corresponding values of the dependent variable
- The analysis of these pairs of values

"Systems of risk evaluation have been calculated in which a range of values of a variable are introduced and the sensitivity of a solution to changes in specific variables is assessed" (Wright 1973). According to the RICS, 2003 the variable is generally a whole life cost measure of the lowest cost option and the "input parameter is an uncertain input element" in calculating the LCC. The aim of this process is to establish the break-even point. The break-even point is "the value of the input-data element that causes the LCC measure of the least-cost alternative to equal that of the next-lowest-cost alternative" (Kirk and Dell'Isola 1995). Flanagan et al, 1989 states that the spiders diagram is the best way to illustrate the sensitivity analysis result. The lines in the diagram show the affect of each restriction on the LCC. The more horizontal the lines, the more sensitive the LCC is to the restriction.

The one main advantage of a sensitivity analysis is that it clearly illustrates the strength of each substitute. Although the sensitivity analysis has a number of draw backs. These are

1. Only one restriction can be calculated at one time. This in turn slows down the entire process. “The sensitivity analysis should be applied when the uncertainty in one input-data element is predominant” (Kirk and Dell’Isola 1995).
2. The sensitivity analysis only recognises the risk sensitive’s of a project. It does not quantify the risk and so does not give definite means of decision making.

4.7.2 Probability Techniques

In the probability approach, all uncertainties are believed to be at random. “A random process is one in which the outcomes of any particular realisation of the process are strictly a matter of chance” (Ashworth and Hogg, 2007). The following sections will discuss two probability techniques. These include the confidence index approach and the Monte Carlo simulation technique.

4.7.2.1 The Confidence Index Approach

According to the Ashworth and Hogg, 2007 the confidence index approach is based on two theories:

- The uncertainties in all cost data are normally distributed
- The high and low 90% estimates for each cost do in fact correspond to the true 90% points of the normal probability distribution for that cost. Kirk and Dell’Isola 1995 stated that the confidence index is a basic probability approach. For example a confidence index is calculated for two substitutes. A confidence level is allocated to the calculations in accordance to the confidence index. The RICS 2003 shows this:
- For CI < 0.15, assign low confidence. This is equivalent to a probability less than 0.6.
- For 0.15 < CI < 0.5, assign medium confidence. This is equivalent to a probability between 0.6 and 0.67.
- For CI < 0.5, assign high confidence. This is equivalent to a probability over 0.67.

4.7.2.2 Monte Carlo Simulation

Monte Carlo technique is used where different variables have a variety of results. "This method utilises a series of random numbers for each variable, selects random solutions for each variable and calculates the result" (Bull 1993). Several calculations can then ascertain the probability of a final result. In this Probabilistic approach "the whole life costing variables, usually the net present values, also become random variables" (Ashworth and Hogg 2007).

According to Flanagan et al (1989), "the decision-maker must weigh the implied trade-off between the lower expected cost of one alternative and the higher risk that this cost will be exceeded by an amount sufficient to justify choice of alternative" (RICS 2003).

Byrne, 1997 stated that many of the simulation techniques are far too complex and the amount of time and effort required to gain knowledge isn't worth its while.

Chapter 5 - Research Methodology

5.1 Introduction

The key aim and purpose of carrying out research is to try to discover answers to questions which already exist but have not yet been discovered (Kothari, 2008). The key objectives of research are:

- To increase ones knowledge on a new phenomenon or to achieve new insights into it.
- To portray accurately the characteristics of a particular situation.
- To test a hypothesis.

(Kothari, 2008)

For the purpose of this dissertation, the author has used a number of different research methods, of both primary and secondary data collection in order to gain extensive insight into construction and life cycle cost analysis of both onshore and offshore wind farms in Ireland.

5.2 Primary Data Collection

The author chose to use a number of primary data sources for data collection. "Primary sources are considered to be the most accurate source of information and are extremely valuable as they contain original research" (Naoum, 2007). By using primary data sources, the author felt she would be able to gain a clear, unbiased view from the original source. The primary sources used in this thesis were interviews and a case study.

5.2.1 Interviews

Interviews are a vital source of primary information and prove to be of significant importance when research is being carried out. Naoum (2007) describes the personal interview as "a face-to-face interpersonal role situation in which an interviewer asks respondents questions designed to elicit answers pertinent to the research hypothesis" (Naoum, 2007). There are generally three forms of interview that can be undertaken; unstructured, structured and semi-structured.

The unstructured interview, also known as the exploratory interview, is often conducted at the beginning of any research, when the researcher knows little about the subject area in question. This form of interview uses "open-ended" or "open" questions in order to gather general ideas and views from the interviewee. Two unstructured telephone interviews were held by the author in composition of this thesis.

The author held an unstructured telephone Interview with Mr. Andrew Woodhouse of GE Energy Ltd on the 15th of March 2012. Mr. Woodhouse is currently working as the Offshore Sales Manager for GE Energy Ltd in the United Kingdom. Mr. Woodhouse was involved in the supply and instalment of the seven GE Energy 3.6MW Offshore Wind Turbines in the Arklow Bank Wind Power Plant. Mr. Woodhouse was able to inform the author of some of the costs and other data required to carry out a Life Cycle Cost analysis on the project. The findings were incorporated into chapter six and seven.

The author interviewed Mr. Dave O'Connor of Hibernian Wind Power, which are involved in the production of wind power plants for ESB on the 23rd of March 2012. Mr. O'Connor was involved in the Crockahenny Wind Power Plant which the author will use as one of his two case studies. During this interview Mr O'Connor was able to outline what the benefits of the project were. These benefits were incorporated into chapter six. Mr. O'Connor was able to give the author information on the capital and O&M costs of the project. These figures were incorporated in chapters six and seven.

A semi-structured interview is one which is "more formal than the unstructured interview in that there are a number of specific topics around which to build the interview" (Naoum, 2007). This technique incorporates using "open" and "closed-ended" questioning, with no specific order in which the questions need to be asked. The prime goal of this interview style is to discover as much as possible about the specific issues related to the subject area of the interviewer.

The author interviewed Mr. Robert Kelly of John Sisk & Sons Ltd on 16th of March 2012. Mr. Kelly is a Civil Engineer who is currently working on the Mynydd y Betws Wind Farm, being constructed in Swansea, Wales for ESB International by John Sisk & Sons Ltd. This was a semi-structured interview as the author had a few specific areas that he wanted to build the interview. The author felt it was worthwhile interviewing Mr. Kelly as he has extensive experience in the construction of Wind Power Plants in the UK. The interview was specifically designed around LCC, the economics of wind and the difference in costs between onshore and offshore. Mr. Kelly was also able to inform the author on some of the project benefits for both options of wind energy production. These findings were incorporated into chapter six. An extract of the interview is located in Appendix C.

In a structured interview, the questions are presented in the same order to each of the people being interviewed. In this form of interview, "the interviewer will have full control of the questions throughout the entire process of the interview" (Naoum, 2007).Some of the advantages of using structured interview as a research method include, obtaining more accurate answers than other interviewing styles, and answers can be explored further through, follow-up "questions asking, Why?" particular answers are given (Naoum, 2007).

5.2.2 Questionnaires

Naoum (2007) justifies the use of questionnaires to aid research when it is possible to answer the research questions in a few short paragraphs. Questionnaires are a useful research method if the author intends to survey the opinions of individuals or professionals specialising in their area of study.

The author felt that a questionnaire would not be a valuable form of research for this thesis topic as a lot of Quantity Surveying firms are highly uneducated in respect to life cycle costing. As a result if any questionnaires were to be sent to these practices it would prove to be a worthless action as very few, if any responses would be returned.

5.2.3 Case Study

A case study is used "when the researcher intends to support his/her argument by an in-depth analysis of a person, a group of persons, an organisation or a particular project" (Naoum, 2007).

For this thesis the author decided to use two case studies to emphasise the research carried out. The author used the wind power plant at Brittas Bay, Arklow, Co. Wicklow as his offshore case study. The decision to use this case study was almost made for the author as this is the only operational offshore wind farm in Ireland. The author decided to use the Wind Power Plant at Crockahenny, Co. Donegal as it was an onshore wind farm of almost the same size as that at Brittas Bay, not in wind turbine size or energy production but in the amount of Wind turbines in place. Another factor leading to the decision to choose Crockaheeny wind power plant was that it is in a completely different area of the country, therefore leading to contrasting data for wind speeds, prices for grid connections and planning permission. The author felt that this would give a great comparison within the LCC analysis in the thesis.

5.3 Primary Literature Sources

"Primary literature is the most accurate source of information as it publishes original research" (Naoum, 2007). There are a number of publications which fall under this category which helped the author to expand his research for this dissertation. These include past dissertations and theses, publications and reports.

5.3.1 Dissertations and Thesis

By using past theses and dissertations as a research method can help the student in two ways. Firstly, "they enable you to have an idea about the content of the work, the standard expected, methodology adopted and the structure and style of writing up" (Naoum, 2007). Secondly, the author "can benefit from the list of references and bibliography that are attached at the back of the work" (Naoum, 2007).

The author took full advantage of the extensive catalogue of past theses and dissertations available at the library in DIT Bolton Street. These illustrated the layout which the author adopted into his thesis, but they also gave practical information for constructing a life cycle analysis and informing the author about wind energy and the wind energy systems used in Ireland.

5.3.2 Reports and Organisation Publications

"Reports and occasional papers can be of great use when conducting research as they provide comprehensive and often up-to-date information" (Naoum, 2007). "Publications are one of the largest and most important sources of information, especially for those students analysing secondary data" (Naoum, 2007).

The author used many reports and publications from a number of organisations who specialise in wind energy, to gather information and statistics about the costs breakdown and the economics of wind energy systems. These publications were very effective when it came to constructing the LCA for both onshore and offshore Wind Power Plants.

5.4 Secondary Literature Sources

Secondary literature sources interpret and analyse information from primary sources. Examples of secondary literature sources that can be used include textbooks, journals, newspaper articles and the internet.

5.4.1 Textbooks

"Textbooks are much easier to trace and obtain than other references are." (Naoum, 2007) In the initial stages of research more can be gained from reading books that are edited as they are likely to contain a wide range of perspectives on a particular subject. However, one disadvantage in particular which can influence conclusions drawn from the literature is the information available in textbooks can tend to be dated in comparison to information available from other secondary sources, like journals and the internet.

The author did have this problem in his research into life cycle analysis but not wind energy. When researching the methods of Life cycle costing some of the literature was outdated although there were some new editions of the books available. In relation to the wind industry, most of the textbooks that were used were recent, as the wind industry is an area of growth and is gaining popularity as a renewable resource. The author believed the information acquired from the textbooks used positively aided his research in composing this thesis.

5.4.2 The Internet

The internet is possibly the world's largest information source and allows students to gain a considerable amount of information which can contribute to their research. However, caution must be taken in using this research method as sometimes, information given on a topic may not be referenced properly or at all.

The author found the internet a useful research tool, as it allowed his to access websites of large turbine manufacturer's, experts dealing with grid connection and civil works for wind projects. Some of the information obtained from the internet was expanded upon using other research methods, and integrated into the literature review and LCA.

Chapter 6 - Case Studies

6.1 Case Study 1: Offshore; Arklow Banks, Co. Wicklow

6.1.2 Introduction

The Arklow banks offshore wind park is located 10km off the coast of Arklow on the Arklow Bank. The 25MW project consists of 7 GE 3.6MW turbines. The 25MW Arklow Wind Park is the first offshore application of this technology, the first offshore wind project with wind turbines above 3MW rated capacity in the world. It was also Ireland's first offshore wind project. The project was expected to generate enough clean, renewable electricity to serve approximately 16,000 Irish households in the Co. Wicklow area.

Figure 6.1 Arklow Bank Wind Park

The 25MW Arklow Bank Offshore Wind Park was introduced by Airtricity as Phase 1 of a much larger offshore project which Airtricity proposed to build. The proposal is to build more than 520MW of offshore wind power on the Arklow Bank. This has been made possible under a Foreshore Lease that Airtricity obtained in January 2002 following completion of extensive environmental and geotechnical studies.

6.1.2 Project Details:

Project Capacity: 25 Megawatts

No. Of Turbines: 7 GE Wind Energy 3.6s Offshore

Location: 10 KM off the Coast of Arklow on the Arklow Bank

Grid Connection: The project is connected to the ESB Network via a connection in the Arklow National Grid Substation. Submarine cables connect the wind park to shore. From shore connection occurs via underground cables. There are no overhead lines.

Assembly and Work Locations: Pre-assembly of some equipment took place at Rosslare port. Rosslare was selected due to its ability to accommodate large sized ships as well as space required for large cranes to be used for off-loading and reloading activities. Once offshore construction was completed, Arklow port was utilized as the main point of activity for boats, personnel, storage of smaller equipment and operations and maintenance dispatch.

6.1.3 Turbine Details:

Figure 6.2 GE 3.6MW Wind Turbine

Source: GE Energy

Wind Turbine Type: GE Wind Energy 3.6s Offshore

GE Wind Energy 3.6MW wind turbine was the first commercially available wind turbine over 3MW specially designed for offshore use.

Turbine Height: 124 meters to blade tip.

Turbine Hub Height: 73.5 meters

Turbine Weight: 290 tons (complete unit)

Foundations: The turbines are supported by a steel monopole foundation, which is driven into the seabed by a hydraulic hammer. This equipment and process is also widely utilized for other similar applications, including installation of monopoles for bridges. The monopole and associated transition piece provide cable access to the tower from the sea beds as well as boat access to the actual tower and associated equipment.

6.1.4 Wind Park Construction Process:

Project Design and Planning:

- Environmental monitoring program
- Wind monitoring installed on the Arklow Bank
- Environmental Impact Statement Completed
- Foreshore Lease Awarded
- Contract signed with GE for 25MW Wind Park.

Construction Activities:

- Installation of onshore cable (underground from Arklow Harbour to ESB substation on the Dublin Road).
- Construction of electrical switch house at Arklow Harbour.
- Delivery of wind turbine components.
- Assembly of components.
- Installation of foundations.
- Installation of undersea turbine interconnecting cables.
- Installation of undersea cable to shore.
- Erection of towers.
- Erection and commissioning.
- Commencement of operation by GE Wind Energy.

6.1.5 Project Benefits:

Increased Energy Independence: Incorporating wind electricity into Ireland's energy mix increases the country's fuel diversity, reducing dependence on foreign fuel imports and their fluctuating costs. It also enhances the country's energy security by allowing production of electricity through Ireland's clean, green and abundant natural energy source...the wind. Stable energy costs: The project's fuel, the wind, is free. Therefore, project costs can be estimated and will not fluctuate or escalate over the project's life due to increases in fuel cost.

Increased local tourism: Over the past decade, wind project site areas have enjoyed increased local tourism due to growing worldwide interest in wind energy. The Arklow project has also spurred tourism opportunities in the area, including boat excursions to view the wind turbines, and other eco-tourism activities.

Households Served: The 25 MW Arklow Bank Wind Park will annually provide enough clean, renewable electricity to serve about 16,000 average Irish households, the equivalent of approximately 45% of the households in County Wicklow.

6.1.6. Life Cycle Analysis Data:

Through a short phone interview with Mr. Andrew Woodhouse of GE Energy on the 15th of March 2012, the author was able to establish the following data, which was needed to carry out the life cycle analysis for a 5MW offshore Wind Power Plant. Any data that the author was unable to obtain about the case study, he was able to estimate using cited formula.

Data Required:	Figure/Answer
Cost of Construction?	€50.3m
Annual O&M Costs?	The O&M costs average around €1.6m/annum.
Capacity the Wind Farm Operates at?	Normally runs at between 40 - 50%. Most onshore wind turbines run for around 2000 – 2500 hours per annum, while offshore turbines can run for anything from 3000 – 4000 hours per annum.
Has there been any major refurbishment?	No at the time of the interview, as the wind park was only commissioned in 2004. Although Mr. Woodhouse did specify that the O&M costs have been increasing and a major refurbishment could be required at a later date.

The author will use this data in his Life Cycle Cost analysis in the next chapter. They figures will be altered from those for a 25MW offshore wind farm which was used here in the case study to those that would be relevant to a 5MW offshore wind power plant, for the purpose of comparing it to an onshore wind power plant of the same capacity.

6.2 Case Study 2: Onshore; Crockahenny Wind Park

6.2.1 Introduction:

The Crockahenny Wind Farm is located approximately 12 KM east of Buncranna, on the Inishowen Peninsula in North Donegal. The 5MW wind farm consists of 10 Enercom 500kW wind turbines. The project developed by Wind Prospect Ltd, produces enough energy to power over 3,000 homes in the Donegal area.

Figure 6.3 Crockahenny Wind Park, Donegal Source: Hibernian Power Ltd

The site on which the wind farm is located benefits from the typically high wind speeds in the area and also the convenient access routes from the regional road network. This made the construction of the farm easier and made the repeated maintenance and operation of the site more accessible. Wind Prospect started construction in the winter of 1997 and completed the site in June 1998.

6.2.2 Project Details:

Project Capacity: 5 Megawatts

No. Of Turbines: 10 Enercom 500kW Wind Turbines

Location: The Inishowen Peninsula, north Donegal

Grid Connection: ESB Network with a predicted output of 13,140 MW per annum. Underground interconnecting cables

Turbine Details:

Figure 6.4 Enercom 500kw Wind Turbine

Source: Enercom

Wind Turbine Type: Enercom 500kW

Turbine Height: 48.8 meters (2-4 pieces)

Turbine Hub Height: 28.8 meters

Turbine Weight: 72.9 tonnes

Foundations: Enercom Concrete Circular Foundation with reinforced steel mesh.

6.2.3 Construction Details:

Project Design and Planning:

- Environmental monitoring program
- Wind monitoring installed on the Inishowen Peninsula
- Environmental Impact Statement Completed
- Planning Permission granted
- Contract signed with Wind Prospect Ltd

Construction Activities:

- Construction of electrical switch house at Crockahenny.
- Delivery of wind turbine components.
- Assembly of components.
- Installation of foundations.
- Installation of underground turbine interconnecting cables.
- Installation of underground grid connection cables
- Erection of towers.
- Erection and commissioning.
- Commencement of operation by Hibernian Wind Power

6.2.4 Project Benefits:

Emission reductions: The project has helped in the reduction of emissions from other energy sources. Since the commissioning of the project, carbon dioxide emissions have decreases by 10,500 tonnes per annum. Sulphur dioxide and Nitrogen oxides have decreases by 55 tonnes per annum.

Increased Local tourism: Like that of many locations of wind farms across the county the site at Crockahenny has helped to increase tourism in the general Buncranna area.

Households Served: The 5MW Crockahenny Wind Park annually produces enough green energy to meet the electricity needs of more than 3,000 homes within the general Buncranna/Donegal area.

6.2.6. Life Cycle Analysis Data:

Through an interview with Mr. Dave O'Connor of Hibernian Wind Power on the 23rd of March 2012, the author was able to establish the following data, which was needed to carry out the life cycle analysis for a 5MW Onshore Wind Power Plant. Any data that the author was unable to obtain about the case study, he was able to estimate using cited formula.

Data Required:	Figure/Answer
Cost of Construction?	€6,250,000.00
Annual O&M Costs?	He wasn't able to give me an accurate amount for annual O&M as the figure varies year on year. (€197,100.00 was calculated by the author, using formula obtained from Wind Energy – The Facts, 2009)
Capacity the Wind Farm Operates at?	Normally runs at 30%
Has there been any major refurbishment?	Not at the time of the interview but they included major refurbishment into the financial forecasting for the job at 15years of around 20% of the original cost of the wind turbines.

The author will use this data in his Life Cycle Cost analysis in the next chapter. As the author wanted to compare two 5MW wind power plants, these figures will be used almost exactly as they are described here.

Chapter 7 - Life Cycle Analysis:

7.1. Introduction:

In this chapter the author will carry out a Life Cycle Cost analysis of both an onshore and offshore wind power plant. Comparisons will be made in terms of capital costs, operation and maintenance costs and occupancy costs over the life cycle of these projects. The author shall be using information acquired from the two case studies in the previous chapter to carry out the life cycle cost analysis. The case studies used had different capacities, 5MW for the onshore and 25MW for the offshore. So for the purpose of trying to compare two similar projects, the author shall be editing the figures so that both options will have a 5MW capacity. Using the knowledge gained from the literature review chapters, interviews conducted during the case studies and from information received through email from Dermot Kehily, Cost and Value Management lecturer, DIT the author carry out a LCC analysis for both options.

7.2. Life Cycle Cost Breakdown

Onshore Wind Power Plant:

- 5MW Capacity Onshore Wind Power Plant
- AEP: 13140000 kWh

LCA Breakdown	Onshore
Capital	6,250,000.00
Annual Operation and Maintenance	197100.00

Table 7.1 Onshore LCA Breakdown

Offshore Wind Power Plant:

- 5MW Capacity Offshore Wind Power Plant
- AEP: 21900000 kWh

LCA Breakdown	Offshore
Capital	10,055,555.56
Annual Operation and Maintenance	350400.00

Table 7.2 Offshore LCA Breakdown

7.3. Assumptions made for Life Cycle Cost Analysis

Before the author calculates the LCC analysis of both options he must establish the time period, the discount rate and the escalation rate to be used in the calculation.

7.3.1. Time Period:

The time period that the author has chosen for the analysis is 20 years. This time period was chosen as a result of research carried out in the literature review. The following reasons helped the author to come to the decision:

- The World Energy Council (WEC) states that a maximum period of 20 years would be often assumed for the economic assessment of wind energy system across Europe (Manwell, 2010).
- "The lifetime of the turbine is set at 20 years, in accordance with most technical design criteria." (EWEA, 2009a)

7.3.2. Discount Rate:

The author has chosen a discount rate of 7.5% for calculating the LCC analysis. The author came to the decision of using 7.5% as the discount rate from research carried out to compile the literature review chapter:

1. "The discount rate is assumed to range between 5 and 10 per cent per annum. In the basic calculations, a discount rate of 7.5 per cent per annum is used, although a sensitivity analysis is also performed." (EWEA, 2009a)

7.3.3. Escalation Rate:

"The inflation rate in Ireland was last reported at 2.2 percent in March of 2012" (Trading Economics, 2012). Between 1976 and 2010, the average inflation in Ireland was 5.49%. During the Celtic Tiger period the inflation rate in Ireland reached an historical high of 23.15% before reaching a record low of -6.56% in October of 2009. The ECB monetary policy aims at maintaining an inflation rate of around 2% (Trading Economics, 2012). The author will assume an escalation rate of 3% for the purpose of the LCC analysis, which is recognised as a healthy stable economic inflation rate.

7.4. Life Cycle Analysis:

In this section the discount rate and escalation rate will be used to calculate the running costs which include major replacements and operation and maintenance costs over a 20 year period. These rates will be used to carry out the LCC analysis of each option, an onshore 5MW wind farm and an offshore 5MW wind farm:

Option 1: Onshore 5MW Wind Farm						**Discount Rate**	**7.5%**
YEAR	**Capital cost**	**Major Replacement**	**Escalated Major Replacement**	**Operation and Maintenance**	**Escalated Operation and Maintenance**	**Escalated Total Costs**	**Total Present Value**
Escal			**Escalation Rate 3%**		**Escalation Rate 3%**		**Discount Rate 7.5%**
0	6,250,000.00					6,250,000.00	6,250,000.00
1		0.00	0.00	197,100.00	203,013.00	203,013.00	188,849.30
2		0.00	0.00	197,100.00	209,103.39	209,103.39	180,943.98
3		0.00	0.00	197,100.00	215,376.49	215,376.49	173,369.58
4		0.00	0.00	197,100.00	221,837.79	221,837.79	166,112.25
5		0.00	0.00	197,100.00	228,492.92	228,492.92	159,158.72
6		0.00	0.00	197,100.00	235,347.71	235,347.71	152,496.26
7		0.00	0.00	197,100.00	242,408.14	242,408.14	146,112.69
8		0.00	0.00	197,100.00	249,680.38	249,680.38	139,996.35
9		0.00	0.00	197,100.00	257,170.79	257,170.79	134,136.04
10		945,000.00	1,270,000.98	197,100.00	264,885.92	1,534,886.90	744,717.80
11		0.00	0.00	197,100.00	272,832.50	272,832.50	123,141.09
12		0.00	0.00	197,100.00	281,017.47	281,017.47	117,986.35
13		0.00	0.00	197,100.00	289,447.99	289,447.99	113,047.38
14		0.00	0.00	197,100.00	298,131.43	298,131.43	108,315.17
15		708,750.00	1,104,209.41	197,100.00	307,075.38	1,411,284.78	476,966.30
16		0.00	0.00	197,100.00	316,287.64	316,287.64	99,436.72
17		0.00	0.00	197,100.00	325,776.27	325,776.27	95,274.25
18		0.00	0.00	197,100.00	335,549.56	335,549.56	91,286.03
19		0.00	0.00	197,100.00	345,616.04	345,616.04	87,464.75
20		0.00	0.00	197,100.00	355,984.52	355,984.52	83,803.44
						LCC	**9,832,614.45**

Table 7.3 LCA 5MW Onshore Wind Power Plant

From the LCC analysis for the onshore 5MW Wind Power Plant the following results where concluded:

	Onshore
Capital Costs	6,250,000.00
Total O&M Costs	3,582,614.45

Table 7.4 LCA Data - Onshore

Option 2: Offshore 5MW Wind Farm						Discount Rate	7.5%
YEAR	**Capital cost**	**Major replacement**	**Escalated Major Replacement Costs**	**Operation and Maintenance**	**Escalated Operation and Maintenance**	**Escalated Total Costs**	**Present Value**
Escal			**Escalation Rate 3%**		**Escalation Rate 3%**		**7.5%**
0	10,055,555.56					10,055,555.56	10,055,555.56
1		0.00	0.00	350,400.00	360,912.00	360,912.00	335,732.09
2		0.00	0.00	350,400.00	371,739.36	371,739.36	321,678.19
3		0.00	0.00	350,400.00	382,891.54	382,891.54	308,212.59
4		0.00	0.00	350,400.00	394,378.29	394,378.29	295,310.67
5		0.00	0.00	350,400.00	406,209.64	406,209.64	282,948.83
6		0.00	0.00	350,400.00	418,395.92	418,395.92	271,104.46
7		0.00	0.00	350,400.00	430,947.80	430,947.80	259,755.90
8		0.00	0.00	350,400.00	443,876.24	443,876.24	248,882.40
9		0.00	0.00	350,400.00	457,192.52	457,192.52	238,464.06
10		985,444.44	1,324,354.92	350,400.00	470,908.30	1,795,263.22	871,050.82
11		0.00	0.00	350,400.00	485,035.55	485,035.55	218,917.49
12		0.00	0.00	350,400.00	499,586.61	499,586.61	209,753.50
13		0.00	0.00	350,400.00	514,574.21	514,574.21	200,973.12
14		0.00	0.00	350,400.00	530,011.44	530,011.44	192,560.30
15		739,083.33	1,151,467.75	350,400.00	545,911.78	1,697,379.53	573,656.60
16		0.00	0.00	350,400.00	562,289.14	562,289.14	176,776.39
17		0.00	0.00	350,400.00	579,157.81	579,157.81	169,376.45
18		0.00	0.00	350,400.00	596,532.54	596,532.54	162,286.27
19		0.00	0.00	350,400.00	614,428.52	614,428.52	155,492.89
20		0.00	0.00	350,400.00	632,861.38	632,861.38	148,983.89
						LCC	**15,697,472.48**

Table 7.5 LCA 5MW Offshore Wind Power Plant

From the LCC analysis for the offshore 5MW Wind Power Plant the following results where concluded:

	Offshore
Capital Costs	10,055,555.56
Total O&M Costs	5,641,916.92

Table 7.6 LCA Data - Offshore

All the formulae that were used in the calculation of this LCC analysis can be found in Appendix D.

7.5. Analysis of Results

	Onshore	Offshore	Difference
Capital costs	6,250,000.00	10,055,555.56	3,805,555.56
Running Costs	3,582,614.45	5,641,916.92	2,059,302.47
Total Life Cycle Costs	9,832,614.45	15,697,472.48	5,864,858.03

Table 7.7 Comparison of Total Life Cycle Costs between Onshore and Offshore

From the results above the author can make the following assumptions:

- The offshore wind power plant has a larger capital cost than the onshore. A large percentage of this difference can be allocated to the cost of the foundations and grid connection. The foundations and grid connection in the offshore wind power plant both account for 21% of the capital costs. Whereas the foundations and grid connection account for 6.5% and 8.9% respectively.
- Running costs are again significantly more for offshore than onshore. This can be accounted for in the way that maintenance has to be carried out, a lot more effort has to be gone through to maintain and clean an offshore wind power plant. Based on experiences in Germany, Spain, Denmark, the UK and Ireland O&M costs are generally estimated to be between 1.2 and 1.5 euro cents per kWh of wind energy produced over the lifetime of the turbines used. Again based on the afore named countries data the O&M costs for an offshore wind power plant are assumed to be €16 per MWh of energy produced. (Wind Energy – The Facts, 2009)
- The graph below shows the comparison between the Capital and O&M costs over the 20 year period of the LCA.

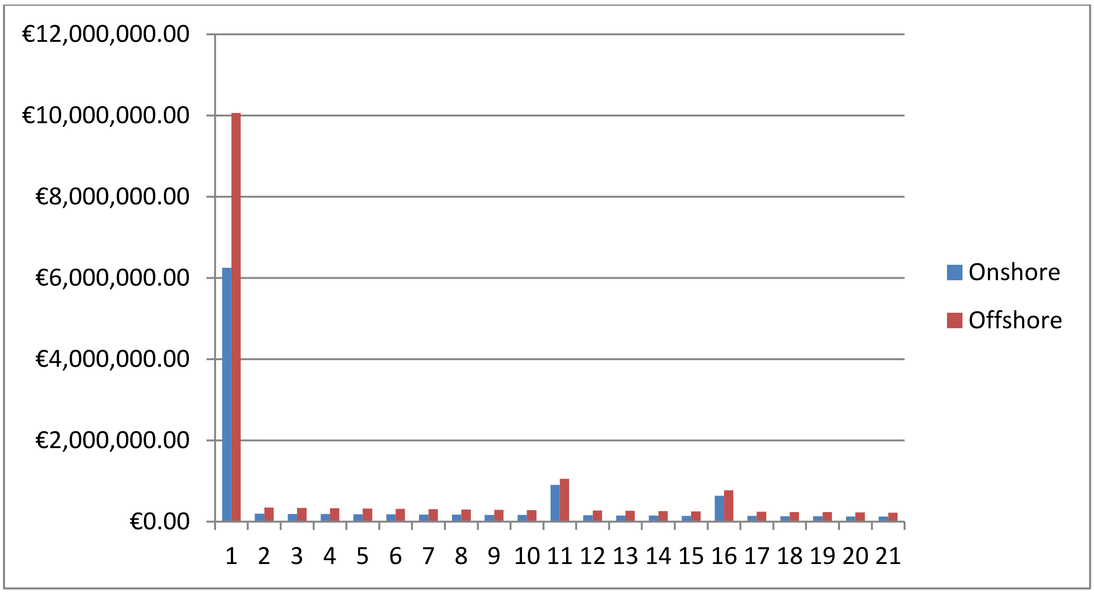
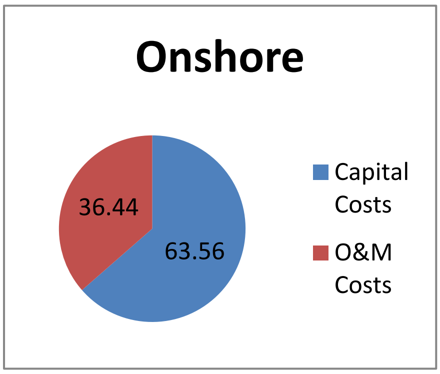


Figure 7.1 Comparisons of Annual Costs between Onshore and Offshore

- According to literature, approximately 75% of the total costs can be related to capital costs for example the cost of the turbine itself, the foundations, electrical equipment and finally connecting the turbine to a grid. In relation to the LCC analysis calculations carried out for both options the capital costs accounted for 60-65% of the total life cycle costs of each. The charts below show the exact percentage breakdown of the Capital and O&M Costs of both.



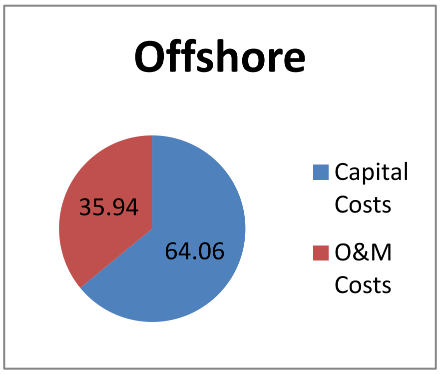


Figure 7.2 Percentage Breakdown of Costs Onshore

Figure 7.3 Percentage Breakdown of Cost Offshore

7.6. Risk Assessment

In order to investigate the affect that a change in the assumptions made by the author would have on the LCC analysis, the author decided to carry out a risk assessment. A sensitivity analysis was chosen to take these assumptions into consideration. The assumptions made by the author which were analysed in the sensitivity analysis are as follows:

- The Discount Rate
- The Escalation Rate
- Time Period

7.6.1 Change in Discount Rate

For the purpose of the sensitivity analysis the author has chosen to use 5% and 10% discount rates. As previously stated in this chapter the literature says that the discount rate is assumed to range between 5 and 10 per cent per annum, this is the reason for the choices.

Discount Rate	Options	Capital Costs	O&M Costs	Total Life Cycle Costs	Difference
5%	Onshore	6,250,000.00	4,551,872.64	10,801,872.64	6,382,479.59
	Offshore	10,055,555.56	7,128,796.67	17,184,352.23	

Table 7.8 Sensitivity Analysis 5% Discount Rate

Discount Rate	Options	Capital Costs	O&M Costs	Total Life Cycle Cost	Difference
10%	Onshore	6,250,000.00	2,875,561.08	9,125,561.08	5,487,943.78
	Offshore	10,055,555.56	4,557,949.30	14,613,504.86	

Table 7.9 Sensitivity Analysis 10% Discount Rate

From the results of the analysis of a change in discount rate you can clearly see that there is less of a difference in the costs between the two options if there is a higher discount rate. The change in discount rate did not make any difference to the fact that the onshore wind power plant is significantly cheaper than that of the offshore wind power plant.

7.6.2 Change in Escalation Rate

For the investigation into the affect of a change in the escalation rate the author decided to use 2% and 4%. In the main LCC analysis the author used an escalation rate of 3%, as it was seen to be a healthy stable economic inflation rate.

Escalation Rate	Options	Capital Costs	O&M Costs	Total Life Cycle Cost	Difference
2%	Onshore	6,250,000.00	3,257,939.19	9,507,939.19	5,691,771.29
	Offshore	10,055,555.56	5,144,154.92	15,199,710.48	

Table 7.10 Sensitivity Analysis 2% Escalation Rate

Escalation Rate	Options	Capital Costs	O&M Costs	Total Life Cycle Costs	Difference
4%	Onshore	6,250,000.00	3,945,785.18	10,195,785.18	6,058,605.99
	Offshore	10,055,555.56	6,198,835.61	16,254,391.16	

Table 7.11 Sensitivity Analysis 4% Escalation rate

From the results of the analysis of a change in escalation rate you can clearly see that there is more of a difference in the costs between the two options if there is a higher escalation rate. The change in escalation rate did not make any difference to the fact that the onshore wind power plant is significantly cheaper than that of the offshore wind power plant.

7.6.3 Change in Time Period

In relation to time period most LCC analysis carried out on Wind Turbines over a 20 year life cycle. This length is chosen as most wind turbines have only a set life time of 20 years working at maximum capacity. After a 20 year period a large overhaul of equipment will have to be made to wind power plant. This will lead to a large cost at year 20 of around 30% of the original capital cost of setting up the wind power plant. The following results have been concluded from using a time period of 30 years:

Time Period	Options	Capital Costs	O&M Costs	Total Life Cycle Cost	Difference
30 Years	Onshore	6,250,000.00	4,852,717.50	11,102,717.50	6,409,764.26
	Offshore	10,055,555.56	7,456,926.21	17,512,481.77	

Table 7.12 Sensitivity Analysis 30 Year Time Period

From the results in the sensitivity analysis into the increase in time period to 30 years, it is clear that the O&M costs have increased significantly for both options. Again this has not caused any difference in the fact that offshore wind power plant costs significantly more to construction and run.

7.7. Break Even Analysis

A break even analysis is not required in a LCC analysis but the author decided to carry out one as it would benefit the overall analysis of onshore versus offshore wind power plants. To carry out a break even analysis the author had to first calculate the Annual Energy Production for each system. AEP is calculated using this formula:
(Full Capacity kW*Hours of Daily use)*365

Annual Energy Production	Onshore	Offshore
Capacity kW	5000	5000
Hours	7.2 (Running @ 30% Capacity)	12 (Running @ 50% Capacity)
Days	365	365
AEP	13140000kWh	21900000kWh

Table 7.13 Annual Energy Production Calculations

The AEP is used then to calculate the annual income for each wind power plant. When the calculation was carried out the wholesale price of energy was €0.070083. (http://www.sem-o.com/Pages/default.aspx).

	Onshore	Offshore
Annual Income	€919909.50	€1533182.5

Table 7.14 Annual Income Calculations

These figures were used in the production of an escalated cash flow for both options. The author was able to establish that the onshore wind power plant broke even in year nine and has a predicted profit of €5,853,192.02 after 20 years. The offshore wind power plant broke even in year eight and has a predicted profit of €10,116,431.15. The following figures show the cumulative cash flow curves for both options. On these curves the breakeven point can be seen.

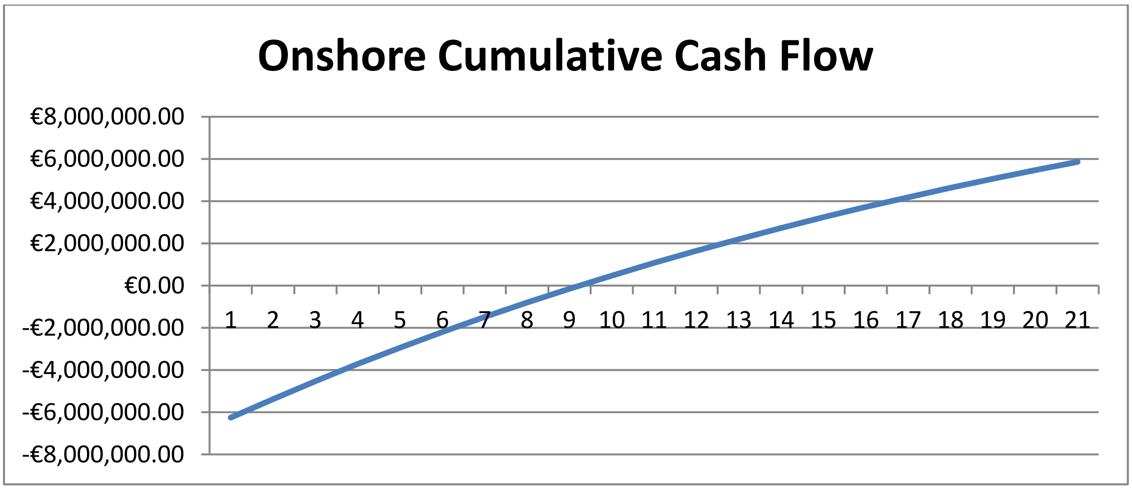


Figure 7.4 Onshore Break Even Analysis

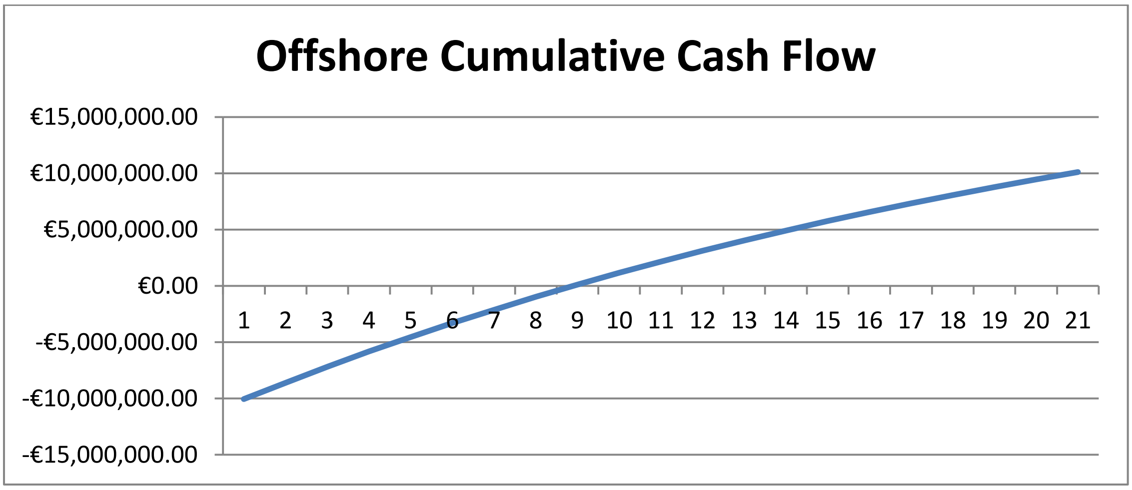


Figure 7.5 Offshore Break Even Analysis Table

7.7. Summary of Results

- The onshore option has a Total Life Cycle Costs of €9,832,614.45, with 63.56% of this being Capital costs and 36.44% on O&M costs.
- The offshore option has a Total Life Cycle Costs of €15,697,472.48, with 64.05% of this being Capital costs and 35.95% on O&M costs.
- After carrying out a sensitivity analysis, the author was able to establish that a change in discount rate, escalation rate and time period does not have an effect on which option is the more attractive to the client in terms of costs. With onshore being a cheaper option to construct and run over a 20 year period.
- The author carried out a break even analysis which showed that the offshore option had a shorter break even period than onshore, breaking even in year eight. While the onshore option broke even in year nine.
- The offshore option has a predicted overall profit of €10,116,431.15 over a twenty year period. This is 57.86% more than that of the onshore option, which had a predicted profit of €5,853,192.02 for the same time period.

Chapter 8 - Conclusions and Recommendations

8.1. Conclusion

8.1.1. Aim

The aim of this thesis was to critically analyse the financial and practical credentials of both onshore and offshore wind power plants, and to determine the life cycle cost of the two chosen types of wind energy production over the life of the turbines. Following a depth of investigation and study it was quite clear that the onshore option was a significantly cheaper than the offshore option in terms of both capital and O&M costs. But in terms of predicted income and breaking even the offshore option was the superior choice. This aim was concluded on the basis of the objectives set at the start of the dissertation.

8.1.2. Objectives

- To examine the concept of both offshore and onshore wind power plants, in relation to how each method is constructed and providing a practical assessment of their use.

After extensive research the author concluded that both onshore and offshore wind power plants were practical in different ways. However offshore wind power plants have fewer disadvantages than that of the onshore option as result. The main and almost only disadvantage to offshore wind power plant was the initial capital cost which was significantly higher than the onshore option.

- To examine the economics of wind energy production.

Through the review of literature on the economics of wind the author was able to distinguish the main costs elements of wind energy production. The main elements were upfront investment costs, cost of capital, O&M costs, turbine lifetime. The author found that the upfront investment costs can be up to 75% of the total costs.

- To investigate the methods used for Life Cycle Costing, and whether it is effective as an option appraisal tool.

From research into Life Cycle Costing the author believes that using life cycle costing allows clients to see the costs of running a particular project over the total life span of the project. It is also a great tool in option appraisal as it allows clients to clearly see the

difference in costs of two construction options. Therefore it encourages the client to thoroughly consider the potential future savings over the initial capital costs of the project, and therefore equips Quantity Surveyors with a tool that clearly highlights value for money.

- To investigate two Irish based wind power plants, by way of case studies and to analyse the different costs associated within the projects life.

The author was able to establish the different costs involved in the setting up and running of both an onshore and offshore wind farm. The author decided to use Crockahenny Wind Power Plant, in Donegal as his onshore case study. From research conducted by the author, he was able to establish that the project had capital costs of €10,055,555.56 and annual O&M costs of €197,100.00. These figures will were used in the conducting of the LCA in chapter seven. As there is only one offshore wind power plant in Ireland, the Arklow Bank Wind Power Plant, of the coast of Wicklow, this project was used as the offshore case study. The author established that the Arklow bank Wind Power Plant had capital costs of €50,277,777.78 and annual O&M costs of €1,752,000.00. These figures were altered to suit a 5MW offshore wind power plant to conduct an accurate comparison LCA.

- To carry out a detailed life cycle cost analysis of both a 5MW offshore and 5MW onshore wind farms.

The author believes the Life Cycle Cost Analysis is very beneficial as it provides the client with all the essential costs before and after construction work. This in turn may become the deciding factor for the selection between two different projects. However the LCA is used to estimate future costs, which leaves a certain element of uncertainty. The author was able to establish a LCA template to use for his analysis, through the review of literature and information received from Dermot Kehily, Cost and Value Management Lecturer, DIT. The author carried out a LCA for both options and the following results were concluded. A 5MW onshore wind power plant had a total life cycle cost of €9,832,614.45, over a 20 year period. This was made up of 63.56% Capital costs and 36.44% O&M costs. A 5MW onshore wind power plant had a total life cycle cost of €15,697,472.48, over the same period of time. This figure was made up of 64.06% capital costs and 35.94% O&M costs. From this the author was able to conclude in terms of costs the onshore option is the most advantageous to the client.

8.2. Recommendations

The author believes there are a number of recommendations which need addressing for both the client and the industry professionals:

- The author feels that there should be further research into the availability of wind, off the coast of Ireland. This may allow Ireland to develop more offshore wind farms, which in turn would make Ireland a more sustainable country.

- The author feels that LCC is a valuable tool in option appraisal. It is a great way to compare construction options based on not only the construction costs but the total life cycle costs over the length of the project. But further research into a universal form of LCC analysis would be the next step in its development.

- A LCC analysis should be carried out every ten years to facilitate any variables that may occur during the life time of the project. As LCC is a relatively new service to most Quantity Surveying practices this continued production of LCC analysis would assist in developing a database over a period of time, which would improve the quality of research for future wind power developments.

Appendix A – Bibliography

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Appendix B – Thesis Proposal

SCHOOL OF REAL ESTATE AND CONSTRUCTION ECONOMICS

CONSTRUCTION ECONOMICS AND MANAGEMENT DEGREE

DT111 AND DT155

THESIS PROPOSAL FORM

2011/2012

THESIS PROPOSALS MUST ONLY BE SUBMITTED IN THIS FORMAT. THIS PROPOSAL CAN BE ACCESSED ON THE MAIN COMPUTER UNDER THE NAME OF :

SUBMISSION DATE: Please fill this form and submit it WEDNESDAY 2nd NOVEMBER 12 NOON. The form is intended to help you formulate your proposal. Your attention is drawn to the Regulations for Construction Economics and Management Degree course thesis guidelines.

STUDENT'S NAME: Gavin McQuaid

PROGRAMME: Construction Economics and Management (DT111/4)

STUDENT MOBILE NO: 086-1099406

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(Write clearly please)

1. WORKING TITLE OF THESIS

- State the main topic you intend to examine or the research question you intend to answer.

"Life Cycle analysis of Onshore Vs Offshore sited Wind Power Plants"

The author intends to critically analyse how a life cycle analyse is carried out for both onshore and offshore wind power plants. The author intends to use two case studies to compare and contrast onshore and offshore wind power plants and how Life cycle analysis was carried out on both projects.

2. OBJECTIVES

- Identify the primary objectives or hypothesis of the dissertation/thesis and detail the key areas requiring specific attention.

vii. To investigate further as to how the process and procedures of wind energy is used as a source of energy.

viii. To investigate the difference between offshore and onshore wind power plants(advantages/disadvantages)

ix. To investigate the best methods of carrying out a Life Cycle Analysis on Wind Power Plants

x. To use two case studies to carry out a detailed life cycle costing of both an offshore and onshore wind power plant.

xi. To conduct all research from a Quantity Surveyors perspective, providing detailed cost analysis.

3. PRELIMINARY CHAPTER HEADINGS

- Include brief outline of topics to be covered in each chapter.
- Indicate proposed sources of information for each chapter.
- Indicate proposed methodology for each chapter, where appropriate

Chapter 1: Introduction

- Introduction

- Background
- Aim
- Objectives
- Scope
- Research Methodology
- Conclusion

Sources of information

- Dr. S. G. Naoum (2007) Dissertation research and writing for construction students, 2nd edition, Elservier Ltd.

Chapter 2: Literature review; Onshore Vs. Offshore Wind Power Plants (Part 1)

- Introduction
- Onshore:
    - Background
    - Installation
    - Advantages
    - Disadvantages
- Offshore:
    - Background
    - Installation
    - Advantages
    - Disadvantages
- Summary

Sources of Information:

- Stiebler, M (2008) *Wind Energy Systems for Electric Power Generation*, 1st Edition, Springer, Berlin.
- Sathyajith, M (2006) *Wind Energy Fundamentals, Resource, Analysis and Economic,* 1st Edition, Springer, Berlin

Proposed Methodology:

- Interview Mr. Michael Gleeson, Lecturer in Building Services to discuss the traditional methods of energy provision which are currently being used in DIT.
- Send a questionnaire to a number of construction contracting firms and quantity surveying practices in order to establish their attitudes to new wind energy principles and construction processes.

Chapter 3: Literature Review - The Economics of Wind Energy (Part 2)

- Introduction
- Factors Affecting Economic Feasibility
    - Upfront Investment Costs
    - Turbine Lifetime
    - Operation and Maintenance Costs
    - Availability of Wind
    - Electricity Production and Average Wind Speed
    - Cost of Capital
- Limitations of the literature

Sources of Information:

- Stiebler, M (2008) *Wind Energy Systems for Electric Power Generation*, 1st Edition, Springer, Berlin.
- Sathyajith, M (2006) *Wind Energy Fundamentals, Resource, Analysis and Economic*, 1st Edition, Springer, Berlin
- O'Sullivan, Gillian: ***Grangegorman : Would wind be a more cost effective source of energy for the campus?***: DIT, 2011

Proposed Methodology:

- Interview Mr. Robert Kelly, Civil Engineer for John Sisk & Sons. Robert has extensive experience working on both onshore and offshore wind power plants.

Chapter 4: Literature Review; Life Cycle Analysis (Part 3)

- Introduction
    - What is Life Cycle Costing
    - Background of Life Cycle Costing
- Methods of Life Cycle Costing and the uses.
- Factors affecting Life Cycle Analysis
- Uncertainty and Risk Assessment in Life Cycle Costing
- Summary

Sources of Information:

- *Life Cycle Costing for Construction*- John W Bull; Blackwell Publishing
- *Whole Life Cycle Costing: Risk and Risk Responses* – Halim Boussabaine and Richard Kirkham; Blackwell Publishing (2003)
- *Whole life costing analysis* – D. Churcher; Bracknell (2008)

Proposed Methodology:

- Interview Mr. Dermot Kehily, Lecturer in Cost and Value Management to discuss methods of Life Cycle Costing, and methods used in Wind Power Plant analysis.

Chapter 5: Research Methodology

- Introduction
- Primary Data Collection
  - Interview
  - Questionnaire
  - Case Study
- Primary Literature Sources
  - Dissertation and theses
  - Reports and Organisation Publications
- Secondary Literature Sources
  - Textbooks
  - The Internet

Sources of information

- Dr. S. G. Naoum (2007) Dissertation research and writing for construction students, 2nd edition, Elservier Ltd.

Chapter 6: Case Studies

- Introduction
  - Offshore Case Study: Arklow Bay Wind Power Plant, Five miles of the coast of Co. Wicklow)
  - Onshore Case Study: Crockahenny Wind Power Plant, Co. Donegal.
- Background information on both studies:
  - Type of Wind turbine used
  - Capacity
- Methods of Life Cycle analysis used on the projects.
- Summary

Proposed Methodology:

- Interview Mr. Dave O'Connor, Hibernian Wind Power Ltd who was part of the team to construct Crockahenny Wind Power Plant in Co. Donegal
- Interview Mr. Andrew Woodhouse, GE Energy/Airtricity about the offshore Wind Power Plant in Arklow Bay, Co. Wicklow.

Chapter 7: Life Cycle Analysis

- Introduction
- Life Cycle Cost Appraisal
  - Assumptions for Life Cycle Cost analysis
- Analysis of Results
- Risk Assessment
  - Sensitivity Analysis: Change in Discount factor
  - Sensitivity Analysis: Change in Time Period
- Summary

Sources of Information:

- Russell, Michael: *Mixed mode ventilation or mechanical ventilation? : A life cycle cost appraisal in accordance with RICS Life Cycle Costing of Sustainable Design* Dublin : DIT, 2011
- *Life Cycle Costing for Construction*- John W Bull
- *Whole life costing analysis* – D. Churcher; Bracknell (2008)

Proposed Methodology:

- Interview Mr. Kevin O'Reilly, Lecturer in Financial Management to discuss Life Cycle Costing and Project Appraisal.

Chapter 8: Recommendations and conclusions

- Introduction
- Review of main findings
- Realisation of objectives
- Recommendations
- Further research
- Conclusion

4.	LIST THE DATE AND OTHER INFORMATION SOURCES, AND ORGAN-ISATIONS/INDIVIDUALS WHO YOU INTEND TO CONSULT IN THE COURSE OF YOUR RESEARCH

Key Websites:

- www.ggda.ie
- www.dit.ie
- www.credit.ie
- www.esb.ie
- www.seai.ie
- www.iwea.ie
- www.environ.ie
- www.dcenr.gov.ie

- www.greenspec.co.uk

- www.cabe.europa.eu

- www.ec.europa.eu

Key Individuals:

Robert Kelly, SISK Engineer
Dave O'Connor, Hibernian Wind Power Ltd
Andrew Woodhouse, GE Energy/Airtricity
Lecturers in Dublin Institute of Technology Financial Management/Quantity Surveying

Key Documents:

- National Development Plan 2007-2013 – "Transforming Ireland, A Better Quality of Life for All"
- Renewable Energy in Ireland – 2010 update (SEAI)

Key Organisations:

- Sustainable Energy Authority of Ireland (SEAI)
- Airtricity
- Hibernian Wind Power Ltd
- GE Energy
- Irish Wind Energy Association
- European Commission for the Environment

5. RESEARCH METHODOLOGY.

- Which of the following methods do you intend to incorporate in your study:

	Please Tick
* Documentary Research	__X__
* Interviews	__X__
* Questionnaire Survey(s)	__X__
* Case Study(s)	__X__
* Other (Specify)	____

Please state why you consider this/these method(s) to be appropriate.

Documentary Research:

It will be important to locate as much information as possible on my chosen topic. Initially this will involve going to the college library and finding text books/theses with relevant core material. I plan to use Internet search engines to find appropriate websites.

Interviews:

I intend on using interviews in my research methodology as they are a vital source of primary data. I hope to interview people in the field that I am studying and that will be able to share their vast knowledge and expertise with me that will in turn help me to answer the questions set out in my thesis.

Questionnaire/Survey:

I plan on using a questionnaire in my research methodology in order to gain first hand information from industry personnel. It will be through a questionnaire that I'm hoping to establish the attitudes of the construction industry towards a new renewable source of energy, such as wind energy.

Case Study:

I propose to use two case studies, one onshore Crockahenny Wind Plant, Co. Donegal and one offshore Arklow Bay, Co. Wicklow to develop a greater understanding as to the processes and procedures involved in a development of this scale. I will hope to also gain a deeper insight into the cost effectiveness of a project like this, allowing me to compare and contrast the two types of wind power plant from a life cycle perspective.

6. PRELIMINARY REFERENCES INCLUDING TEXTBOOKS, LIBRARY CATALOGUES, JOURNALS, DATABASES, PREVIOUS THESES

Books:

- Stiebler, M (2008) *Wind Energy Systems for Electric Power Generation*, 1st Edition, Springer, Berlin
- O'Sullivan, J (2007) "A Construction Economic Analysis" of an 850KW Wind Turbine, B.Sc (C.E.M.D) unpublished dissertation, Dublin Institute of Technology, Bolton Street, Dublin.
- National Development Plan 2007-2013 – "Transforming Ireland, A Better Quality of Life for All"
- The National Sustainable Development Strategy 1997-2002, Making Ireland's Development Sustainable, Review, Assessment and Future Action
- *Building Economics and Cost Control: Worked Solutions* – Allan Ashworth; Butterworth.
- *The Economics of Building; A Practical Guide for the Design Professional* – Robert E Johnson
- *Life Cycle Costing for Construction*- John W Bull
- *Pre Contract Studies* 3rd Edition – Allan Ashworth
- *Whole Life Cycle Costing: Risk and Risk Responses* – Halim Boussabaine and Richard Kirkham; Blackwell Publishing (2003)
- *Whole life costing analysis* – D. Churcher; Bracknell (2008)
- Dr. S. G. Naoum (2007) *Dissertation research and writing for construction students*, 2nd edition, Butterworth-Heinemann.

<u>Thesis:</u>

- **Russell, Michael:** *Mixed mode ventilation or mechanical ventilation? : A life cycle cost appraisal in accordance with RICS Life Cycle Costing of Sustainable Design*: **DIT, 2011**

- **Garrett, Jonathan:** *A comparison analysis of the life cycle cost of internal wall insulation to external wall insulation*: **DIT, 2011**

- **O'Sullivan, Gillian:** *Grangegorman : Would wind be a more cost effective source of energy for the campus?*: **DIT, 2011**

Appendix C - Interview Transcript

The following is an extract from an interview held with Mr. Robert Kelly a site engineer for John Sisk & Sons Ltd on the 16th of March 2012

Author: Is your company involved in more Onshore or Offshore Wind Installations?

Robert: I have been at John Sisk & Sons for over two years, I have only worked on two wind farm installations, the one I'm currently working on the Mynydd y Betws Wind Farm in Swansea and the Whitelee wind farm extension in Glasgow. Both of these have been onshore. Sisk have not carried out any offshore wind farms to date.

Author: Do you carry out Life Cycle Analysis when deciding on the type of wind installation?

Robert: Personally, I do not carry out LCC analysis I have been working as a Site Engineer on both projects so far. So I was not directly involved in the financial planning of the wind farms. Although I do know that Sisk & Sons have incorporated LCC analysis into their new sustainable development plans for 2013 – 2015.

Author: Do you feel that LCC analysis is a worthwhile method for evaluating different systems?

Robert: I feel that it is very worthwhile method. I actually carried out a LCC on the different types of concrete used in the construction of offshore wind farms for my undergraduate degree. I have to say it is a great tool for option appraisal and financial forecasting.

Author: Do you feel that Life Cycle Costing carried out on a wide scale basis throughout the wind energy industry?

Robert: At Sisk & Sons, LCC is being used more now even from when I started working here. I feel that it is a somewhat new technique in the industry in practice at least. Especially in Ireland in particular it wouldn't be used on wide scale basis.

Author: Do you feel if there was a more standardised method of Life Cycle Costing, it would be used on a wider scale?

Robert: To be honest I think it will become more widely used in the industry whether a completely standardised method does come about or not. Actually I do feel that the different methods of LCC can be more suited to different types of construction projects.

Author: Do you agree that a large share of the total costs of installing a wind farm is the upfront investment costs?

Robert: That I do agree with, when it comes to wind farms both onshore and offshore a great deal of the total costs does come from upfront costs. In the case of onshore, the wind turbine is the greatest expense. With offshore, the foundations can be almost as much as the wind turbines, in some cases more depending on the depth and the type of concrete needed. From research I carried out myself for my undergraduate thesis the higher amount of chloride content in the water the more expensive the concrete foundations would be.

Author: In relation to operation and maintenance cost, what do you believe to be the biggest annual cost?

Robert: I have only been involved on two wind farms to date, and have mainly been involved in the construction of foundations, access roads and other earthworks. So the O&M cost after commissioning would not be an area that I would have a great deal of experience with.

Author: Do you feel there is a greater energy production capability onshore or offshore?

Robert: There would be a greater capacity to produce energy offshore due to the size of wind turbines that could be installed at sea. The wind speed at sea can be faster than on land so the wind turbines usage would be greater hence increasing the energy production.

Author: What way do you see the wind energy industry going in the future, towards onshore or offshore wind farms?

Robert: Well, if the costs of offshore wind farms could be reduced, or the capacity increased through the development of larger, more efficient wind turbines, then I could see the industry heading that way. But in general I believe the lower cost to produce wind energy onshore will continue to be a deciding factor in which option a company chooses.

Appendix D – LCC Analysis Formulae

Single Present Value (SPV):

$$\frac{1}{(1+i)^n}$$

Uniform Present Value (UPV)

$$\frac{(1+i)^n - 1}{i(1+i)^n}$$

Single Present Value Modified (SPV*)

$$\left[\frac{1+e}{1+i}\right]^n$$

Uniform Present Value Modified (UPV*)

$$\frac{1 - \left[\frac{1+e}{1+i}\right]^n}{\left[\frac{1+i}{1+e}\right] - 1}$$

All formulae were source from Kehily, D (2011) *Guide to Life Cycle Costing*, Society of Chartered Surveyors Ireland, Published December 2011.

Appendix E – Onshore Cost Breakdown

Price/kW	1250
turbine size	500
no of turbines	10
total investment cost	**6250000**

AEP	13140000
price/kWh	0.015
O&M Costs/annum	**197100**

Cost Breakdown	**% Breakdown**	**Investment**
Turbine ex works	75.6	4725000
Foundation	6.5	406250
electric installation	1.5	93750
grid connection	8.9	556250
control system	0.3	18750
Consultancy	1.2	75000
Land	3.9	243750
financial costs	1.2	75000
Infrastructure	0.9	56250
Total	**100**	**6250000**

O&M Breakdown	**%Breakdown**	**Cost**
Land rent	18	35478
Insurance	13	25623
Service and spare parts	26	51246
Power from the grid	5	9855
Administration	21	41391
Cleaning	17	33507
Total	**100**	**197100**

Annual Energy Production	
Capacity kW	5000
30% of Full Capacity	7.2
Days per year	365
AEP	13140000

Appendix F - Offshore Cost Breakdown

Cost Breakdown	% Breakdown	
Turbine ex works, including transport and erection	49	4927222.222
Transformer station and main cable to coast	16	1608888.889
Internal grid between turbines	5	502777.7778
Foundations	21	2111666.667
Design and Project Management	6	603333.3334
Environmental Analysis	3	301666.6667
Total	**100**	10055555.56

Output	21900
Price/MWh	16
O&M Costs/annum	**350400**

O&M Breakdown	% Breakdown	Cost
Foreshore Lease	18	63072
Insurance	13	45552
Service and spare parts	26	91104
Power from the grid	5	17520
Administration	21	73584
Cleaning	17	59568
Total	**100**	350400

Annual Energy Production	
Capacity	5000
Running @ 50% Capacity	12
Days per Year	365
AEP	**21900000**

Appendix G - Sensitivity Analysis

Change in Discount Rate – 5%

Option 1: Onshore Wind Power System									**Discount Rate**	**5%**
YEAR	Capital cost	Major Replacement	Escalated Major Replacement	Operation and Maintenance	Escalated Operation and Maintenance	Occupancy Costs	Escalated Occupancy Costs	Escalated Total Costs	Total Present Value
Escal			0.030		0.030		0.030		0.050
0.00	6,250,000.00							6,250,000.00	6,250,000.00
1.00		0.00	0.00	161,622.00	166,470.66	35,478.00	36,542.34	203,013.00	193,345.71
2.00		0.00	0.00	161,622.00	171,464.78	35,478.00	37,638.61	209,103.39	189,662.94
3.00		0.00	0.00	161,622.00	176,608.72	35,478.00	38,767.77	215,376.49	186,050.31
4.00		0.00	0.00	161,622.00	181,906.98	35,478.00	39,930.80	221,837.79	182,506.50
5.00		0.00	0.00	161,622.00	187,364.19	35,478.00	41,128.73	228,492.92	179,030.18
6.00		0.00	0.00	161,622.00	192,985.12	35,478.00	42,362.59	235,347.71	175,620.08
7.00		0.00	0.00	161,622.00	198,774.67	35,478.00	43,633.46	242,408.14	172,274.94
8.00		0.00	0.00	161,622.00	204,737.91	35,478.00	44,942.47	249,680.38	168,993.51
9.00		0.00	0.00	161,622.00	210,880.05	35,478.00	46,290.74	257,170.79	165,774.59
10.00		945,000.00	1,270,000.98	161,622.00	217,206.45	35,478.00	47,679.47	1,534,886.90	942,287.41
11.00		0.00	0.00	161,622.00	223,722.65	35,478.00	49,109.85	272,832.50	159,519.51
12.00		0.00	0.00	161,622.00	230,434.33	35,478.00	50,583.14	281,017.47	156,481.04
13.00		0.00	0.00	161,622.00	237,347.36	35,478.00	52,100.64	289,447.99	153,500.45
14.00		0.00	0.00	161,622.00	244,467.78	35,478.00	53,663.66	298,131.43	150,576.63
15.00		708,750.00	1,104,209.41	161,622.00	251,801.81	35,478.00	55,273.57	1,411,284.78	678,852.11
16.00		0.00	0.00	161,622.00	259,355.86	35,478.00	56,931.78	316,287.64	144,895.01
17.00		0.00	0.00	161,622.00	267,136.54	35,478.00	58,639.73	325,776.27	142,135.11
18.00		0.00	0.00	161,622.00	275,150.64	35,478.00	60,398.92	335,549.56	139,427.77
19.00		0.00	0.00	161,622.00	283,405.16	35,478.00	62,210.89	345,616.04	136,772.00
20.00		1,417,500.00	2,560,162.68	161,622.00	291,907.31	35,478.00	64,077.21	2,916,147.20	1,099,065.21
								LCC	**11,766,771.02**

Option 2: Offshore Wind Power System								Discount Rate	5%
YEAR	Capital cost	Major replacement	Escalated Major replacement costs	Operation and Maintenance	Escalated Operation and Maintenance	Occupancy Costs	Escalated Occupancy Costs	Escalated Total Costs	Present Value
Escal			**0.030**		**0.030**		**0.030**		**0.050**
0.00	10,055,555.56							10,055,555.56	10,055,555.56
1.00		0.00	0.00	287,328.00	295,947.84	63,072.00	64,964.16	360,912.00	343,725.71
2.00		0.00	0.00	287,328.00	304,826.28	63,072.00	66,913.08	371,739.36	337,178.56
3.00		0.00	0.00	287,328.00	313,971.06	63,072.00	68,920.48	382,891.54	330,756.11
4.00		0.00	0.00	287,328.00	323,390.20	63,072.00	70,988.09	394,378.29	324,455.99
5.00		0.00	0.00	287,328.00	333,091.90	63,072.00	73,117.73	406,209.64	318,275.88
6.00		0.00	0.00	287,328.00	343,084.66	63,072.00	75,311.27	418,395.92	312,213.48
7.00		0.00	0.00	287,328.00	353,377.20	63,072.00	77,570.60	430,947.80	306,266.56
8.00		0.00	0.00	287,328.00	363,978.51	63,072.00	79,897.72	443,876.24	300,432.91
9.00		0.00	0.00	287,328.00	374,897.87	63,072.00	82,294.65	457,192.52	294,710.38
10.00		985,444.44	1,324,354.92	287,328.00	386,144.81	63,072.00	84,763.49	1,795,263.22	1,102,135.89
11.00		0.00	0.00	287,328.00	397,729.15	63,072.00	87,306.40	485,035.55	283,590.24
12.00		0.00	0.00	287,328.00	409,661.02	63,072.00	89,925.59	499,586.61	278,188.52
13.00		0.00	0.00	287,328.00	421,950.85	63,072.00	92,623.36	514,574.21	272,889.69
14.00		0.00	0.00	287,328.00	434,609.38	63,072.00	95,402.06	530,011.44	267,691.79
15.00		739,083.33	1,151,467.75	287,328.00	447,647.66	63,072.00	98,264.12	1,697,379.53	816,468.58
16.00		0.00	0.00	287,328.00	461,077.09	63,072.00	101,212.04	562,289.14	257,591.13
17.00		0.00	0.00	287,328.00	474,909.40	63,072.00	104,248.41	579,157.81	252,684.63
18.00		0.00	0.00	287,328.00	489,156.69	63,072.00	107,375.86	596,532.54	247,871.59
19.00		0.00	0.00	287,328.00	503,831.39	63,072.00	110,597.13	614,428.52	243,150.23
20.00		1478166.667	2,669,733.42	287,328.00	518,946.33	63,072.00	113,915.05	3,302,594.80	1,244,713.25
								LCC	**18,190,546.68**

Change in Discount Rate – 10%

Option 1: Onshore Wind Power System								Discount Rate	10%
YEAR	Capital cost	Major Replacement	Escalated Major Replacement	Operation and Maintenance	Escalated Operation and Maintenance	Occupancy Costs	Escalated Occupancy Costs	Escalated Total Costs	Total Present Value
Escal			0.030		0.030		0.030		0.100
0.00	6,250,000.00							6,250,000.00	6,250,000.00
1.00		0.00	0.00	161,622.00	166,470.66	35,478.00	36,542.34	203,013.00	184,557.27
2.00		0.00	0.00	161,622.00	171,464.78	35,478.00	37,638.61	209,103.39	172,812.72
3.00		0.00	0.00	161,622.00	176,608.72	35,478.00	38,767.77	215,376.49	161,815.55
4.00		0.00	0.00	161,622.00	181,906.98	35,478.00	39,930.80	221,837.79	151,518.19
5.00		0.00	0.00	161,622.00	187,364.19	35,478.00	41,128.73	228,492.92	141,876.13
6.00		0.00	0.00	161,622.00	192,985.12	35,478.00	42,362.59	235,347.71	132,847.65
7.00		0.00	0.00	161,622.00	198,774.67	35,478.00	43,633.46	242,408.14	124,393.70
8.00		0.00	0.00	161,622.00	204,737.91	35,478.00	44,942.47	249,680.38	116,477.74
9.00		0.00	0.00	161,622.00	210,880.05	35,478.00	46,290.74	257,170.79	109,065.52
10.00		945,000.00	1,270,000.98	161,622.00	217,206.45	35,478.00	47,679.47	1,534,886.90	591,765.34
11.00		0.00	0.00	161,622.00	223,722.65	35,478.00	49,109.85	272,832.50	95,626.13
12.00		0.00	0.00	161,622.00	230,434.33	35,478.00	50,583.14	281,017.47	89,540.83
13.00		0.00	0.00	161,622.00	237,347.36	35,478.00	52,100.64	289,447.99	83,842.77
14.00		0.00	0.00	161,622.00	244,467.78	35,478.00	53,663.66	298,131.43	78,507.32
15.00		708,750.00	1,104,209.41	161,622.00	251,801.81	35,478.00	55,273.57	1,411,284.78	337,850.36
16.00		0.00	0.00	161,622.00	259,355.86	35,478.00	56,931.78	316,287.64	68,833.41
17.00		0.00	0.00	161,622.00	267,136.54	35,478.00	58,639.73	325,776.27	64,453.10
18.00		0.00	0.00	161,622.00	275,150.64	35,478.00	60,398.92	335,549.56	60,351.54
19.00		0.00	0.00	161,622.00	283,405.16	35,478.00	62,210.89	345,616.04	56,510.98
20.00		1,417,500.00	2,560,162.68	161,622.00	291,907.31	35,478.00	64,077.21	2,916,147.20	433,466.70
								LCC	**9,506,112.95**

Option 2: Offshore Wind Power System									**Discount Rate**	**10%**
YEAR	Capital cost	Major replacement	Escalated Major replacement costs	Operation and Maintenance	Escalated Operation and Maintenance	Occupancy Costs	Escalated Occupancy Costs	Escalated Total Costs	Present Value
Escal			**0.030**		**0.030**		**0.030**		**0.100**
0.00	10,055,555.56							10,055,555.56	10,055,555.56
1.00		0.00	0.00	287,328.00	295,947.84	63,072.00	64,964.16	360,912.00	328,101.82
2.00		0.00	0.00	287,328.00	304,826.28	63,072.00	66,913.08	371,739.36	307,222.61
3.00		0.00	0.00	287,328.00	313,971.06	63,072.00	68,920.48	382,891.54	287,672.08
4.00		0.00	0.00	287,328.00	323,390.20	63,072.00	70,988.09	394,378.29	269,365.68
5.00		0.00	0.00	287,328.00	333,091.90	63,072.00	73,117.73	406,209.64	252,224.22
6.00		0.00	0.00	287,328.00	343,084.66	63,072.00	75,311.27	418,395.92	236,173.59
7.00		0.00	0.00	287,328.00	353,377.20	63,072.00	77,570.60	430,947.80	221,144.36
8.00		0.00	0.00	287,328.00	363,978.51	63,072.00	79,897.72	443,876.24	207,071.54
9.00		0.00	0.00	287,328.00	374,897.87	63,072.00	82,294.65	457,192.52	193,894.26
10.00		985,444.44	1,324,354.92	287,328.00	386,144.81	63,072.00	84,763.49	1,795,263.22	692,151.69
11.00		0.00	0.00	287,328.00	397,729.15	63,072.00	87,306.40	485,035.55	170,002.00
12.00		0.00	0.00	287,328.00	409,661.02	63,072.00	89,925.59	499,586.61	159,183.69
13.00		0.00	0.00	287,328.00	421,950.85	63,072.00	92,623.36	514,574.21	149,053.82
14.00		0.00	0.00	287,328.00	434,609.38	63,072.00	95,402.06	530,011.44	139,568.58
15.00		739,083.33	1,151,467.75	287,328.00	447,647.66	63,072.00	98,264.12	1,697,379.53	406,339.16
16.00		0.00	0.00	287,328.00	461,077.09	63,072.00	101,212.04	562,289.14	122,370.50
17.00		0.00	0.00	287,328.00	474,909.40	63,072.00	104,248.41	579,157.81	114,583.29
18.00		0.00	0.00	287,328.00	489,156.69	63,072.00	107,375.86	596,532.54	107,291.62
19.00		0.00	0.00	287,328.00	503,831.39	63,072.00	110,597.13	614,428.52	100,463.97
20.00		1478166.667	2,669,733.42	287,328.00	518,946.33	63,072.00	113,915.05	3,302,594.80	490,909.67
								LCC	**15,010,343.72**

Change in Escalation Rate – 2%

Option 1: Onshore Wind Power System								Discount Rate	7.5%
YEAR	Capital cost	Major Replacement	Escalated Major Replacement	Operation and Maintenance	Escalated Operation and Maintenance	Occupancy Costs	Escalated Occupancy Costs	Escalated Total Costs	Total Present Value
Escal			**0.020**		**0.020**		**0.020**		**0.075**
0.00	6,250,000.00							6,250,000.00	6,250,000.00
1.00		0.00	0.00	161,622.00	164,854.44	35,478.00	36,187.56	201,042.00	187,015.81
2.00		0.00	0.00	161,622.00	168,151.53	35,478.00	36,911.31	205,062.84	177,447.56
3.00		0.00	0.00	161,622.00	171,514.56	35,478.00	37,649.54	209,164.10	168,368.85
4.00		0.00	0.00	161,622.00	174,944.85	35,478.00	38,402.53	213,347.38	159,754.63
5.00		0.00	0.00	161,622.00	178,443.75	35,478.00	39,170.58	217,614.33	151,581.14
6.00		0.00	0.00	161,622.00	182,012.62	35,478.00	39,953.99	221,966.61	143,825.82
7.00		0.00	0.00	161,622.00	185,652.87	35,478.00	40,753.07	226,405.95	136,467.29
8.00		0.00	0.00	161,622.00	189,365.93	35,478.00	41,568.13	230,934.06	129,485.25
9.00		0.00	0.00	161,622.00	193,153.25	35,478.00	42,399.49	235,552.75	122,860.42
10.00		945,000.00	1,151,949.73	161,622.00	197,016.32	35,478.00	43,247.48	1,392,213.53	675,493.55
11.00		0.00	0.00	161,622.00	200,956.64	35,478.00	44,112.43	245,069.08	110,610.26
12.00		0.00	0.00	161,622.00	204,975.78	35,478.00	44,994.68	249,970.46	104,951.13
13.00		0.00	0.00	161,622.00	209,075.29	35,478.00	45,894.58	254,969.87	99,581.54
14.00		0.00	0.00	161,622.00	213,256.80	35,478.00	46,812.47	260,069.26	94,486.67
15.00		708,750.00	953,884.18	161,622.00	217,521.93	35,478.00	47,748.72	1,219,154.83	412,032.91
16.00		0.00	0.00	161,622.00	221,872.37	35,478.00	48,703.69	270,576.06	85,065.60
17.00		0.00	0.00	161,622.00	226,309.82	35,478.00	49,677.77	275,987.58	80,713.40
18.00		0.00	0.00	161,622.00	230,836.02	35,478.00	50,671.32	281,507.34	76,583.88
19.00		0.00	0.00	161,622.00	235,452.74	35,478.00	51,684.75	287,137.48	72,665.63
20.00		1,417,500.00	2,106,330.43	161,622.00	240,161.79	35,478.00	52,718.44	2,399,210.67	564,805.74
								LCC	**10,003,797.07**

Option 2: Offshore Wind Power System								Discount Rate	7.5%
YEAR	Capital cost	Major replacement	Escalated Major replacement costs	Operation and Maintenance	Escalated Operation and Maintenance	Occupancy Costs	Escalated Occupancy Costs	Escalated Total Costs	Present Value
Escal			**0.020**		**0.020**		**0.020**		**0.075**
0.00	10,055,555.56							10,055,555.56	10,055,555.56
1.00		0.00	0.00	287,328.00	293,074.56	63,072.00	64,333.44	357,408.00	332,472.56
2.00		0.00	0.00	287,328.00	298,936.05	63,072.00	65,620.11	364,556.16	315,462.33
3.00		0.00	0.00	287,328.00	304,914.77	63,072.00	66,932.51	371,847.28	299,322.40
4.00		0.00	0.00	287,328.00	311,013.07	63,072.00	68,271.16	379,284.23	284,008.23
5.00		0.00	0.00	287,328.00	317,233.33	63,072.00	69,636.58	386,869.91	269,477.58
6.00		0.00	0.00	287,328.00	323,578.00	63,072.00	71,029.32	394,607.31	255,690.35
7.00		0.00	0.00	287,328.00	330,049.56	63,072.00	72,449.90	402,499.46	242,608.52
8.00		0.00	0.00	287,328.00	336,650.55	63,072.00	73,898.90	410,549.45	230,195.99
9.00		0.00	0.00	287,328.00	343,383.56	63,072.00	75,376.88	418,760.44	218,418.52
10.00		985,444.44	1,201,251.27	287,328.00	350,251.23	63,072.00	76,884.42	1,628,386.92	790,083.45
11.00		0.00	0.00	287,328.00	357,256.25	63,072.00	78,422.10	435,678.36	196,640.46
12.00		0.00	0.00	287,328.00	364,401.38	63,072.00	79,990.55	444,391.92	186,579.78
13.00		0.00	0.00	287,328.00	371,689.41	63,072.00	81,590.36	453,279.76	177,033.84
14.00		0.00	0.00	287,328.00	379,123.19	63,072.00	83,222.16	462,345.36	167,976.30
15.00		739,083.33	994,708.85	287,328.00	386,705.66	63,072.00	84,886.61	1,466,301.12	495,559.95
16.00		0.00	0.00	287,328.00	394,439.77	63,072.00	86,584.34	481,024.11	151,227.72
17.00		0.00	0.00	287,328.00	402,328.57	63,072.00	88,316.03	490,644.59	143,490.49
18.00		0.00	0.00	287,328.00	410,375.14	63,072.00	90,082.35	500,457.49	136,149.12
19.00		0.00	0.00	287,328.00	418,582.64	63,072.00	91,883.99	510,466.63	129,183.35
20.00		1478166.667	2,196,477.91	287,328.00	426,954.29	63,072.00	93,721.67	2,717,153.88	639,653.75
								LCC	**15,716,790.26**

Change in Escalation Rate – 4%

Option 1: Onshore Wind Power System									**Discount Rate**	**7.5%**
YEAR	Capital cost	Major Replacement	Escalated Major Replacement	Operation and Maintenance	Escalated Operation and Maintenance	Occupancy Costs	Escalated Occupancy Costs	Escalated Total Costs	Total Present Value	
Escal			**0.040**		**0.040**		**0.040**		**0.075**	
0.00	6,250,000.00							6,250,000.00	6,250,000.00	
1.00		0.00	0.00	161,622.00	168,086.88	35,478.00	36,897.12	204,984.00	190,682.79	
2.00		0.00	0.00	161,622.00	174,810.36	35,478.00	38,373.00	213,183.36	184,474.51	
3.00		0.00	0.00	161,622.00	181,802.77	35,478.00	39,907.92	221,710.69	178,468.37	
4.00		0.00	0.00	161,622.00	189,074.88	35,478.00	41,504.24	230,579.12	172,657.77	
5.00		0.00	0.00	161,622.00	196,637.88	35,478.00	43,164.41	239,802.29	167,036.35	
6.00		0.00	0.00	161,622.00	204,503.39	35,478.00	44,890.99	249,394.38	161,597.96	
7.00		0.00	0.00	161,622.00	212,683.53	35,478.00	46,686.63	259,370.15	156,336.63	
8.00		0.00	0.00	161,622.00	221,190.87	35,478.00	48,554.09	269,744.96	151,246.60	
9.00		0.00	0.00	161,622.00	230,038.50	35,478.00	50,496.26	280,534.76	146,322.29	
10.00		945,000.00	1,398,830.85	161,622.00	239,240.04	35,478.00	52,516.11	1,690,587.00	820,262.55	
11.00		0.00	0.00	161,622.00	248,809.64	35,478.00	54,616.75	303,426.39	136,949.44	
12.00		0.00	0.00	161,622.00	258,762.03	35,478.00	56,801.42	315,563.45	132,490.62	
13.00		0.00	0.00	161,622.00	269,112.51	35,478.00	59,073.48	328,185.99	128,176.97	
14.00		0.00	0.00	161,622.00	279,877.01	35,478.00	61,436.42	341,313.43	124,003.77	
15.00		708,750.00	1,276,418.71	161,622.00	291,072.09	35,478.00	63,893.87	1,631,384.67	551,352.58	
16.00		0.00	0.00	161,622.00	302,714.97	35,478.00	66,449.63	369,164.60	116,060.55	
17.00		0.00	0.00	161,622.00	314,823.57	35,478.00	69,107.61	383,931.19	112,281.83	
18.00		0.00	0.00	161,622.00	327,416.52	35,478.00	71,871.92	399,288.44	108,626.15	
19.00		0.00	0.00	161,622.00	340,513.18	35,478.00	74,746.80	415,259.97	105,089.48	
20.00		1,417,500.00	3,105,917.06	161,622.00	354,133.70	35,478.00	77,736.67	3,537,787.43	832,841.68	
								LCC	**10,926,958.89**	

Option 2: Offshore Wind Power System									**Discount Rate**	**7.5%**
YEAR	Capital cost	Major replacement	Escalated Major replacement costs	Operation and Maintenance	Escalated Operation and Maintenance	Occupancy Costs	Escalated Occupancy Costs	Escalated Total Costs	Present Value
Escal			**0.040**		**0.040**		**0.040**		**0.075**
0.00	10,055,555.56							10,055,555.56	10,055,555.56
1.00		0.00	0.00	287,328.00	298,821.12	63,072.00	65,594.88	364,416.00	338,991.63
2.00		0.00	0.00	287,328.00	310,773.96	63,072.00	68,218.68	378,992.64	327,954.69
3.00		0.00	0.00	287,328.00	323,204.92	63,072.00	70,947.42	394,152.35	317,277.10
4.00		0.00	0.00	287,328.00	336,133.12	63,072.00	73,785.32	409,918.44	306,947.14
5.00		0.00	0.00	287,328.00	349,578.45	63,072.00	76,736.73	426,315.18	296,953.52
6.00		0.00	0.00	287,328.00	363,561.58	63,072.00	79,806.20	443,367.78	287,285.26
7.00		0.00	0.00	287,328.00	378,104.05	63,072.00	82,998.45	461,102.50	277,931.79
8.00		0.00	0.00	287,328.00	393,228.21	63,072.00	86,318.39	479,546.60	268,882.85
9.00		0.00	0.00	287,328.00	408,957.34	63,072.00	89,771.12	498,728.46	260,128.52
10.00		985,444.44	1,458,698.50	287,328.00	425,315.63	63,072.00	93,361.97	1,977,376.10	959,410.88
11.00		0.00	0.00	287,328.00	442,328.26	63,072.00	97,096.45	539,424.70	243,465.66
12.00		0.00	0.00	287,328.00	460,021.39	63,072.00	100,980.30	561,001.69	235,538.88
13.00		0.00	0.00	287,328.00	478,422.24	63,072.00	105,019.52	583,441.76	227,870.17
14.00		0.00	0.00	287,328.00	497,559.13	63,072.00	109,220.30	606,779.43	220,451.14
15.00		739,083.33	1,331,047.32	287,328.00	517,461.50	63,072.00	113,589.11	1,962,097.93	663,122.43
16.00		0.00	0.00	287,328.00	538,159.96	63,072.00	118,132.67	656,292.63	206,329.87
17.00		0.00	0.00	287,328.00	559,686.35	63,072.00	122,857.98	682,544.33	199,612.15
18.00		0.00	0.00	287,328.00	582,073.81	63,072.00	127,772.30	709,846.11	193,113.15
19.00		0.00	0.00	287,328.00	605,356.76	63,072.00	132,883.19	738,239.95	186,825.75
20.00		1478166.667	3,238,845.19	287,328.00	629,571.03	63,072.00	138,198.52	4,006,614.74	943,209.79
								LCC	**17,016,857.91**

Change in Time Period – 30 Years

Option 1: Onshore Wind Power System									**Discount Rate**	**7.5%**
YEAR	Capital cost	Major Replacement	Escalated Major Replacement	Operation and Maintenance	Escalated Operation and Maintenance	Occupancy Costs	Escalated Occupancy Costs	Escalated Total Costs	Total Present Value
Escal			**0.030**		**0.030**		**0.030**		**0.075**
0.00	6,250,000.00							6,250,000.00	6,250,000.00
1.00		0.00	0.00	161,622.00	166,470.66	35,478.00	36,542.34	203,013.00	188,849.30
2.00		0.00	0.00	161,622.00	171,464.78	35,478.00	37,638.61	209,103.39	180,943.98
3.00		0.00	0.00	161,622.00	176,608.72	35,478.00	38,767.77	215,376.49	173,369.58
4.00		0.00	0.00	161,622.00	181,906.98	35,478.00	39,930.80	221,837.79	166,112.25
5.00		0.00	0.00	161,622.00	187,364.19	35,478.00	41,128.73	228,492.92	159,158.72
6.00		0.00	0.00	161,622.00	192,985.12	35,478.00	42,362.59	235,347.71	152,496.26
7.00		0.00	0.00	161,622.00	198,774.67	35,478.00	43,633.46	242,408.14	146,112.69
8.00		0.00	0.00	161,622.00	204,737.91	35,478.00	44,942.47	249,680.38	139,996.35
9.00		0.00	0.00	161,622.00	210,880.05	35,478.00	46,290.74	257,170.79	134,136.04
10.00		945,000.00	1,270,000.98	161,622.00	217,206.45	35,478.00	47,679.47	1,534,886.90	744,717.80
11.00		0.00	0.00	161,622.00	223,722.65	35,478.00	49,109.85	272,832.50	123,141.09
12.00		0.00	0.00	161,622.00	230,434.33	35,478.00	50,583.14	281,017.47	117,986.35
13.00		0.00	0.00	161,622.00	237,347.36	35,478.00	52,100.64	289,447.99	113,047.38
14.00		0.00	0.00	161,622.00	244,467.78	35,478.00	53,663.66	298,131.43	108,315.17
15.00		708,750.00	1,104,209.41	161,622.00	251,801.81	35,478.00	55,273.57	1,411,284.78	476,966.30
16.00		0.00	0.00	161,622.00	259,355.86	35,478.00	56,931.78	316,287.64	99,436.72
17.00		0.00	0.00	161,622.00	267,136.54	35,478.00	58,639.73	325,776.27	95,274.25
18.00		0.00	0.00	161,622.00	275,150.64	35,478.00	60,398.92	335,549.56	91,286.03
19.00		0.00	0.00	161,622.00	283,405.16	35,478.00	62,210.89	345,616.04	87,464.75
20.00		1,417,500.00	2,560,162.68	161,622.00	291,907.31	35,478.00	64,077.21	2,916,147.20	686,499.39
21.00		0.00	0.00	161,622.00	300,664.53	35,478.00	65,999.53	366,664.06	80,295.39
22.00		0.00	0.00	161,622.00	309,684.47	35,478.00	67,979.52	377,663.98	76,934.18
23.00		0.00	0.00	161,622.00	318,975.00	35,478.00	70,018.90	388,993.90	73,713.68
24.00		0.00	0.00	161,622.00	328,544.25	35,478.00	72,119.47	400,663.72	70,627.99
25.00		0.00	0.00	161,622.00	338,400.58	35,478.00	74,283.05	412,683.63	67,671.47
26.00		0.00	0.00	161,622.00	348,552.59	35,478.00	76,511.54	425,064.14	64,838.71
27.00		0.00	0.00	161,622.00	359,009.17	35,478.00	78,806.89	437,816.06	62,124.54
28.00		0.00	0.00	161,622.00	369,779.45	35,478.00	81,171.10	450,950.54	59,523.97
29.00		0.00	0.00	161,622.00	380,872.83	35,478.00	83,606.23	464,479.06	57,032.27
30.00		0.00	0.00	161,622.00	392,299.02	35,478.00	86,114.42	478,413.43	54,644.88
								LCC	**11,102,717.50**

Option 2: Offshore Wind Power System **Discount Rate 7.5%**

YEAR	Capital cost	Major replacement	Escalated Major replacement costs	Operation and Maintenance	Escalated Operation and Maintenance	Occupancy Costs	Escalated Occupancy Costs	Escalated Total Costs	Present Value
Escal			**0.030**		**0.030**		**0.030**		**0.075**
0.00	10,055,555.56							10,055,555.56	10,055,555.56
1.00		0.00	0.00	287,328.00	295,947.84	63,072.00	64,964.16	360,912.00	335,732.09
2.00		0.00	0.00	287,328.00	304,826.28	63,072.00	66,913.08	371,739.36	321,678.19
3.00		0.00	0.00	287,328.00	313,971.06	63,072.00	68,920.48	382,891.54	308,212.59
4.00		0.00	0.00	287,328.00	323,390.20	63,072.00	70,988.09	394,378.29	295,310.67
5.00		0.00	0.00	287,328.00	333,091.90	63,072.00	73,117.73	406,209.64	282,948.83
6.00		0.00	0.00	287,328.00	343,084.66	63,072.00	75,311.27	418,395.92	271,104.46
7.00		0.00	0.00	287,328.00	353,377.20	63,072.00	77,570.60	430,947.80	259,755.90
8.00		0.00	0.00	287,328.00	363,978.51	63,072.00	79,897.72	443,876.24	248,882.40
9.00		0.00	0.00	287,328.00	374,897.87	63,072.00	82,294.65	457,192.52	238,464.06
10.00		985,444.44	1,324,354.92	287,328.00	386,144.81	63,072.00	84,763.49	1,795,263.22	871,050.82
11.00		0.00	0.00	287,328.00	397,729.15	63,072.00	87,306.40	485,035.55	218,917.49
12.00		0.00	0.00	287,328.00	409,661.02	63,072.00	89,925.59	499,586.61	209,753.50
13.00		0.00	0.00	287,328.00	421,950.85	63,072.00	92,623.36	514,574.21	200,973.12
14.00		0.00	0.00	287,328.00	434,609.38	63,072.00	95,402.06	530,011.44	192,560.30
15.00		739,083.33	1,151,467.75	287,328.00	447,647.66	63,072.00	98,264.12	1,697,379.53	573,656.60
16.00		0.00	0.00	287,328.00	461,077.09	63,072.00	101,212.04	562,289.14	176,776.39
17.00		0.00	0.00	287,328.00	474,909.40	63,072.00	104,248.41	579,157.81	169,376.45
18.00		0.00	0.00	287,328.00	489,156.69	63,072.00	107,375.86	596,532.54	162,286.27
19.00		0.00	0.00	287,328.00	503,831.39	63,072.00	110,597.13	614,428.52	155,492.89
20.00		1478166.667	2,669,733.42	287,328.00	518,946.33	63,072.00	113,915.05	3,302,594.80	777,474.24
21.00		0.00	0.00	287,328.00	534,514.72	63,073.00	117,334.36	651,849.08	142,747.76
22.00		0.00	0.00	287,328.00	550,550.16	63,074.00	120,856.31	671,406.47	136,772.66
23.00		0.00	0.00	287,328.00	567,066.67	63,075.00	124,483.97	691,550.63	131,047.67
24.00		0.00	0.00	287,328.00	584,078.67	63,076.00	128,220.52	712,299.19	125,562.31
25.00		0.00	0.00	287,328.00	601,601.02	63,077.00	132,069.23	733,670.26	120,306.56
26.00		0.00	0.00	287,328.00	619,649.06	63,078.00	136,033.46	755,682.52	115,270.80
27.00		0.00	0.00	287,328.00	638,238.53	63,079.00	140,116.69	778,355.22	110,445.83
28.00		0.00	0.00	287,328.00	657,385.68	63,080.00	144,322.48	801,708.16	105,822.81
29.00		0.00	0.00	287,328.00	677,107.25	63,081.00	148,654.51	825,761.76	101,393.31
30.00		0.00	0.00	287,328.00	697,420.47	63,082.00	153,116.57	850,537.04	97,149.22
								LCC	**17,512,481.77**

Appendix H - Breakeven Analysis

Onshore Escl Cashflow	0	1	2	3	4	5	6
Annual Expenditure	6250000	0.00	180,943.98	173,369.58	166,112.25	159,158.72	152,496.26
Cumulated Expenditure		6,250,000.00	6,430,943.98	6,604,313.57	6,770,425.82	6,929,584.53	7,082,080.79
Annual Income	0	881,401.66	844,505.78	809,154.37	775,282.79	742,829.10	711,733.92
Onshore Cumulated Income	-€6,250,000.00	-€5,368,598.34	-€4,524,092.56	-€3,714,938.19	-€2,939,655.40	-€2,196,826.30	-€1,485,092.38

7	8	9	10	11	12	13	14	15
146,112.69	139,996.35	134,136.04	744,717.80	123,141.09	117,986.35	113,047.38	108,315.17	476,966.30
7,228,193.49	7,368,189.83	7,502,325.87	8,247,043.67	8,370,184.76	8,488,171.11	8,601,218.49	8,709,533.66	9,186,499.96
681,940.41	653,394.07	626,042.69	599,836.25	574,726.83	550,668.49	527,617.25	505,530.95	484,369.19
-€803,151.97	-€149,757.90	€476,284.79	€1,076,121.04	€1,650,847.87	€2,201,516.36	€2,729,133.62	€3,234,664.57	€3,719,033.76

16	17	18	19	20
99,436.72	95,274.25	91,286.03	87,464.75	83,803.44
9,285,936.68	9,381,210.93	9,472,496.96	9,559,961.71	9,643,765.15
464,093.27	444,666.11	426,052.18	408,217.44	391,129.27
€4,183,127.03	€4,627,793.14	€5,053,845.32	€5,462,062.76	€5,853,192.02

Annual Expenditure	197,100.00
Refurbishment @ 10 Years	1,142,100.00
Refurbishment @ 17 Years	905,850.00
AEP	13140000
Wholesale Energy Price	0.070008333
Income	919,909.50

Offshore Escl Cashflow	0	1	2	3	4	5	6
Annual Expenditure	10,055,555.56	335,732.09	321678.1915	308212.5927	295310.6703	282948.8282	271104.4587
Cumulated Expenditure		10,391,287.65	10,712,965.84	11,021,178.43	11,316,489.10	11,599,437.93	11,870,542.39
Annual Income		1469002.767	1407509.628	1348590.621	1292137.99	1238048.493	1186223.207
Offshore Cumulated Income	-€10,055,555.56	-€8,586,552.79	-€7,179,043.16	-€5,830,452.54	-€4,538,314.55	-€3,300,266.06	-€2,114,042.85

7	8	9	10	11	12	13	14	15
259755.9	248882.3972	238464.0643	871050.8156	218917.4912	209753.5032	200973.124	192560.2956	573656.6024
12,130,298.29	12,379,180.69	12,617,644.75	13,488,695.57	13,707,613.06	13,917,366.56	14,118,339.69	14,310,899.98	14,884,556.58
1136567.352	1088990.114	1043404.481	999727.0843	957878.0436	917780.8231	879362.091	842551.5849	807281.9836
-€977,475.50	€111,514.62	€1,154,919.10	€2,154,646.18	€3,112,524.22	€4,030,305.05	€4,909,667.14	€5,752,218.72	€6,559,500.71

16	17	18	19	20
176776.3916	169376.4496	162286.2727	155492.8938	148983.889
15,061,332.98	15,230,709.42	15,392,995.70	15,548,488.59	15,697,472.48
773488.7843	741110.184	710086.967	680362.3963	651882.11
€7,332,989.49	€8,074,099.68	€8,784,186.64	€9,464,549.04	€10,116,431.15

Annual Expenditure	350,400.00
Refurbishment @ 10 Years	2,335,844.44
Refurbishment @ 17 Years	1,089,483.33
AEP	21900000
Wholesale Energy Price	0.070008333
Income	1533182.5