University of Strathclyde Engineering

Department of Mechanical & Aerospace Engineering

A FEASIBILITY STUDY OF OFFSHORE WIND FARMS IN THE BAHAMAS

Project Consenting Guidelines with a Technical & Financial Analysis of an offshore wind farm project

Author: Christopher Cassar - 201489119

Supervisor: Cameron Johnstone

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Signed: Christopher-John Cassar Date: 04/09/2015

Abstract

The main objective of this project is to research the viability of a prospective offshore wind farm in the Bahamas. Also its goal is to create a set of project consenting guidelines that can be used as a reference in the pre-development stage of such a project that would also give insight in to the environmental sensitivity of the islands. To achieve the previously stated objectives a combination of academic research and software simulations were carried out that would support the outcome of the project. The end result of the project proved successful as the data found led to the conclusion that an offshore wind farm of 15 turbines would be financially and technically feasible in the Bahamas. The by-product of the research was a set of project consenting guidelines that is specifically designated for the Bahamas' environment.

Acknowledgements

I would like to extend my gratitude to my supervisor Mr. Cameron Johnstone for helping me to stay concise and detailed with the objectives of my individual project. Also I would like to extend my thanks to any other staff and students of Strathclyde University that have helped me with research material needed for the completion of this thesis paper.

To all of the people I have met on this course and because of this course I would like to thank you for the experiences and laughs we shared during the year.

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These are pictures used to describe the methodology in Chapter 7

Glossary

- Inflation Rate – The general level of prices rise over an annual period.
- Wind Shear Exponent – The value represents the wind moving across the earth's surface being slowed by obstructions.
- Debt Ratio – The ratio of total debt to total assets and represents the proportion company assets that are financed by any debt.
- Debt Interest Rate – The amount of annual interest that the debt accumulates.
- Debt Term – The length of the debt's payback period
- O&M – Operation & Management
- Pre-tax IRR equity – (Internal Rate of Return) represents the true interest yield created by the offshore wind farm project equity over its lifespan before tax.
- Pre-tax IRR assets – (Internal Rate of Return) represents the true interest yield created by the offshore wind farm project assets over its lifespan before tax.
- Payback Period – Equity – Amount of time it takes for the investors to regain its initial investment from the offshore wind farm's cash flow.
- MVA – Mega Volt Ampere

1. Introduction

1.1. Aim

The aims of this project are to conclude whether or not it is possible for the Bahamas to be able to set up, operate and maintain an offshore wind farm. The resultant information will hopefully be used as the basis for further research or to give insight to political leaders and investors that are interested in the prospect of an offshore wind farm creating sustainable energy in the Bahamas.

1.2. Objectives

The objectives of this project is set as the following:

- Geological information of the Bahamas will be gathered using information from academic reports and environmental impact statements.
- Data regarding the weather, mainly wind resources, will be found using a combination of online weather software and data collected from weather reports.
- Information about the current electrical demand of the Bahamas, particularly the island of New Providence, will be found from sustainability reports and previous academic research.
- Utilizing software such as RETScreen will be used to model the electrical demand of the Bahamas and find out the compatibility of the prospective offshore wind turbines with the electrical demand of the island.
- Economic data will also be calculated of the turbines in terms of their profitability and expenses using a combination of research information and results obtained from RETScreen.

1.3. Scope of Work

This project's intention is to formally address the lack of renewable energy systems in the islands of the Bahamas. Whether it be due to lack of capital or lack of enlightenment this project will allow the reader to gain an insight into the current trends involved in the offshore wind industry, the economic position of the Bahamas in terms of its sustainability efforts, and how the use of wind energy could help not only relieve some of the country's dependency on oil but also create an industry that would create jobs for the country. The information and data that is utilized in this paper came from of a combination of previous academic research, industry sustainability reports, environmental impact assessments, and sustainability modelling results from a variety of software.

The type of turbines that are the subject of the analysis of this report are the 3MW models. Based upon on the information gathered from the turbine it is then placed in a farm scenario of 15 turbines and further analysed technically and economically. Also offshore turbine foundations are examined in this paper giving brief insight to the type of procedure that takes place in the design phase with respect to the environment. All of these decisions are based upon factors such as the environmental impact and the financial costs.

The wind resources of the Bahamas are estimated based upon data collected from annual meteorology reports. This information is from meteorological monitoring stations that have taken into account the monthly average wind data for the Bahamas. Due to the difficulty of finding information for the islands of the Bahamas any data that was found was checked against modelled data in order to increase the reliability of the information.

In order to make a full statement of the possibility of offshore wind energy in the Bahamas a sensitivity analysis was performed. This information gave insight the capital costs and the payback period of an offshore wind farm in such an environment. The environmental issues that are typical with these types of projects are also addressed; any potential impacts that could affect the marine wildlife, ornithology, and benthic fauna are listed in the project consenting aspect of this project.

This report does not address any power losses from the turbines to the grid or any wake losses that may occur from the wind farm. Although information about soil types on the sea floor was taken into account it was not explained in great detail as this was out of the scope of this project. Where available any information that was found from the literature review that was seen applicable to any section of this report that was seen lacking in this report was used in an effort for the project to achieve its aims.

1.4. Structure of Thesis

This project has 11 chapters that help to address the following sub-topics of the aims:

- Chapter 1 Introduction: Summarises the aim, objectives, and scope of work of the project. Also describes a brief history of the Bahamas.
- Chapter 2 Literature Review: Provides insight and relevance into the supporting documents of the project.
- Chapter 3 Background Information: Describes the historical presence of wind turbines and their development as sources of power.
- Chapter 4 Offshore wind turbine structure and park designs: Presents past and current examples of turbines structural and park designs.
- Chapter 5 Bahamas Electricity Demand: Analyses the country's most current electrical demand data.
- Chapter 6 Project Consenting: Looks into all of the factors that are involved with getting a project of this nature approved in the Bahamas and states basic guidelines of project procedures.
- Chapter 7 Feasibility Study: Utilizes modelling software and provided data to create comparable data that is used in the technical and economic analysis. Also examines the technical and economic information that is present for the country and makes economically conscious conclusions that would be best suited for the Bahamas in terms of utilizing an offshore wind farm project. Information from a similar environment (The Canary Islands) will be used to support the information that is found regarding the prospect of an offshore wind farm in the Bahamas in relation to an offshore wind farm project.
- Chapter 8 Conclusion & Discussion: Finalises and summarises results obtained.
- Chapter 9 Recommendations: States factors that could improve thesis.
- Chapter 10 Future Work Proposals: States areas that should be further researched.
- Chapter 11 Bibliography: Lists the references and sources used in the research process of the project.
- Chapter 12 Appendices: Lists charts and tables from the simulation process.

1.5. Brief History of the Bahamas

Prior to 1492 the Bahamas was populated mostly by a peaceful set of people called the Arawaks in contrast to their warlike neighbours the Caribs. Christopher Columbus landed in the Bahamas in 1492 where he first met the Arawaks stating "*have opened their hearts to us. We have become great friends*" (nationsonline.org, 2010). Within a span of 20 years around 40,000 Arawaks were shipped to Hispaniola where most of them perished working within the mines. British pirates then began to use used the islands as a port for their vessels during the 16th century. The first British settlers were the refugees escaping the religious persecution of Charles; they went to Cigatoo that was renamed to Eleuthera, which means freedom. The newly settled refugees then introduced the plantation economy and with it African slave labour (nationsonline.org, 2010).

During 1717 a democratic government was established but then abolished once the British crown resumed government. Due to the lack of formal possession from the colonial powers the then settlers were harassed by French, Spanish, and by pirates. The islands saw also that fortunes fluctuated during this era. The population count increased during the late 18th century when the Americans of loyalist families and their slaves arrived shortly after the American Revolution. From 1783 to 1784 the population was seen to be about 4,060 but by 1789 the population increased to over 11,000. Once the end of slavery was put into power in 1834 the islands saw a large economic change due to it being a central hub for slave trading.

The islands of the Bahamas saw a brief period of prosperity during 1861-1865 "*as a depot for ships running the blockade against the Confederate States during the American Civil War. Decline followed, however, compounded by a severe hurricane in 1866*" (nationsonline.org, 2010).

The Bahamas then saw economic prosperity during the 20th century when the islands became a port for American bootlegging trade during the prohibition. During this time the Bahamas saw other industries developed such as pineapples, sponges, supplying sisal and conch shells farming. In 1901 the sponge industry saw its peak but crashed in 1939 due to the emergence of fungal diseases (nationsonline.org, 2010). During the early 1950s the Bahamas' tourism industry began to increase and thus later the offshore financial industry saw its success soon after. The PLP saw its rise in 1953 in order to represent black interests during a time when the government system was still largely dominated by whites.

A new constitution was set up in 1964 that would reform the system of government in order to fully represent majority interests and issues. "*After the subsequent general election in 1967, the United Bahamian Party (the so-called 'Bay Street Boys') was forced into opposition for the first time in the assembly's history*" (nationsonline.org, 2010). The leader of the PLP, Lynden Pindling, then formed a government that would support the Bahamians labour party. This political success helped the PLP to win then next two general elections and Lynden Pindling then saw that The Bahamas became independent under a newly created constitution on the 10th of July 1973.

Figure 1 - Map of the Bahamas

2. Literature Review

2.1. Deep Water Offshore Wind Technologies

This thesis paper focuses on the prospective importance of offshore wind energy and in result discusses the importance of utilizing the ocean’s seabed for the foundation of an offshore wind farm.

As noted from the paper the use of onshore wind turbines for the generation of electricity has currently been an increasing trend. As discussed in the paper there is a set of drawbacks with using onshore wind turbines. The first most noticeable is that the wind potential on land is not as high as on the sea. The second argument against onshore wind turbines is that they create a visual impediment on the landscape also the noise created from the rotation of the blades can be disturbing to any local human population.

The reasons above then lead the paper to discuss the possible solutions that offshore wind turbines present. Firstly the impact they have on the local environment is minimal if the sites are chosen analytically. Humans do not inhabit the sites that are suitable for offshore wind turbines so there is no disturbance to local human daily life in terms of visual or noise impacts. Due to the lack of naturally or unnaturally created (man-made) obstacles there is also the prospect of higher electricity created from the turbines due to the undisturbed air path flow and wind velocity.

The main scope of the project was to design a 495 MW deep-water offshore wind farm that would take advantage of the wind resource located on sea conditions. The thesis paper then digressed into studies concerning the location of the wind farm, the potential wind resource of the site, and any environmental impacts that are possible from the installation of the wind farm. There is also research done on the economical components that are needed for the operation of an offshore wind farm while briefly looking into the future technologies that will be used for wind turbines. The paper then finalizes that the Aegean Sea near Greece was chosen for the proposed site of the wind park. As further research and designs were completed the paper concluded that deep-water technology is not as developed when compared with onshore wind technology. There is conclusive data presented in this thesis paper that states that the potential offshore wind resources are greater than onshore wind resources but the costs of offshore technology is far greater than onshore.

The final results found that for the proposed wind farm construction would be approximately 0.089 EURO/kWh, while for the cost for constructing the currently largest offshore wind farm (Horns Rev) was found to be 0.49 EURO/kWh. Both of these figures can be seen to have a decreasing trend due to the wind resource potential and the commercialization of the technology used.

The information of this thesis that overlaps with the direction of this project's objectives is the methodology the author used in his feasibility study. The majority of the research used in this thesis is a good starting point for the direction of research that is done for this project. The information that is covered in this thesis is broad as the author is shown to do research for general areas around the globe until he utilizes the information for the designing of a possible offshore wind farm in Greece. The most important piece of research is the RETScreen data that was found for the Aegean Sea. This information would be a highly important comparative to the information that will be found for The Bahamas' waters.

2.2. Deep Water – The next step for offshore wind energy

The European Wind Energy Association produced this report in July 2013, which proceeds to elaborate on Europe's need for sustainable energy. The target audience of this report is those in positions of political influence. The issue stated in this paper is the lack of progress in the offshore wind energy as mentioned in the report stating "*Europe's seas and oceans are rich in opportunities and sources of employment for our economy*" (EWEA, 2013). The offshore economy or the "blue economy" as stated in the report was found to have employed 58,000 people in 2012 and as it continues to grow it has the potential to decarbonise the current electricity system.

The information gathered for the report is based on the research done by the 'Deep offshore and new foundation concepts' Task Force, which is a part of the European Wind Energy Association's Offshore Wind Industry Group. Firstly, data on the current situation of the offshore wind industry is collected, and then the Task Force evaluates the information. Finally the Task Force produces the required steps that are suggested to be used for large-scale development of an offshore wind farm.

There are still some considerable challenges involved in the offshore industry. One of the major challenges stated in the report is that there isn't enough political and economic support that can allow for large scale growth, which is where offshore wind technology will be able to meet its potential.

Although there is not as much support for offshore wind energy as there should be the data presented from the report states that offshore wind is one of the faster growing sectors in the maritime industry. "*It's installed capacity was 5 GW at end 2012, and by 2020 this could be eight times higher, at 40 GW, meeting 4% of European electricity demand*" (EWEA, 2013). If the predicted progression continues at the same rate stated previously it is noted that offshore wind energy could meet approximately 14% of the EU's total electricity demand.

The report goes on to state that in order for there to be substantial growth for the offshore wind industry there has to not only be a supportive legislative framework but also the development of new offshore designs must continue. The continued push for progression in the offshore wind industry is what will allow the industry to tap into the full potential of the wind resources that are available in the Atlantic, Mediterranean and the deep North Sea waters. Current structures are limited to ocean depths of 40m-50m.

The final analysis that was completed by EWEA found the following results:

- In order to unlock the full potential of the offshore wind energy mark in the Atlantic, Mediterranean and deep North Sea Waters deep offshore designs are needed.
- The use of deep offshore design will then in turn constitute an export opportunity for a variety of countries. Once the capacity of the deep offshore industry increases, expertise, skills, and the technologies developed in Europe can then be exported to other nations across the world including the US and Japan.
- Any energy that is produced from the turbines placed in the deep waters of the North Sea can meet the EU's electricity demand four times over.
- Deep offshore designs also have a competitive levelised cost of energy (LCOE) with the turbines that have bottom fixed foundations placed in more the 50m water depths. In order for the technology to achieve commercial and large-scale success the industry must be able to overcome its political, economic, and technical challenges.
- It is possible for the first large-scale wind farms to be installed and grid connected by 2017 once the previously stated challenges are solved.

The information from this report coincides with the direction of research of this project. The data states that deep-water offshore wind farms are possible and up to 40m currently is viable. The information given does focus more on the prospective future of deep-water wind farms whereas the waters of the Bahamas are typically 15m-30m deep. But the data found by EWEA does give insight in the current trends of large-scale wind farm development and its possibilities for grid connection. It is the previously stated information that is important for the purpose of this project, which intends to focus on large-scale wind farm developments in the Bahamas.

2.3. EIA Guide to offshore wind farms

The Crown Estate created this guide in order to break down the costs and stages involved in the development of an offshore wind farm. The document takes into account the components of an offshore wind farm substation, the development process, the necessary installation efforts, and the operation factors involved in maintaining a wind farm.

The main aim of the report is to help companies and political figures gain insight into the components and processes that are involved in each of the stages of wind farm development. This information is intended to "*help them realise the opportunities that will arise from the anticipated £75 billion investment over the next decade*" (The Crown Estate, 2014).

The report indicates that there is not a standard way of building an offshore wind farm, and with that the associated challenges of scale, water depths, and distances from shore still have not been solved with an optimal solution. "*The pace of innovation in the wind industry has been rapid by any standards over the past decade (at the turn of the new millennium few saw the prospect of 5MW machines with rotor diameters over 120m)*" (The Crown Estate, 2014). Crown Estate states that there isn't any way to predict the accuracy of which technologies and processes will actually be used for each of the stages but the document will still be seen as an informative piece of information for industrial and political usage.

Each of the stages of building an offshore wind farm, as described in the report, are called 'Rounds'. The first round is the design stage, the second round is the construction stage and the third round is the operations stage. Due to the variability of round 3 there isn't a standard figure that can be used so the report states "*For the purposes of this document, we have assumed that the zones will be constructed in blocks of around 500MW at around 50 miles from shore, and we will use this to inform our judgements on the cost and processes used*" (The Crown Estate, 2014).

There is also a list of possible suppliers that can be used for each of the processes involved in a project like this but it is stated that these examples are exhaustive. The companies that were chosen were done so due to the reputation of the services and capabilities they provided. The list was mostly confined to UK companies.

For the future there will need to be a new capacity to take part in the supply chain as the offshore wind industry continues to grow. "*There is also competition for some resources from the oil and gas and infrastructure sectors which has particular impact on installation vessels and export cable supply and availability of experienced staff at many levels*" (The Crown Estate, 2014).

As shown this report gives the steps and components involved in taking on an offshore wind farm project. The information given is explained in a technical manner while giving the financial estimates of the processes involved. The information given in this report is highly important to the general background research of the feasibility study of this individual project as it then the thesis paper to undertake a technical and economical approach to what is involved in projects such as these.

2.4. National Environmental Management Action Plan for The Bahamas

This paper was written by SENES Consultants Limited for the Bahamas Environment Science and Technology (BEST) Commission for the purpose of acknowledging the variation of factors involved in the local environment and the procedures needed to continue its sustainability. Over the past few decades one of the more major issues of the global community has been the arising problem of climate change, biodiversity, desertification/land degradation and wetlands. The issues that surround the previously stated areas have been acknowledged with international conventions, which is crucial in the steps of obtaining sustainable development and the conservation of resources. It is noted that the use of such conventions allows a sense of urgency to be placed into all of the participating countries especially the smaller ones that are currently in the developing stage.

The country of The Bahamas is a small island in the developing state; that is involved with a number of international environmental conventions. The main issue that the country has found with effectively implementing the international conventions is due to its lack of capacity. One of the faults is due to the size of The Bahamas, which leads to its lack of capacity. The report then states "*this is further compounded by the vast number and* *archipelagic nature of its islands and their differing ecosystems, the scarcity of freshwater reserves, the limited options for and high cost of waste disposal and the rate and pace of economic development*"(BEST, 2005).

The government of the Bahamas has come to acknowledge the importance of increasing its capacity in order to fully implement the purposed international conventions. This acknowledgement comes through the National Capacity Needs Self-Assessment (NCSA) Project, which has been put into place in order to identify and analyse the main priorities and capacity development needs that are within the scope of the implementing the main international environmental conventions.

With the use of the NCSA project the government of the Bahamas will then be able to assess its global environment responsibilities, prioritize the most critical needs, and then determine the steps to accomplish building its capacity in order to meet the international conventions. These results will be finalized with the usage of a detailed self-assessment methodology and consultations with stakeholders and the public. "*The end result of this process will be the development of a National Environmental Management Action Plan (NEMAP) for The Bahamas that can serve as a tool for the GOB to identify gaps and deficiencies in meeting its environmental international commitments and in addressing other environmental management issues in the country*" (BEST, 2005). This will allow the country to define appropriate actions while providing a baseline standard to be used in the evaluations of the effectiveness and efficiency of each the said actions. These actions will eventually allow for the government to develop a system in which mistakes can be noticed at early stages and any deficiencies can be solved accordingly.

The significance of this report to the feasibility study is the detailed information given about the local ecosystem and current infrastructure. This information will allow for an educated analysis to be appropriately made for areas that would be considered plausible for the installation of an offshore wind farm. Naturally the Bahamas' has a marine ecosystem that is highly cherished by the country due to its large connection to the tourism industry, so any sort of construction proposals have to take into account the marine life that would be affected. The report not only gives detail coverage of the type of marine life that is present in Bahamian waters but also give account to the type of soils and foundations that are present on the sea floor. This information is important for the construction of an offshore wind turbine, as there are different criteria that have to be taken into account for each of the different types of offshore wind turbine foundations.

2.5. Promoting Sustainability in the Bahamas

A consultancy company called Fichtner in September 2010 wrote this report. The analysis was done using the electrical demand data of The Bahamas in an effort to reduce the country's dependency on oil. To derive the necessary information for the report a total number of 46 energy audits were done on local hotels, houses, and public buildings throughout the Bahamas. This information was collectively analysed and used as a benchmark for estimating the saving potential of the Bahamas. The report states that the Bahamas has the potential to save 226 million kWh of the total power demand according to the arrived information from the 2009 data. The way to save some of the electricity can be done through passive means but other methods include deriving some of the electrical demand from renewable sources.

One of the major sources of electricity usage comes from the tourism industry in the Bahamas. Due to the large hotels and the amount of water, air conditioning, and lighting that is used this is the reason for hotels accounting for 60% of the country's total power usage. The other 40% comes from domestic homes. The electricity that is used is mostly from lighting, refrigerating, and electronics. The analysis states that the local Bahamian households have a potential of saving 57% of the total electricity demand. This percentage can be increased if passive efforts are combined with renewable efforts.

The research that was done on the renewable energy potential is stated to be an estimate based off of the average climate conditions of the Bahamas. Although it being just an estimate some of the figures state that for wind and solar energy there is a combined potential of 94 TWh/a. There is also information given on the structural potential of each of the types of renewable energy. The structural potential for wind power is seen to start at 598 GWh/a in 2010 and would grow to 810 GWh/a in 2020. This information shows that that the potential for wind energy in the Bahamas is sufficient for national usage and it has enough resources to partially supply the energy demand of the Bahamas lowering its dependency on oil.

One of the major findings of the Bahamas surrounding its policies for renewable energy is that there is a lack of awareness of the potential applications of renewable energy. Also combined with the lack of knowledge and skill there then is the issue of the lack of capital needed to pay for any upfront costs. There is also the split in incentives, which then leads to the demands of Bahamas Electricity Corporation that have a form of monopoly on the power market of the Bahamas.

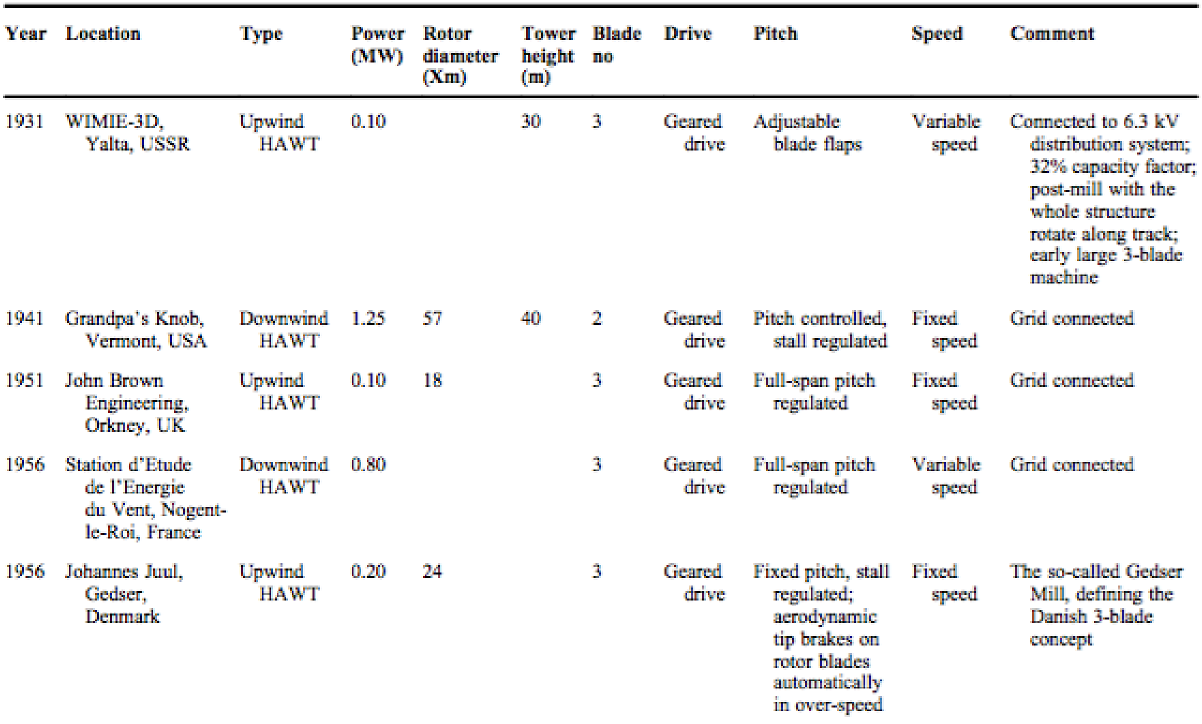
This report shows that there is statistical evidence that shows the Bahamas is capable of sustainable efforts as it does have the resources needed to generate renewable energy. This paper is important to the research of this MSc project as it complements the aims of the overall project, which is to investigate the possibility of an offshore wind farm being placed in the Bahamas. The only issues other than the financial factors are the ones dealing with local policies in the Bahamas. This technical report will prove to be a valuable source of information as the project continues to progress.

3. Background Information of Offshore Wind Farms

3.1. Development of wind power

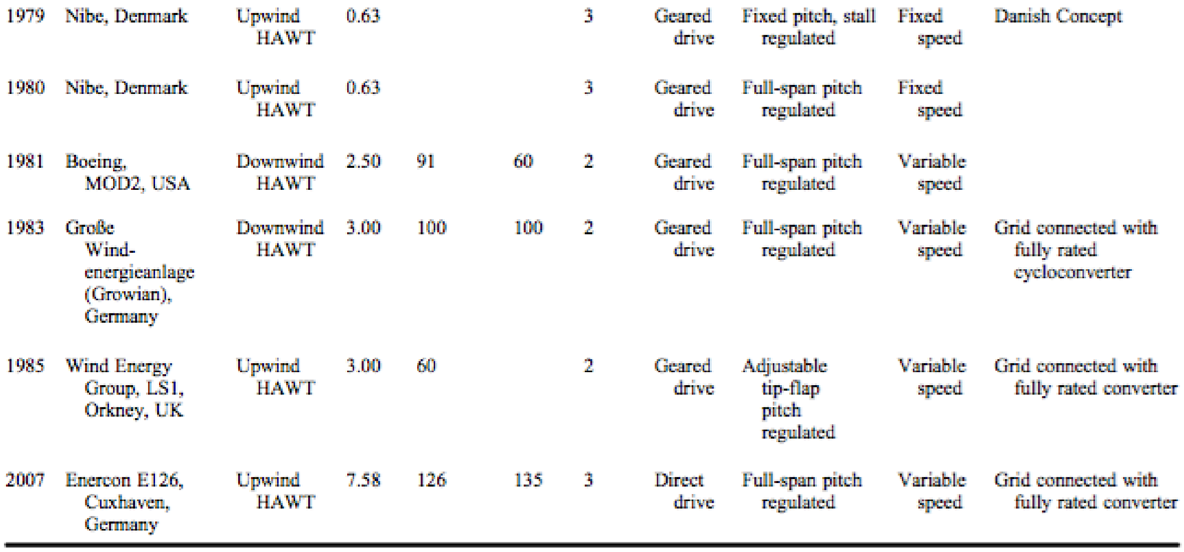
The first man-made development of rotating wind power machines started over 2000 years ago across the world but more so in Chine and Iran. These technical developments were later used as the basis for the creation of wind turbines that would be used for generating electricity, which were first seen in the late 19th century. The three most historic wind turbines were: "*a horizontal- axis wind turbine (HAWT) in the United States in 1883 (the Brush turbine), a vertical-axis wind turbine (VAWT) in Scotland in 1887 (the Blyth turbine) and an HAWT in Denmark in 1887 (the la Cour turbine)*" (Tavner, 2012).

The larger electric power wind turbines (>100kW, <1MW) were created in Germany, Russia and the United States between the 1930s and 1940s. Modern large wind turbines were developed in Europe and the United States during the 1970s and 1980s due to encouragement caused by the European Union and the US department of Energy experimental programs. The incentive behind this was due to the 1973 war between Egypt, Syria and Israel, which caused the oil prices to increase. The main wind turbine projects are given in the figures 2 and 3.



Year	Location	Type	Power (MW)	Rotor diameter (Xm)	Tower height (m)	Blade no	Drive	Pitch	Speed	Comment
1931	WIMIE-3D, Yalta, USSR	Upwind HAWT	0.10		30	3	Geared drive	Adjustable blade flaps	Variable speed	Connected to 6.3 kV distribution system; 32% capacity factor; post-mill with the whole structure rotate along track; early large 3-blade machine
1941	Grandpa's Knob, Vermont, USA	Downwind HAWT	1.25	57	40	2	Geared drive	Pitch controlled, stall regulated	Fixed speed	Grid connected
1951	John Brown Engineering, Orkney, UK	Upwind HAWT	0.10	18		3	Geared drive	Full-span pitch regulated	Fixed speed	Grid connected
1956	Station d'Etude de l'Energie du Vent, Nogent-le-Roi, France	Downwind HAWT	0.80			3	Geared drive	Full-span pitch regulated	Variable speed	Grid connected
1956	Johannes Juul, Gedser, Denmark	Upwind HAWT	0.20	24		3	Geared drive	Fixed pitch, stall regulated; aerodynamic tip brakes on rotor blades automatically in over-speed	Fixed speed	The so-called Gedser Mill, defining the Danish 3-blade concept

Figure 2 - Wind turbine Development 1931 – 1956 (Tavner, 2012)



1979	Nibe, Denmark	Upwind HAWT	0.63			3	Geared drive	Fixed pitch, stall regulated	Fixed speed	Danish Concept
1980	Nibe, Denmark	Upwind HAWT	0.63			3	Geared drive	Full-span pitch regulated	Fixed speed	
1981	Boeing, MOD2, USA	Downwind HAWT	2.50	91	60	2	Geared drive	Full-span pitch regulated	Variable speed	
1983	Große Wind-energieanlage (Growian), Germany	Downwind HAWT	3.00	100	100	2	Geared drive	Full-span pitch regulated	Variable speed	Grid connected with fully rated cycloconverter
1985	Wind Energy Group, LS1, Orkney, UK	Upwind HAWT	3.00	60		2	Geared drive	Adjustable tip-flap pitch regulated	Variable speed	Grid connected with fully rated converter
2007	Enercon E126, Cuxhaven, Germany	Upwind HAWT	7.58	126	135	3	Direct drive	Full-span pitch regulated	Variable speed	Grid connected with fully rated converter

Figure 3 - Wind Turbine Development 1979 – 2007 (Tavner, 2012)

This major development period, after competing with the vertical axis wind turbine, the horizontal axis wind turbine designs and other design configurations, affected the final design elements of the turbines. The trial and error stage was an important piece of the creation of a standard wind turbine design as many of the older designs had poor efficiency ratings.

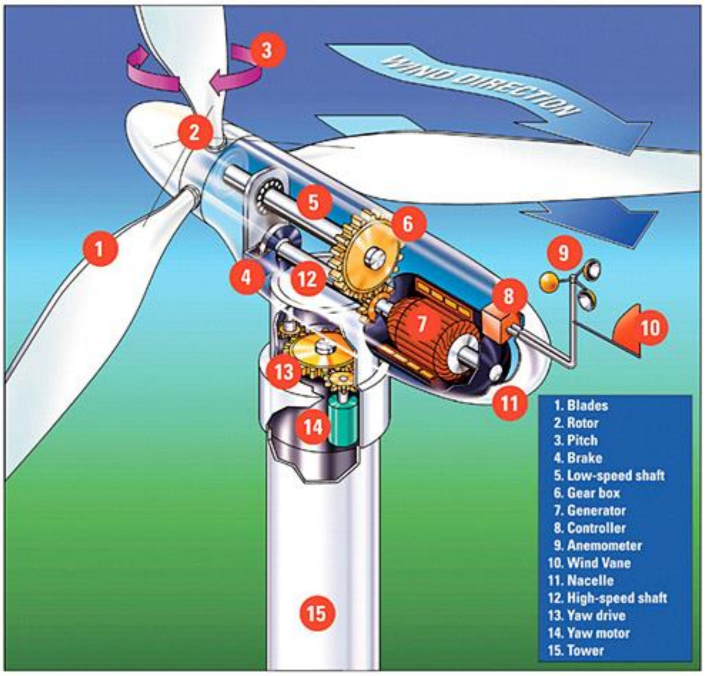


Figure 4 - Modern Wind Turbine Structure (AENews, 2015)

As wind turbine development progressed and the efficiency rating continued to increase the electricity production had also continued to increase. Figure 5 shows the gradual increase of the world's wind turbine installed capacity.

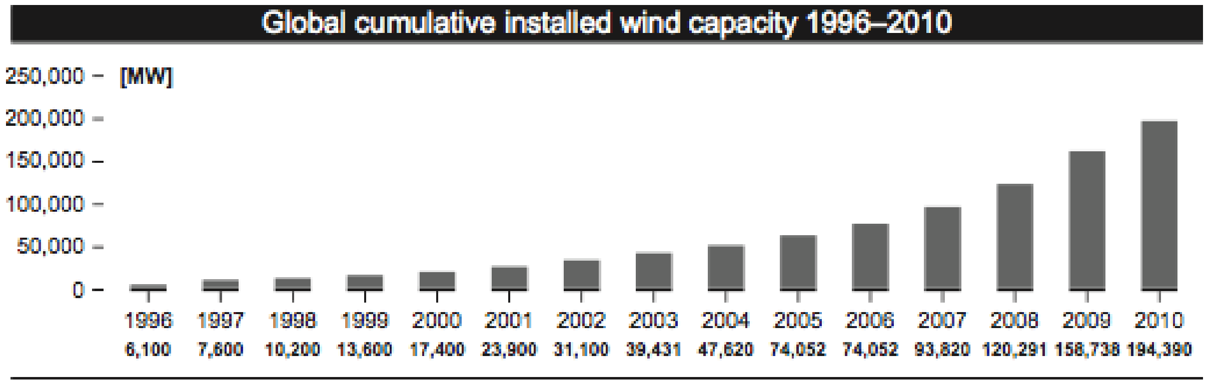


Figure 5 - World Installed Wind Capacity (Tavner, 2012)

During 1985 in Europe the reliability of wind turbines began to make an industrial mark, which was inspired by the German and Danish wind energy economy, along with the growth of wind farms in the United States in 1973. What brought concerns about the factors involved in the maintenance access of offshore wind farms was the work done in the Netherlands in the 1990s. These concerns focused on the reliability of offshore wind farms but also the amount of maintenance that would be involved in order to create high wind turbine availability. This development in the wind turbine market would be seen as a form of low cost sustainable energy that would be able to compete with fossil fuels.

The production of energy for larger onshore turbines (>1MW) based upon the performance ratings gained from the Danish Concept now has an operational availability of >98% "*and mean time between failures (MTBFs) of >7000 hours, which is a failure rate of just over 1 failure(s)/turbine/year, where a failure could be described as a stoppage with a duration of 24 hours*" (Tavner, 2012). This quote is further explained in figure 6.

The graph in figure 6 shows the improvements that took place for onshore wind turbine reliability from the late 1980s to mid-2000s. This information was collected from a variety of public domain sources and then compared with a set of grid-connected generation sources. As shown in the graph there is room for improvement in the wind turbine industry, which is being addressed as sustainability is becoming more of a global effort.

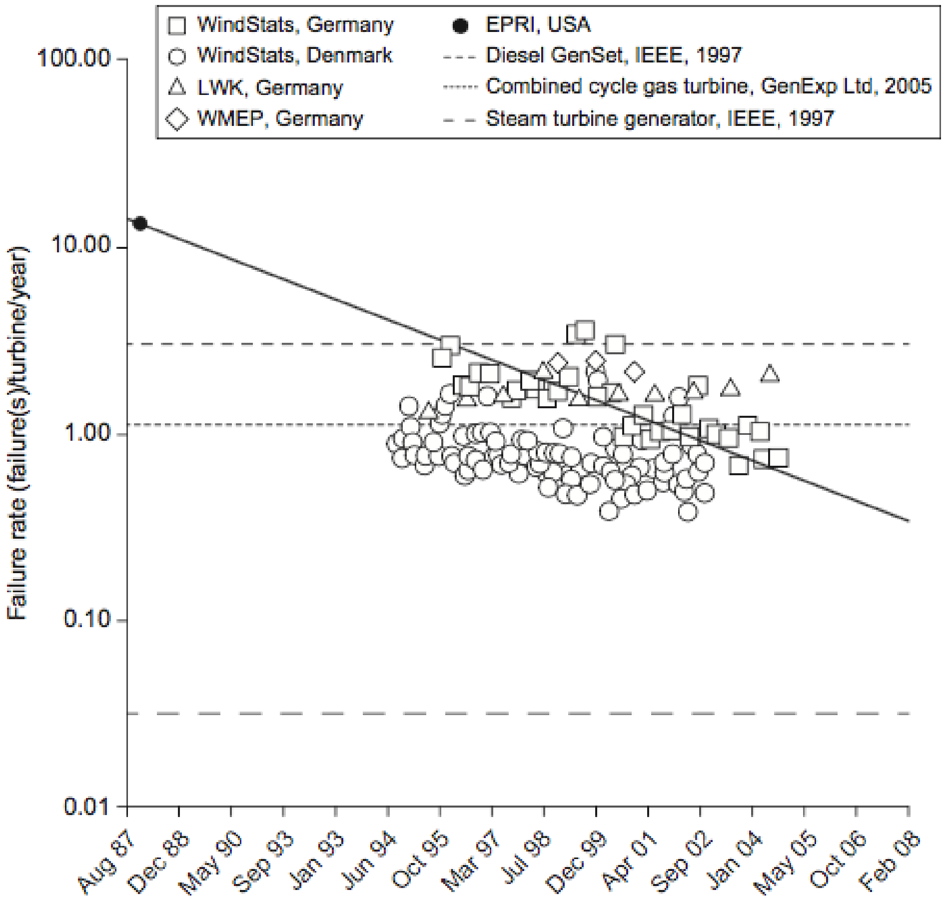


Figure 6 - Gross Failure Rates for onshore Wind Turbines from 1987-2008 (Xiang, 2006)

3.2. Large Wind Farm Development

The use of large wind farms started in the late 1970s to early 1980s, which started off as a way of gaining more power from wind resources by gathering wind turbines in a designated geographical point. One of the first large wind farms were built in the 1970s in California (see figure 7), which utilized small 100kW wind turbines arranged in an array of 100 turbines collectively.

Figure 7 - Example of a wind farm in California (Paulman, 2011/)

The main justification of utilizing wind turbines in a farm is that the combined electrical output would not only be much higher but also the long-term costs would be reduced. Any reduction in costs is due to the amount of electricity that is produced from the farm. Although there will be higher maintenance costs due to the large number of turbines this cost in the long-term is covered by the shorter payback period that is generated from the amount of electricity that is produced. Also as the technology is improved over time the overall reliability of the machines is seen to increase as shown in figure 6; the correlation between the reliability of the machines and the costs have not been technically tested but it is accurate to state that once the reliability of a device has increased to a certain standard the overall chances of the machine breaking down decreases to such an extent that there is less down time and more utilized time for the creation of electricity.

One of the major disadvantages that are the result of large onshore wind farms is the visual impact that effects local human life. This is mostly common in highly populated countries like the United Kingdom, where space, visual impact and noise amenity are usually high up on the agenda during the environmental impact process. "*In general, while large wind farms have been established in the United States, Spain and northern Germany, they are not common in the United Kingdom where the planning process has militated against the concentration process*" (Tavner, 2012). This meant initially the largest wind farms were seen to range from 5-30 wind turbines but in 2010 a wind farm in Whitelee (see Figure 8) that has 140 Siemen 2.3MW horizontal axis wind turbines was established.

Figure 8 - Whitelee Wind Farm (johnsiskandson, 2014)

The Gansu Wind Farm project is a set of large onshore wind farms that have been grouped together in the western Gansu Province in China. The project is located in the desert areas near Jiuquan (see figure 9).

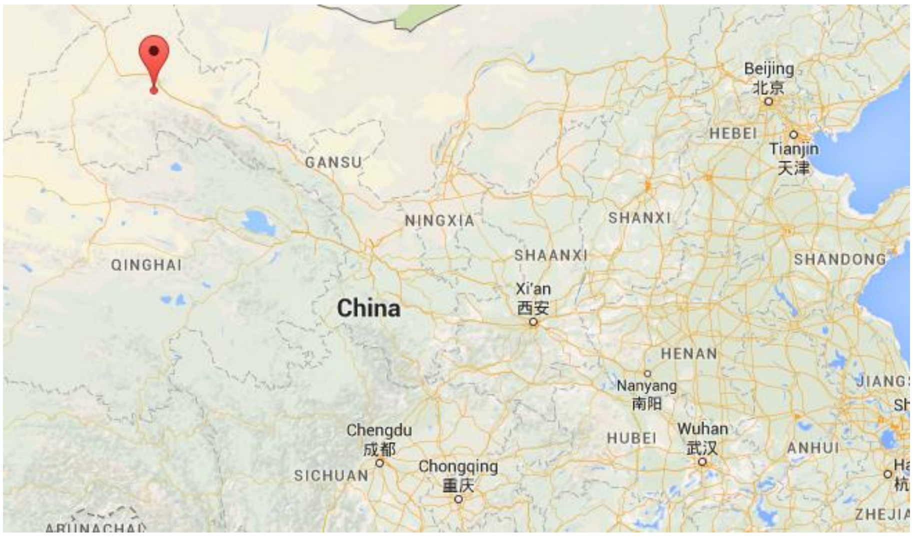


Figure 9 - Site Location of Gansu Wind Farm (www.googlemaps.com)

The project is projected to be one of the six national mega wind power projects that have been approved by the Chinese government and is expected to reach 20000 MW by 2020 (Chen, 2009). The cost for the project itself is estimated to be $17.5 billion and is being constructed by more than 20 developers in the Gauzhou and Yumen areas (Watts, 2012) (Chen, 2009).

Due to the large size of the project the construction phase was split into three sub-phases. The initial phase consists of the construction of eighteen 200 MW wind parks and two 100 MW wind parks. The second phase will consist of constructing forty 200 MW wind parks.

Figure 10 - Photograph of Gansu Wind Farm (G., 2015)

The scheduled capacity of the wind farm is 5,160 MW by 2010, 12,700 MW by 2015 and finally the proposed 20,000 MW by 2020 (Chen, 2009). The ambition of this project will most likely lead it to being the world's largest producer of wind energy once it is finished.

The construction began on the 750 kV AC power line that would be used to transport the electricity from the wind farm in 2008 (Lim, 2009). The construction of the wind turbines started in August of 2009 (Chen, 2009). The price per kWh of the power produced is rated to be .54 yuan, which is currently more expensive that the power produced from coal (Watts, 2012). Since the start of the wind farm in October 2011 around 6 billion kWh has been generated with the around 5 billion kWh being produced in 2011 alone (TMC, 2011).

In November 2010 the wind park's installed capacity was rated to be 5,160 MW which then saw a rise to just over 6,000 MW in March 2012, which was equal to the UK's entire wind power capacity in 2012; the new wind turbines are being constructed at an estimated rate of 36 per day (Watts, 2012).

It was in November 2010 that the first phase of the wind farm was officially completed, which involved the completion of 3,500 wind turbines that have an installed capacity of just over 5,100 MW. The wind farm at that time was said to be producing just over 1,100 MW of electricity (China Daily, 2010).

On the 1st of March 2012 the wind power coordination control system was installed for the wind farm in order to adjust and control the output of the 18 wind farms, which was saw a total of 10 million kW, in order to fully meet the requirements of the transmission grid, which had a limitation of 1.5 million kW. With the installation of the control system active the overall stability of the wind project increased allowing a production of 1 million kWh more a day than what was previously set (JEC, 2012). In order to gain better stability in the operations of wind turbines there is a method of reducing power output, which can sometimes lead to losing any available output once the main grid's transmission capacity has reached its limitations. The use of energy storage or local industrial usage can also be seen as a methodical way off increasing the stability or efficiency of a wind farm.

3.3. Offshore Wind Farm Development

One of the first offshore wind farm developments that was successfully deployed was in Denmark in 1991 at a place called Vindeby that had 11 wind turbines sheltered in Baltic waters near Fyn Island. In 2001 a small offshore wind farm (2 wind turbines) was installed in tidal waters inshore at Blyth (Northumberland, United Kingdom) near the North Sea (See Figure 11).

Figure 11 - Britian's First Offshore Wind Farm at Blyth (Black, 2009)

In order to fully gain the potential profit from offshore wind farms it was noted, from the large initial capital needed to install the turbines in the ocean, that it should be encouraged to focus on larger offshore wind farms if such projects are proposed. This lesson was learnt by the Danish as the "*first substantial offshore wind farm was installed at Middelgrunden near Copenhagen in Denmark in 2000, with 20 Siemens SWT1.0/54 WTs*" (Tavner, 2012).

Once these initial projects saw success the rest of Europe followed suit and the offshore wind industry started to grow at a healthy rate. The first projects helped to prove that operating a wind turbine on the coastline is not only possible but successful as well. Other offshore wind farm projects then followed suit and learnt from the first projects, acknowledging any difficulties and making the according preparations.

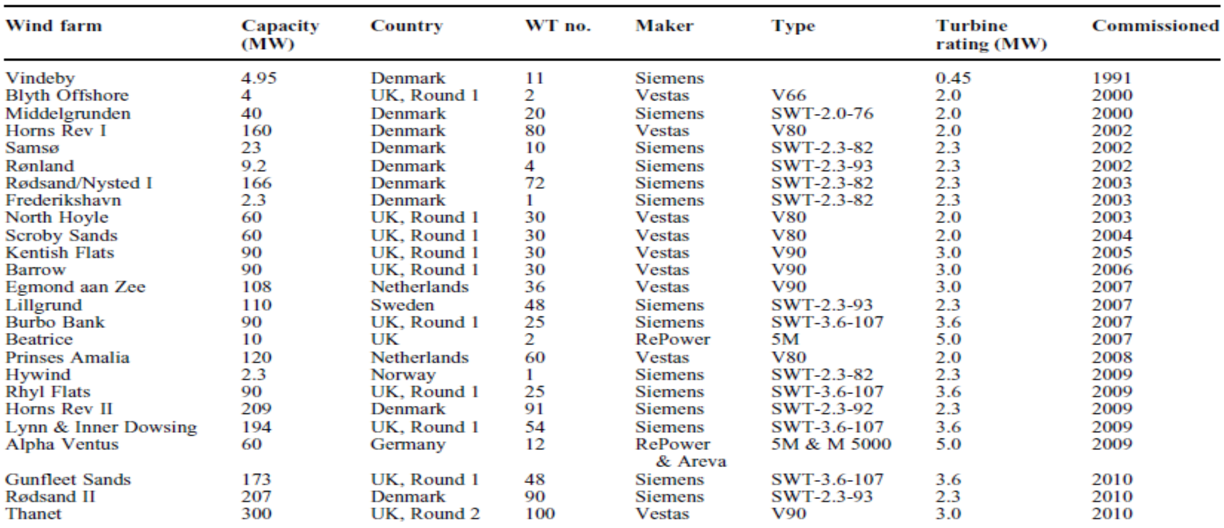
3.4. Overview of Offshore Wind Farms in Northern Europe

One of the main areas of wind farm development was seen in the Baltic Sea, which is non-tidal but has windy conditions coupled with the potential for ice and wave environments. "*The first large offshore wind farm in the Baltic Sea was installed in 2000 at Middelgrunden (20 WTs) close to Copenhagen in Denmark*" (Tavner, 2012). Once the first offshore wind farm was installed in Middelgrunden the amount of wind farm projects began to increase as was seen in Nysted, Denmark, Lillgrund, Sweden and Rodsand in Denmark.

The same ripple effect was seen in the United Kingdom (see Table 1 & 2) as depicted in the successful installation at Blyth. Afterwards the Crown Estate then initiated the licensing of UK offshore wind farm sites. The licensing process would occur in three rounds. The first round took the cautious procedure in which around 25-30 wind turbines per wind farm were allowed giving the developers, installers, and operators the experience they needed to handle the new type of machinery. This model was shown to be successful as the capacity of the offshore wind farms started to increase.

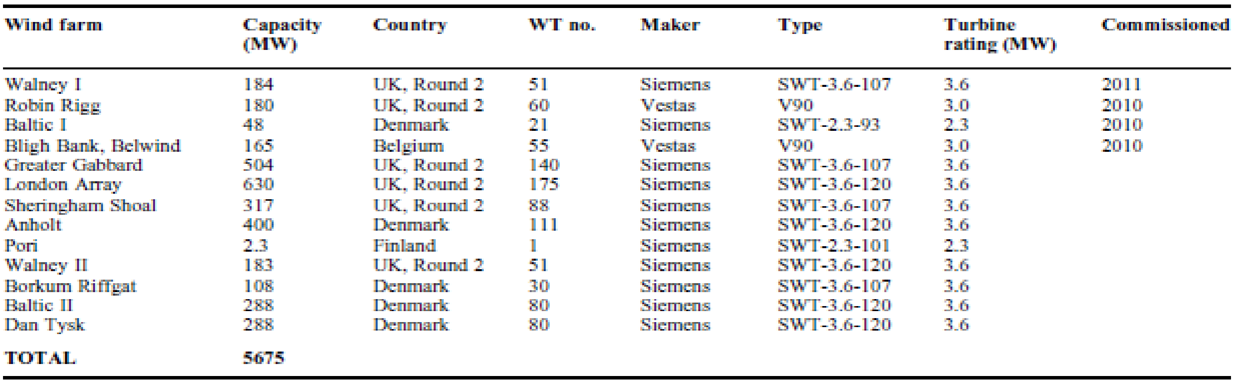
Denmark accelerated its wind farm process (see Table 1 & 2) in more calm waters, which resulted to be a success as the size of offshore wind farms largely increased in the North Sea. The type of designs used in offshore wind turbines were changed as operational issues began to arise from taking the wind turbine designs for onshore purposes and using them for offshore platforms. This made the equipment manufacturers and developers of North Sea designs re-evaluate the types of wind turbine designs that should be used, which consequently slowed down development.

Table 1 - European Offshore Wind Farm Development Up To 2010 (Tavner, 2012)



Wind farm	Capacity (MW)	Country	WT no.	Maker	Type	Turbine rating (MW)	Commissioned
Vindeby	4.95	Denmark	11	Siemens		0.45	1991
Blyth Offshore	4	UK, Round 1	2	Vestas	V66	2.0	2000
Middelgrunden	40	Denmark	20	Siemens	SWT-2.0-76	2.0	2000
Horns Rev I	160	Denmark	80	Vestas	V80	2.0	2002
Samsø	23	Denmark	10	Siemens	SWT-2.3-82	2.3	2002
Rønland	9.2	Denmark	4	Siemens	SWT-2.3-93	2.3	2002
Rødsand/Nysted I	166	Denmark	72	Siemens	SWT-2.3-82	2.3	2003
Frederikshavn	2.3	Denmark	1	Siemens	SWT-2.3-82	2.3	2003
North Hoyle	60	UK, Round 1	30	Vestas	V80	2.0	2003
Scroby Sands	60	UK, Round 1	30	Vestas	V80	2.0	2004
Kentish Flats	90	UK, Round 1	30	Vestas	V90	3.0	2005
Barrow	90	UK, Round 1	30	Vestas	V90	3.0	2006
Egmond aan Zee	108	Netherlands	36	Vestas	V90	3.0	2007
Lillgrund	110	Sweden	48	Siemens	SWT-2.3-93	2.3	2007
Burbo Bank	90	UK, Round 1	25	Siemens	SWT-3.6-107	3.6	2007
Beatrice	10	UK	2	RePower	5M	5.0	2007
Prinses Amalia	120	Netherlands	60	Vestas	V80	2.0	2008
Hywind	2.3	Norway	1	Siemens	SWT-2.3-82	2.3	2009
Rhyl Flats	90	UK, Round 1	25	Siemens	SWT-3.6-107	3.6	2009
Horns Rev II	209	Denmark	91	Siemens	SWT-2.3-92	2.3	2009
Lynn & Inner Dowsing	194	UK, Round 1	54	Siemens	SWT-3.6-107	3.6	2009
Alpha Ventus	60	Germany	12	RePower & Areva	5M & M 5000	5.0	2009
Gunfleet Sands	173	UK, Round 1	48	Siemens	SWT-3.6-107	3.6	2010
Rødsand II	207	Denmark	90	Siemens	SWT-2.3-93	2.3	2010
Thanet	300	UK, Round 2	100	Vestas	V90	3.0	2010

Table 2 - European Offshore Wind Farm Development from 2010 - 2011 (Tavner, 2012)



Wind farm	Capacity (MW)	Country	WT no.	Maker	Type	Turbine rating (MW)	Commissioned
Walney I	184	UK, Round 2	51	Siemens	SWT-3.6-107	3.6	2011
Robin Rigg	180	UK, Round 2	60	Vestas	V90	3.0	2010
Baltic I	48	Denmark	21	Siemens	SWT-2.3-93	2.3	2010
Bligh Bank, Belwind	165	Belgium	55	Vestas	V90	3.0	2010
Greater Gabbard	504	UK, Round 2	140	Siemens	SWT-3.6-107	3.6	
London Array	630	UK, Round 2	175	Siemens	SWT-3.6-120	3.6	
Sheringham Shoal	317	UK, Round 2	88	Siemens	SWT-3.6-107	3.6	
Anholt	400	Denmark	111	Siemens	SWT-3.6-120	3.6	
Pori	2.3	Finland	1	Siemens	SWT-2.3-101	2.3	
Walney II	183	UK, Round 2	51	Siemens	SWT-3.6-120	3.6	
Borkum Riffgat	108	Denmark	30	Siemens	SWT-3.6-107	3.6	
Baltic II	288	Denmark	80	Siemens	SWT-3.6-120	3.6	
Dan Tysk	288	Denmark	80	Siemens	SWT-3.6-120	3.6	
TOTAL	**5675**						

As shown in Table 1 the UK Round 1 wind farms started to increase to just over 50 wind turbines but the development speed started to slow down. "*However, early operational success with the smaller UK Round 1 sites, where the severe problems at Horns Rev were largely avoided, even though some sites used the same WTs*" (Tavner, 2012). The use of previous information led to the acceleration of installing of Round 2 wind farms allowing for the sites to achieve 100 wind turbines as seen in Thanet (see Table 1). The Belgian, Danish and Dutch developers learnt from the past trends occurring in the industry and applied them to their newer wind farm developments, which then led to an increase in installation speed.

Consequently the round 3 wind farm sites are to hold a much larger capacity of wind turbines ranging from 300-600 for the United Kingdom. There has been an estimation by the UK Offshore Energy Strategic Environmental Assessment in January 2009 that there around 33 GW of possible offshore wind energy around the UK's surrounding waters. This is what led to the creation of the Round 3 offshore wind energy programme that will eventually help the United Kingdom to meet its 2020 energy demand. As quoted from The Crown Estate the main goal of the programme is to:

- "*Support growth of the UK's offshore renewables industry*"
- "*Contribute to energy security objectives*"
- "*Generate revenue for the benefit of the nation.*"

The environmental analysis revealed that there are 9 sites (see figure 13) in the United Kingdom that will deliver the capacity needed to categorise it as a Round 3 site. After the final analysis report was published a few renewable energy developers started to exclusively bid for the rights to develop in the defined zones. The development partners to be involved in the projects were announced of which eight of these projects are currently under development.

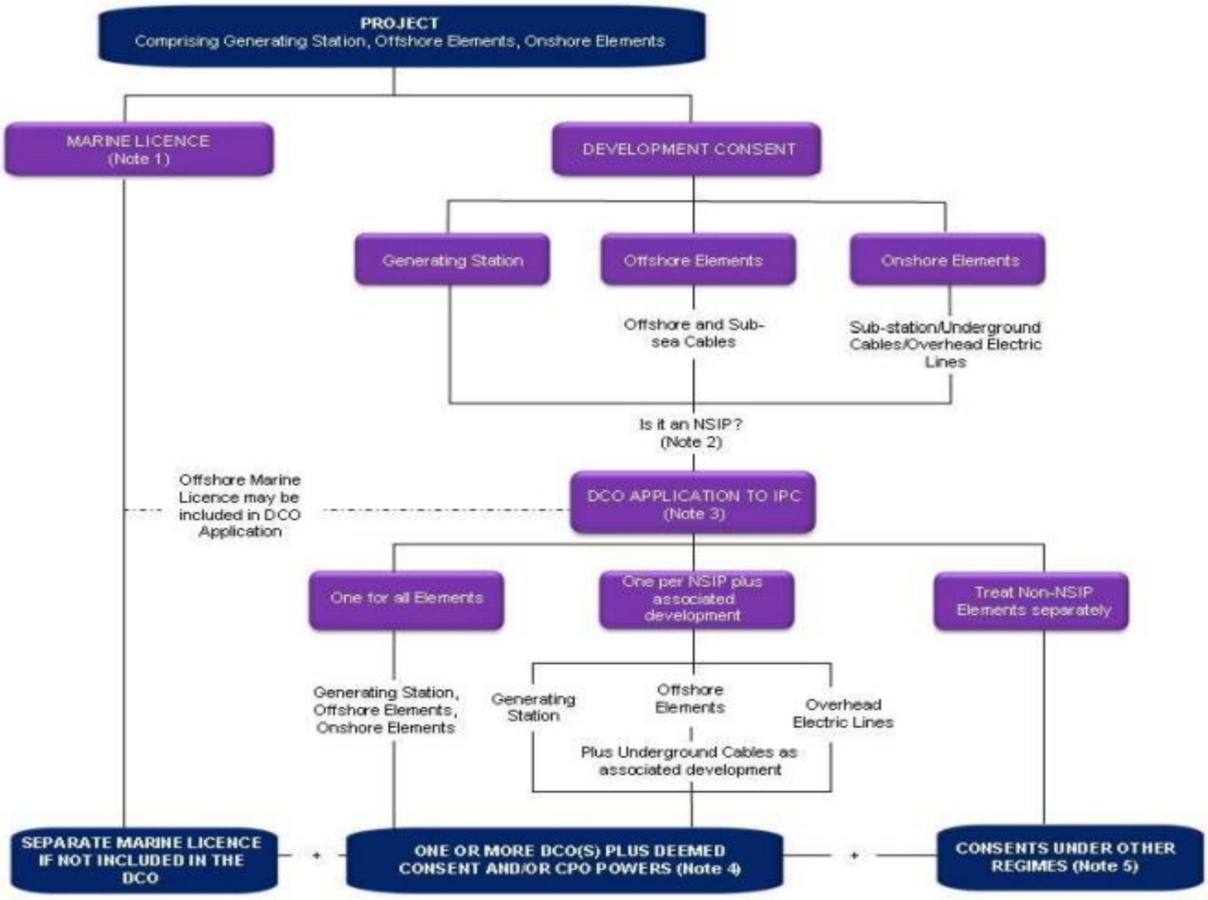


Figure 12 - Project Consenting Flow Chart for England/Wales (The Crown Estate, 2010)

The companies involved in the development of the wind farm projects are currently taking on environmental and engineering studies, while liaising with the investors. All of these precautions are being done so when the project is presented the Crown Estate can approve it. An example of the steps of this type of project consenting can be seen in Figure 12. Once the project is consented by the Crown Estate it will then need to "*obtain the necessary statutory consents before progressing with construction*" (The Crown Estate, 2010).

One of the first Round 3 wind farm projects were sent to the Planning Inspectorate and Marine Scotland for consenting in 2012. Once approved the construction process will start sometime in the middle of this decade.

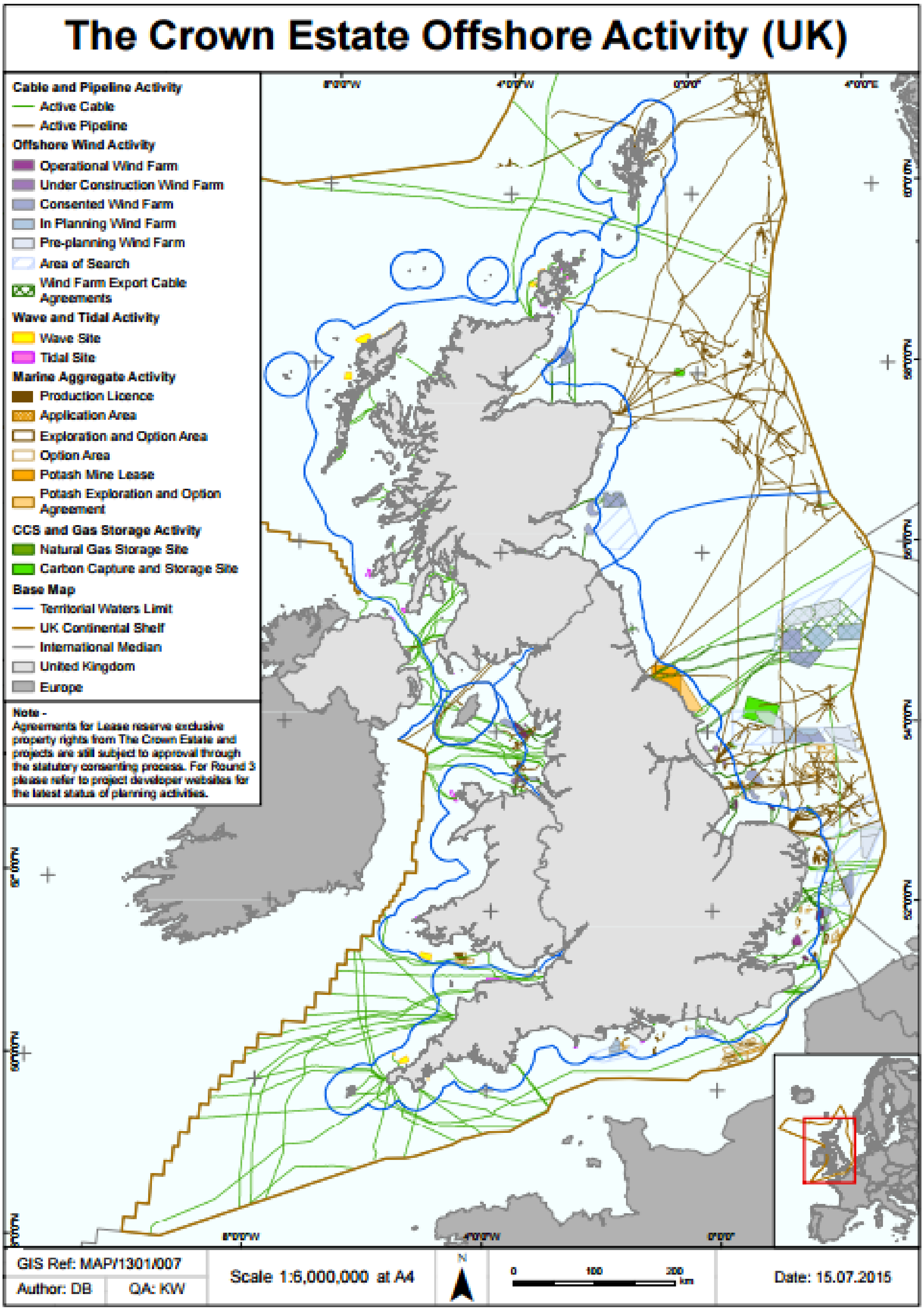


Figure 13 - Offshore Activity in the UK (The Crown Estate, 2015)

3.5. Overview of Offshore Wind Farms in Major Continents

Although currently there are no online offshore wind farms in the United Stated the development of a five wind turbine park located near Block Island, Rhode Island in the Atlantic Ocean has started (Cardwell, 2015). The project is being developed by a renewable company named Deepwater Wind, which also has plans to construct 150 6MW wind turbines by the fourth quarter of 2016 (Alstom, 2015).

The Block Island Wind farm will be placed 2.5 miles southeast of Block Island. The farm is planned to have an output of 125,000 MW hours annually. The power will be transferred from the turbines to the electric grid via a 34km submarine power cable that will be placed under the ocean floor. The size of the turbines will be 180 meters higher and have the ability to withstand up to 129 mph (Deepwater wind, 2015). Wind farms will allow New Shoreham to reduce its usage of diesel generators and eventually be replaced by the power from the park. The project is a part of a larger project that will be a 100 turbine project that will be able to produce 1.3 TWh of electricity annually, which will be about 15% of all the electricity used in the United States. In 2009, Deepwater Wind has been issued the permits to begin the pilot projects and also the National Grid came to an agreement to sell power from wind power generated to the mainland (Deepwater Wind, 2015).

The construction of the streel work needed for the wind farm near Block Island began in late 2014 and will primarily focus on the turbines' foundations, which will be a pile-anchored type foundation. Movement of the foundations from Louisiana to the site took place in 2015. The turbines are going to be delivered later in 2015 by a French company named Alstom Group and are expected to be erected in the designated place by 2016 (Kuffner, 2015).

In 2011 the company Fisherman's Energy gave an application to the Board of Public for the Offshore Wind Economic Development Act in the United States for a proposal project that will involve building 6 wind turbines off the coast of Atlantic City (Fisherman's Energy, 2011). The small wind farm was stated to be online by the third quarter of 2011 but due to certain delays the project was delayed until the end of 2012.

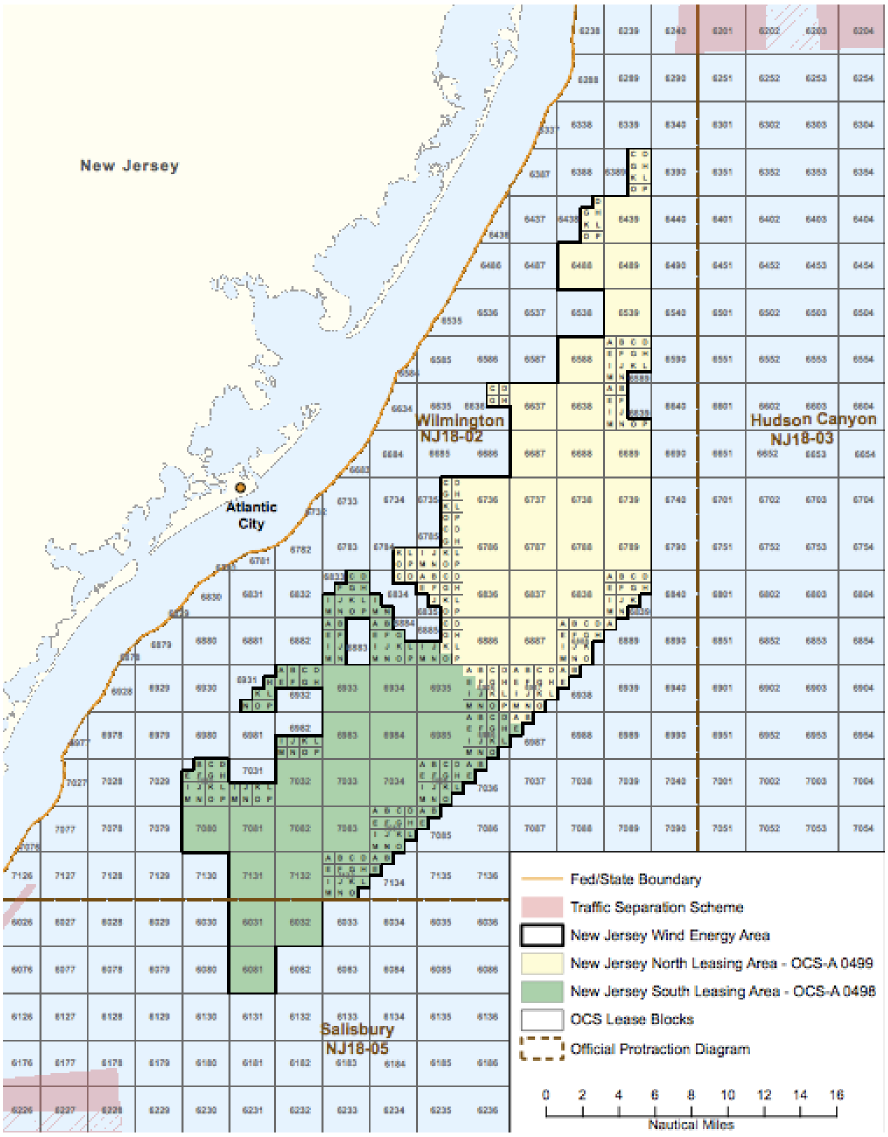


Figure 14 - Federal Map of Leasing Areas near Atlantic City (BOEM, 2015)

The federal Department of Energy awarded the company involved in the project a grant of $47 million stating that the project is something positive for the citizens of Atlantic City. After a few amendments to the original development plans the final designs have been finalised; the proposal projects will use a twisted jack type of offshore platform foundation (see figure 15), which is cheaper to construct. The ground breaking for the onshore section of the project has started in 2014.

Figure 15 - Example of Twisted Jack Foundation (Bacque, 2013)

3.6. Economics & Terminology of Offshore Wind Farms

This section will briefly explain the terminology and economics of the offshore wind farm industry. The definition that is set by the International Electro-technical Commission [standard IEC 61400-Pt 26] states that a wind turbine generating system is "*converting wind energy into electrical energy and/or providing reactive compensation*" (Raben, 2010). According to the UK DTI (Department of Trade and Industry) and BERR (Department for Business Enterprise and Regulatory Reform) the two availability definitions that have been taken by the industry are the following:

- Technical Availability – is the amount of time that one wind turbine or wind farm is able to produce electricity in the form of a percentage.
- Commercial Availability – is stated to be "*the focus of commercial contracts between wind farm owners and WT OEMs* [Wind Turbine Original Equipment Manufacturer] *to assess the operational performance of a wind farm project*" (Tavner, 2012).

The technical availability of a wind turbine will always be at a lower rate compared to the commercial availability due to the fact that there are more acknowledgements of downtime for the technical availability (Tavner, 2012)(Raben, 2010). This leads to one of main issues for offshore wind, which is that availability, '*A*', is stated to be affected by wind speed and time, *'A (u, t)', 'u'* (Faulstich, 2011).

With respect to the terms related to reliability the following expressions will be stated in order to further explain the terminology that will be used:

1. $\text{Mean time to failure} = \text{MTTF}$
2. $\text{Mean time to repair} = \text{MTTR}$
3. $\text{Logistic Delay Time} = \text{LDT}$
4. $\text{Downtime} = \text{MTTR} + \text{LDT}$
5. $\text{Mean Time Between Failure} = \text{MTBF} \approx \text{MTTF}$
6. $\text{MTBF} \approx \text{MTTF} + \text{MTTR} = \frac{1}{\lambda} + \frac{1}{\mu}$
7. $\text{MTBF} = \text{MTTF} + \text{MTTR} + \text{LDT}$
8. $\text{Failure Rate} = \lambda = \frac{1}{\text{MTBF}}$
9. $\text{Repair Rate} = \mu = \frac{1}{\text{MTTR}}$
10. $\text{Commercial Availability} = \text{A} = \frac{\text{MTBF}-\text{MTTR}}{\text{MTBF}} = 1 - \frac{\lambda}{\mu}$
11. $\text{Technical Availability} = \text{A} = \frac{\text{MTTF}}{\text{MTBF}} < 1 - \frac{\lambda}{\mu}$

All of these terms are expressed with respect to the variable time. In point number 14 the energy expression is calculated with respect to energy production, which will be useful to operating engineers.

Two of the more commonly used terms that describe the productivity of a wind turbine are the capacity factor and the specific energy yield. "*Capacity factor, C, is defined as the percentage of the actual annual energy production E (MWh) over the rated annual energy production, AEP, from a WT or wind farm of rated power output P*" (Tavner, 2012).

12. $C = AEP \times \frac{100}{P \times 8760}\%$

The specific energy yield is denoted by 'S' (MWh/m^2/yr), and is defined as the annual energy production (AEP) of a wind turbine that is normalised to its swept rotor area, which is denoted by, 'A' (m^2):

13. $S = \frac{AEP}{A}$

For the rated power, ‘P’, the ratio, ‘R_S’, of the swept rotor area, ‘A’, is noted to be a fixed value for each wind turbine type:

14. $R_S = \frac{P}{A} = \frac{S}{C \times 8760}$

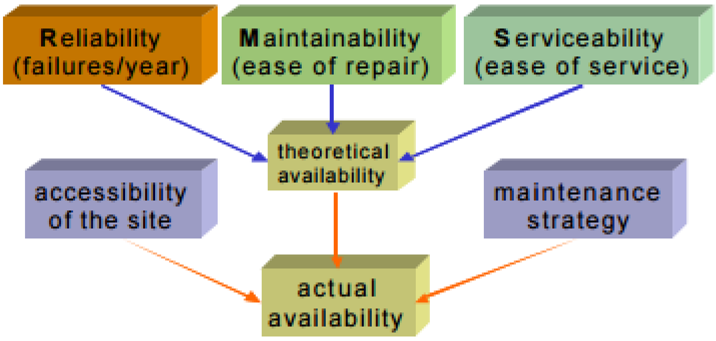


Figure 16 - Availability as a function of site accessibility, machine properties, and maintenance strategies (Bussel, 2001)

In order to check the specific energy yield for a type of wind turbine the use of the following formula is common:

15. $S = R_S \times C \times 8760$

In conclusion the operational performance of a wind turbine/farm can then be calculated in the form of a percentage over the predicted/achieved specific energy yield, ‘S’, or capacity factor, ‘C’.

The costs involved in offshore wind power are relative to the type of wind turbines that are used in the offshore park. Following recent designs and offshore wind farms of the past the majority of successful wind parks use large wind turbines that have an estimated cost of $1.8 million /MW (BERR & UK DTI, 2007 & 2009). In most cases the wind turbines used in offshore wind farms are large; the size of the turbine’s hub for a 3.5 MW machine is usually placed 90 meters about the surface of the ocean. The diameter of the rotor in these types of structures is usually 100 meters. In the current stage of offshore wind turbine designs most are constructed in water depths of 5-20 meters and the weight of these structures is around 400 tonnes. This compared to oil and gas structures is relatively small when taking into account size, wind, and wave overturning forces. Around 35% of the capital costs of offshore wind turbines is due to the foundation design and construction. Taking this information into account the capital cost of a wind turbine will increase depending on the depth of the purposed surrounding waters, relatively deep waters (30 meters +) will only be viable with more stable foundations, which usually means more material in order to contribute to the factors involved with foundation stability.

The foundation for an offshore wind turbine can be mass-produced, which in turn will save costs on the designing phase, as each wind turbine does not need to have a unique foundation made for it. This is different for the oil and gas industry as each offshore platform has to be uniquely designed for specific environment that it is in. So it can be concluded that offshore wind farm turbine foundations will experience a price drop as the farm expands.

A common way of evaluating the economic performance of a wind farm is to calculate the Cost of energy or 'CoE'. A set of formula was adapted from a report by the European Organisation of Economic Co-operation and Development (OECD) that shows how to calculate the 'CoE' and other formula. They will be shown and explained accordingly for the sake of investors who might use it in their preliminary research:

16. $CoE = \frac{(ICC+FCR\ O\&M)}{AEP}$

Where 'ICC' is the initial capital cost, 'FCR' is the annual fixed charged rate (%), 'AEP' is the annual energy production (MWh) and the 'O&M' is the annual operations and maintenance cost.

The annual fixed charged rate percentage is a function of the discount rate, 'r', and it is simplified as the following:

17. $FCR = \frac{r}{1-(1+r)^n}$

Where 'r' is not equal to 0. In order to accurately find the discount rate, 'r', the sum of the inflation and real interest rates must be calculated. The discount rate will equal the interest rate if inflation is ignored. In scenarios that involve 'r=0' the "*FCR will be ICC divided by the economic lifetime of the wind farm in years, currently estimated at n = 20 years*" (Tavner, 2012). An example of the 'CoE' calculated can be seen in figure 18 that was calculated in a paper for The Institution of Engineering and Technology by Peter Tavner.

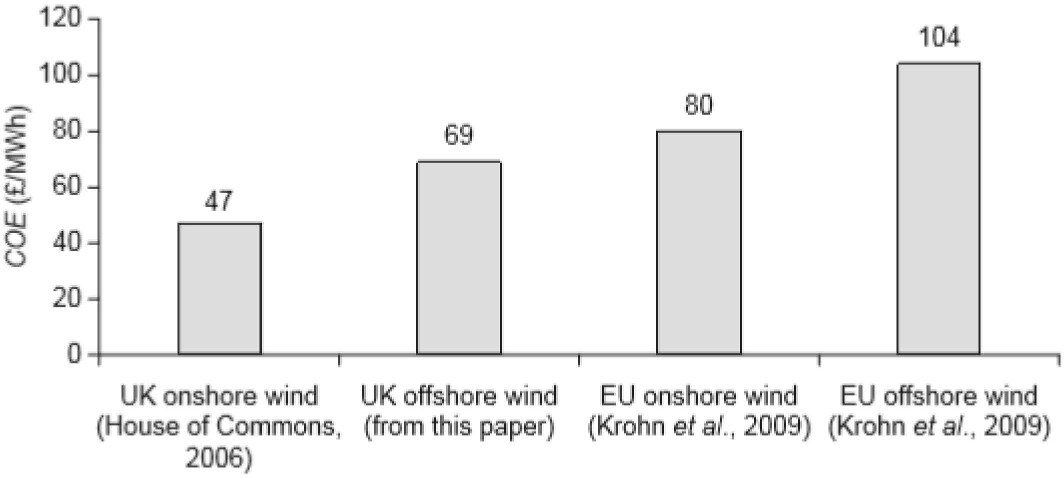


Figure 17 - CoE comparing offshore wind in UK and EU (Tavner, 2012)

As shown in Figure 18 the cost of energy is more expensive initially for offshore wind but as experience in the industry broadens the price is expected to drop significantly. The wind resource potential for the offshore wind industry is higher than the onshore industry but due to current technical restraints of current technology the prices are higher than onshore.

In order to accurately estimate the cost of the energy from an offshore wind park the site has to be taken into account; this variability, also depending on the conditions of the surrounding ocean, can make offshore wind energy more expensive than onshore wind energy.

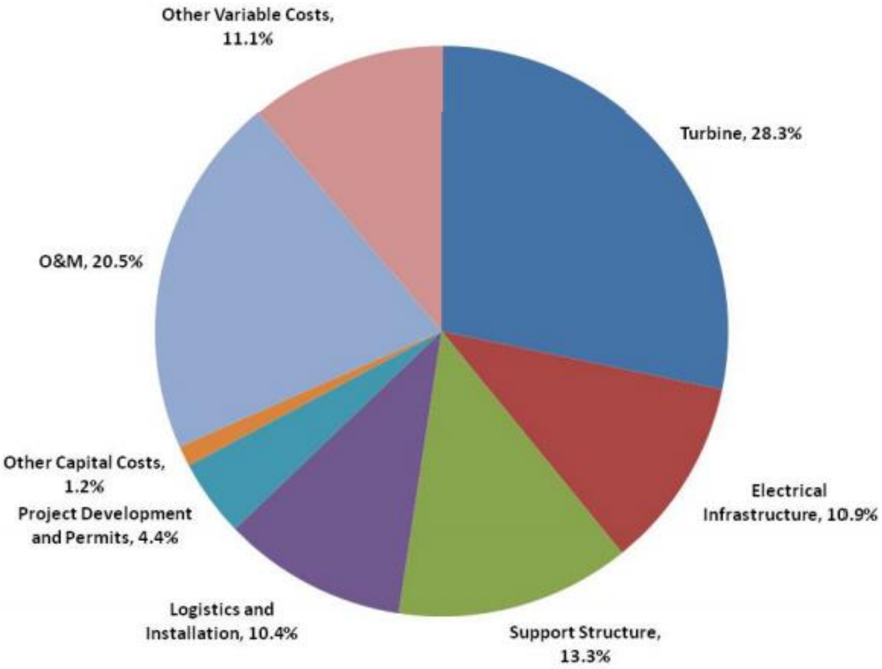


Figure 18 - Typical Offshore Wind Farm Lifecycle Costs (Meadows, 2011)

As offshore wind turbine designs start to fully become optimised for the offshore environment the price of an offshore wind farm's energy output will decrease. One of the major costs for the typical lifecycle of an offshore wind farm is the operation and management costs, which are shown in figure 18. Operation and management for an offshore wind farm is more expensive than onshore wind farms due to its greater complexity. During the lifecycle of an offshore wind farm the operation and management costs can sometimes make up to 20% of the entire project's lifecycle costs, which if compared to onshore wind farms the costs can make up to 12% of the entire lifecycle's costs (Tavner, 2012). The factors included in the offshore wind farms operational and management costs can include commissioning operations, accessibility management for routine maintenance, and servicing. When it is winter the entire farm can become inaccessible due to harsher ocean conditions, greater wind speeds, and visibility issues. Even during weather that is favourable the costs that make up the regular operation of the wind farm can be seen to be more expensive than onshore wind farms; this can be due to the reasons such as the distance of the site from onshore; the size of the farm; site accessibility; the reliability of the wind turbines; and the strategies involved in the maintenance of the turbines. The type of equipment that will be used will also play a part in the expense of an offshore farm; this can include the type of lifting equipment used to deal with any assemblies that are needed, which if it is not already on site it can increase expenses due to the increased downtime.

Figure 19 - Example of Offshore Wind Turbines in poor visibility (Forewind, 2015)

Therefore it is essential to note that it is important that information from the sources such as the Supervisory Control Data Acquisition and Condition Monitoring Systems should be attached to each of the wind turbines allowing failure prediction in each of the sections of the turbines. Due to the varying condition of the ocean it is recommended that in order to maintain production efficiency visual inspections and remote monitoring should become a routine part of an offshore wind farm operations and management strategy as this will allow to for the highest amount of turbine availability possible and increased capacity factor levels for the park.

As shown in equation 16 the ‘CoE’ is an important factor when investigating the profitability of an offshore wind farm. In order to find out relationship between reliability, maintenance, and costs the formulae can be expressed as a function of ‘λ’ and ‘μ’:

$$18.\ CoE = \frac{ICC \times FCR + O\&M\left(\lambda,\left(\frac{1}{\mu}\right)\right)}{AEP\left(A\left(\frac{1}{\lambda,\mu}\right)\right)}$$

Equation 18 shows that reductions in failure rate, ‘λ’, can improve the reliability MTBF, ‘1/λ’, and also the availability, ‘A’, which can reduce the operation and maintenance costs. A reduction in turbine downtime, ‘MTTR’, will also improve the maintainability, ‘μ’ and also the availability, ‘A’, which would lower the operation and maintenance costs. In conclusion the cost of energy will see a decrease as the failure rate and maintainability improves (Tavner, 2012).

Figure 20 - Example of Offshore Wind Turbine Maintenance (DNV, 2014)

3.7. Roles Involved in Offshore Wind Farms

3.7.1. Stakeholders

There are a variety of individual and group roles that are needed in order to have a functional wind farm. The types of individuals that are involved in an operational offshore wind farm can include stakeholders who are the initial investors that not only start the project but also usually are the ones that set in place the objectives of the company responsible for the wind farm. These objectives are the ones that give the wind farm the guidelines to deliver reliable electricity at competitive prices that will in return provide a reasonable return for the stakeholders.

3.7.2. Regulators

For wind farms in the United Kingdom there is usually an individual or a set of individuals called regulators. These regulators are responsible for setting the market landscape for the offshore wind farm. In the UK the development of the role called Offshore Transmission Operators are responsible for making sure that the offshore wind farm project is connected to the onshore transmission grid through safe and secure means.

3.7.3. Investors of the Wind Farm Project

For offshore wind farm projects the usual types of investors are from banks, landowners, and energy companies. In the United Kingdom the Crown Estate has licensed certain offshore areas that are suitable for wind farm development (Tavner, 2012). One of the main issues for investors is the availability, stability, and the reliability that wind energy can produce because it is through the avail of these aspects that they can receive their return on the investment. Because renewable energy is not as commercially explored as oil & gas the technical difficulties often have to be thoroughly explained so that there can be a defined area in which their investment can be placed.

3.7.4. Certifiers & Insurers

The certifiers are responsible for making sure that the offshore wind turbine designs and the needed offshore structures are up to a certain professional standard. The project insurers are there to make sure the necessary steps are taken in order to insure the wind farm project especially if it is to be a large project. Often the regulations and insurance policies can be cohesive, which would include making sure that certain health and safety standards are upheld for the installation and operation stages so that the individuals working on the site are placed in as little danger as possible. It is important for these aspects to be taken seriously as the offshore environment has more complicated scenarios that the onshore environment.

3.7.5. Developers

The developers of an offshore wind farm are the associates of those involved with the project. Their main goal is to make sure that the project is able to create a return on the electricity generation assets that are sold to the operators like the electricity generating companies and those involved in the transmission process. Because of the size and detail of an offshore wind farm asset there job is to also get other investors involved in the development team especially in areas that require financial expertise in order for them understand the issues that may be of concern.

Another major part of the instillation, deployment, and operation of an offshore wind farm project are the factors involved in the marine installation assets; this can include port and docking for any needed marine craft, installation and maintenance vessels, infrastructure and manpower that will be needed to manage and operate the previously stated factors. Usually these necessities can be provided by marine engineering companies/firms that have naval architects and marine engineers that specialize in the offshore industry.

3.7.6. First Party Equipment Managers

These are the people that are in charge of any equipment that belong to the wind turbine operation equipment. The main role of these individuals is to be mixed within every role making sure that the project has onsite manpower that can provide a degree of sustainability.

3.7.7. Asset Managers and Operators

For an offshore wind farm the operators are the electrical companies that would be providing the electricity into the main onshore grid. The operators usually have generators that are fossil fuelled, nuclear fired, and renewable generation. In recent cases the new offshore wind farms are designing their electrical output to be compatible with current onshore electrical generation such as onshore wind and oil and gas.

3.7.8. Maintainers/Field Engineers

The maintainers are placed through different positions in the wind farm project. Due to the size of the project in most usual cases there are a large number of experience maintainers who have the technical knowledge to maintain their wind turbines. These individuals have access to current data of the condition of the wind farm and of each individual turbine. The maintainers also have information of the development stages of each turbine through prototype testing information, supply chain tests, and also production data (Tavner, 2012). The individuals that work with the staff are trained to use the wind turbine machinery and understand the faults and issues with each individual wind turbine. This information is not only useful during the installation period but also during the operation period of the wind farm because if any issue arises the maintainers will know the procedures needed to solve the problem.

Figure 21 - Example of Offshore Maintainer (Scorer, 2013)

4. Selection, Design and Construction Process of Offshore Wind Farm

4.1. Design Process

The design procedure for an offshore wind farm firstly involves the initial site selection; that is then followed by a critique and assessment of related external conditions and factors. The assessment takes into account the wind turbine size selection, an investigation of subsurface activity, any geological hazards that the area of question might present, support and foundation structure design and selections; the design of the load cases, and finally a geotechnical and structural analysis (Malhotra, 2011).

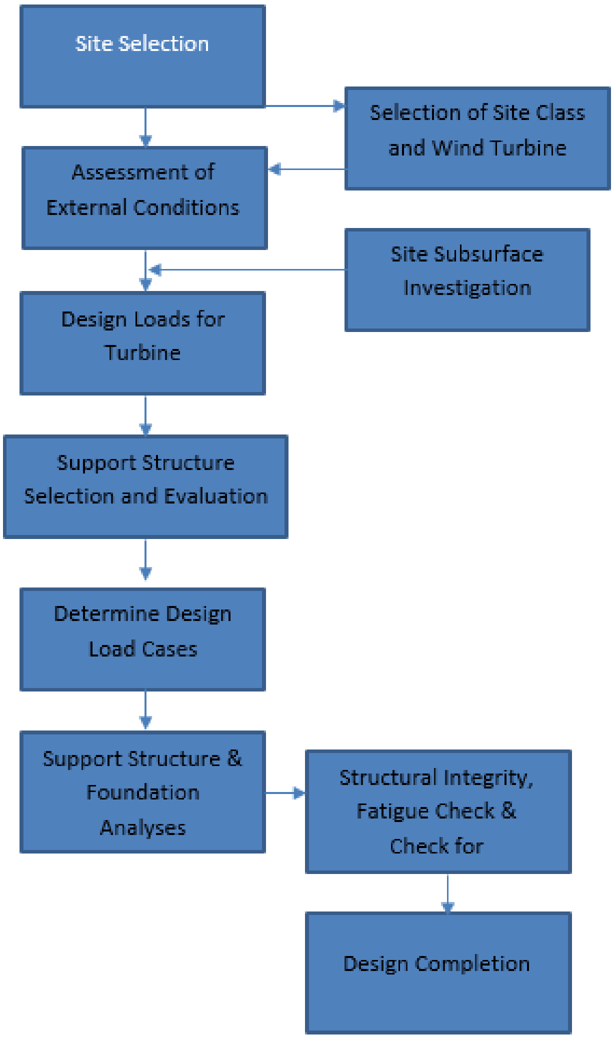


Figure 22 - Flow Chart for Typical Design Process (Malhotra, 2011)

In order for the investing company to achieve economies of scale usually wind turbines are mass produced for a farm; unless it is a small farm made for research purposes. Once the site selection has taken place it is up to the designer to choose one of the predefined turbine class types that best suit the chosen site. Due to the complex variabilities that accompany the offshore environment the foundation design must be predesigned for the site. The factors that are taken into account when engineering the foundation for the offshore wind turbine are the water depth, seabed conditions, wave heights, current velocities, and ice climate. Also the foundation systems that accompanies the foundation of the turbine are planned, which is designed based upon factors that include the design loads, water depths, site geology, and environmental impact are. If a large offshore wind turbine type is needed then an integrated analytical model for the turbine, foundation system, support structure, site specific wind, and wave regimes will be calculated or researched.

4.2. Site Selection

Once the wind conditions have been found as potentially viable for the chosen site the other factors that are included in the site selection are processed. The other factors that are part of the site selection is the adjacency to deliver electricity to the demand site, concurrence to electricity distribution companies included, an environmental impact analysis that states the degree that the project affects shipping and fishing routes and dredge channels, any affects that the wind farm installation and operation has on the telecom installations, also the distance from the site to any airports and the wind farm's effect on airplane routes (Malhotra, 2011).

Due to the complexities and variety of downfalls that may arise in the development of an offshore wind farm an extensive study must be done in order to predict and solve such issues. An example of the factors that are included in the study is an environmental impact study phase that will need public involvement, while using permitted process time that will require input from stakeholders including fishermen, local communities, airport authorities, marine authorities, and a local engineering consultancy. Allowing the public to have access to progress information usually helps to quicken the procedure. Taking steps like choosing a site that is further from the shore will reduce the visual impact. Making sure that the collaborators involved with the grid connection are chosen and are updated accordingly throughout the project will also reduce installation complications.

Antecedent apperception and analysis of any possible grid connection areas in order to design and develop substation locations and cable connection routes is necessary for gaining the approval of the public. The development of a high quality performance plant will mean that a compatibility analysis between the wind farm export and the grid will need to be done as to avoid system downtime during operation.

4.3. Farm Layout

The standard layout of commercial offshore wind farms includes the various wind turbines placed in the selected site, each connected by a set of cables that lead to an adjacent offshore transformer station. The offshore station is then connected to an onshore station through an external underwater sea cable, which allows the onshore station to connect to an existing power grid (See Figure 23). Usually the wind turbines are placed up a lateral distance of 8 times the rotor diameter between each other. If the turbines are placed closely together it can reduce the costs used for cables but it will increase the turbulence and wake effects that the turbine has to endure.

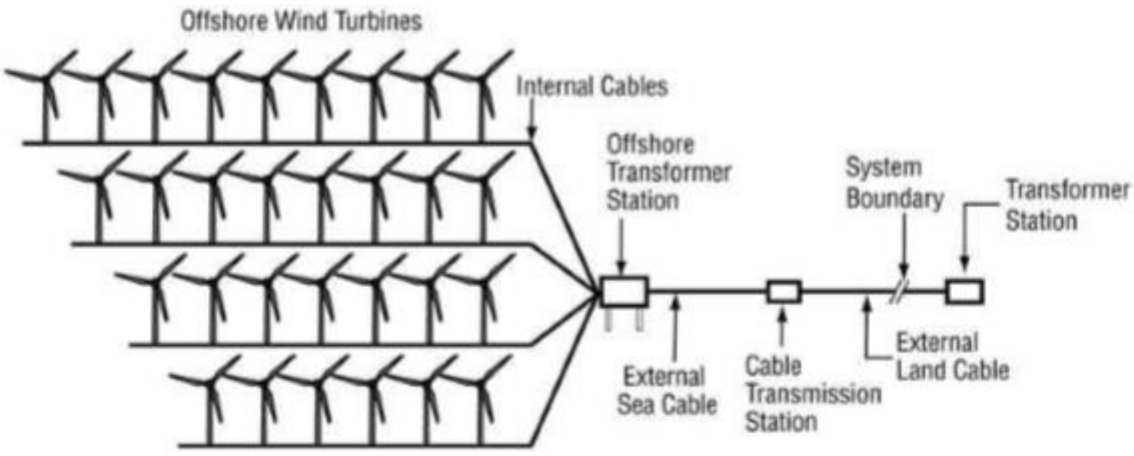


Figure 23 - Simple Wind Farm Component Layout (Malhotra, 2011)

To arrive at an optimal farm layout often an engineering consultancy will utilise the collected site information and perform a layout parameterisation. This analysis will done using a combination of modelling tools and site information research. The results of such of an analysis will lead to calculating the ideal width of separation between the farms; the size of the space in the centre of the wind farm will be efficiently concluded; the concise amount of turbines that will be needed for the farm layout; the individual positioning of each turbine; and also the shape of the layout for the farm (See Figure 24).

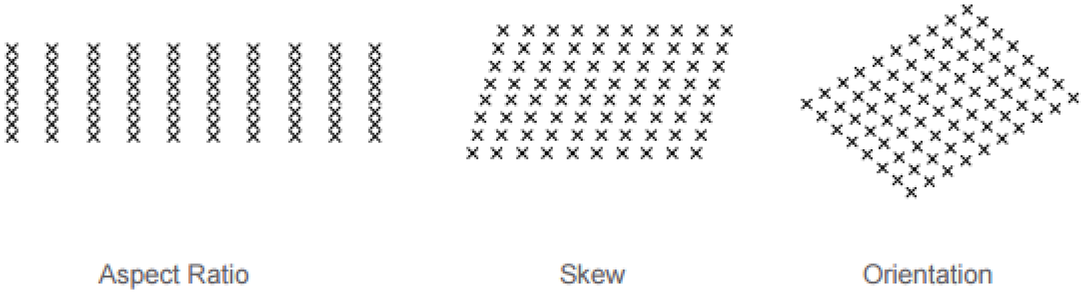


Figure 24 - Example of Offshore Wind Farm Layout Types (Gribben, 2010)

4.4. Turbine Components

The main components that make up an offshore wind turbine includes the nacelle, rotor blades, the tower, the transition piece, the support and foundation (See Figure 25). The rotor blades and nacelle are the main wind converting components that take on incoming wind speeds and convert them into electricity via a turbine unit placed inside of the nacelle chamber. The tower is what holds the nacelle structure and also is connected to the transition piece that usually holds a small platform for maintenance workers to use. The tower and transition piece is made from rolled steel specifically made for the nacelle and rotor blades' weight. The foundation is made to keep the structure supported while being able to withstand waves and wind, it can be made from a variety of materials depending on the site requirements.

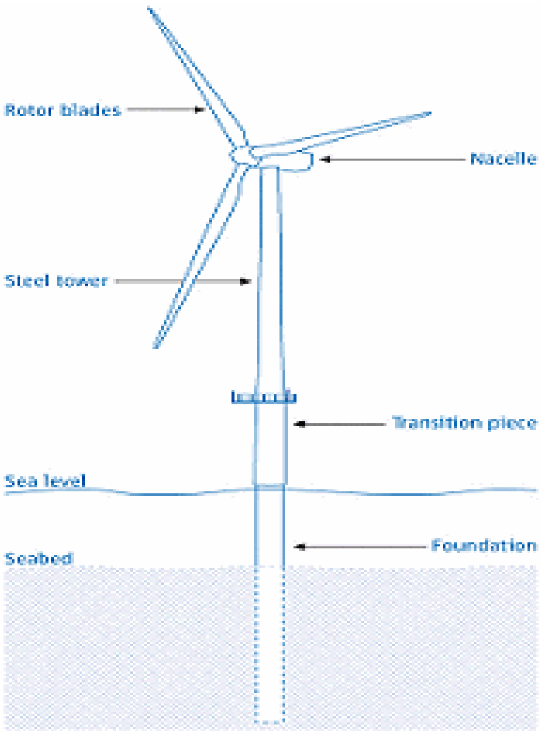


Figure 25 - Offshore Wind Turbine Components (RWE Technology, 2015)

4.5. Turbine Operation

Once air begins to flow through the rotor blades it forces them to rotate transferring the kinetic energy from the wind into mechanical energy. The mechanical energy is then used to drive a shaft through which a gearbox is then used to power a generator in the nacelle that creates the current using electromagnetic induction. If wind direction changes the nacelle can turn vertically to face the force. The electricity that is created is then sent to the transformer, located at the base of the turbine, where it is then converted to a higher voltage for appropriate usage. "*The power that can be harnessed from the wind is proportional to the cube of wind speed up to a theoretical maximum of about 59 percent*" (Malhotra, 2011). The technical designs of current wind turbines only allow functionality up to a certain wind speed in order avoid structural damage. "*So far, it is considered cost optimal to start power regulation at 10-min wind speed of 9-10 m/s, have full regulation at mean wind speeds above 14-15 m/s and shut-down or idle mode at 25 m/s*" (Malhotra, 2011). The use of a power regulatory system will allow an increase in electricity output stability during a variety of load conditions giving the overall system wider availability. In order to further increase system output stability the pitch of the blades should be regulated along with the movement of the wind. Because of the wind forces the yaw of the wind turbine can vary every 30s to 60s depending on the size of the turbine, which in result creates gyroscopic loads. The resultant effects of the pitching and yawing of the turbine can create non-linear aerodynamics that could affect the performance of the turbine, in order to fully analyse the performance of the turbine and also correct any issues that may arise as a result of these conditions it should be modelled into the turbine response systems.

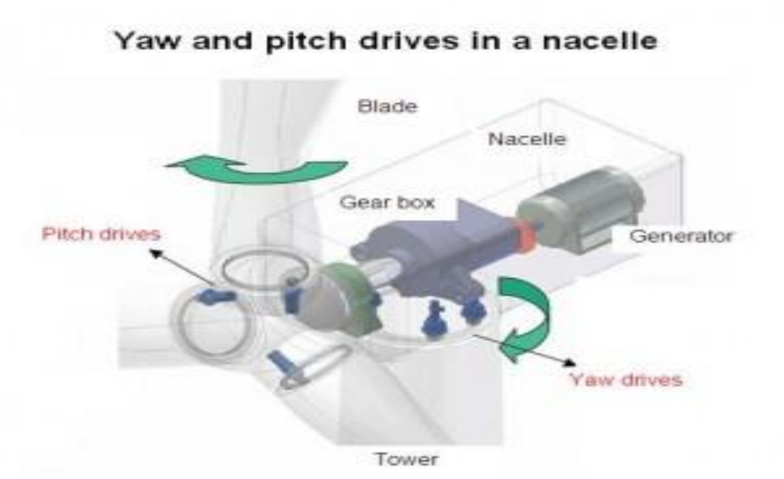


Figure 26 - Diagram of yaw and pitch control (Dvorak, 2012)

4.6. Wind Turbine Foundation Requirement & Dynamics

The requirements of the wind turbine's foundation are to withstand any deformation based upon operation data given by the turbine's manufacturer. The tolerances of the foundation are a maximum allowable rotation at the pile head once installation is complete; also there is usually a maximum permanent rotation from the cycle loading over the wind turbines' operational life. For an offshore wind turbine the maximum tilt is 0.5 degrees (0.009 radians). The permanent tilt that is created from construction must be subtracted from the tolerance specifications. "*Typical values of construction tolerances range from 0.003 to 0.0044 radians (0.20 degrees to 0.25 degrees)*" (Malhotra, 2011).

The dynamics of the foundation is an important aspect of the offshore wind turbine's structure, as the foundation must be designed in accordance to the maximum vibrations that are created from the rotation of the blades. For a three bladed rotor once it reaches peak turbulence it then begins to resist forces of 1P and 3, where in this case P is the blade passing a frequency. "*For a typical variable speed turbine, the blade passing frequency is between an approximate range of 0.18 Hz and 0.26 Hz, and rotation frequency, which is between about 0.54 Hz and 0.78 Hz*" (Malhotra, 2011 & Gaythwaite, 1990). Sea waves cause frequencies from 0.04 Hz to 0.34 Hz, so in order to avoid unwanted resonance the entire turbine's design must be designed using a difference natural frequency. Figure 30 from Sanjeev Malhotra's research paper shows a visual depiction of the natural frequencies of each entity involved in offshore wind turbines.

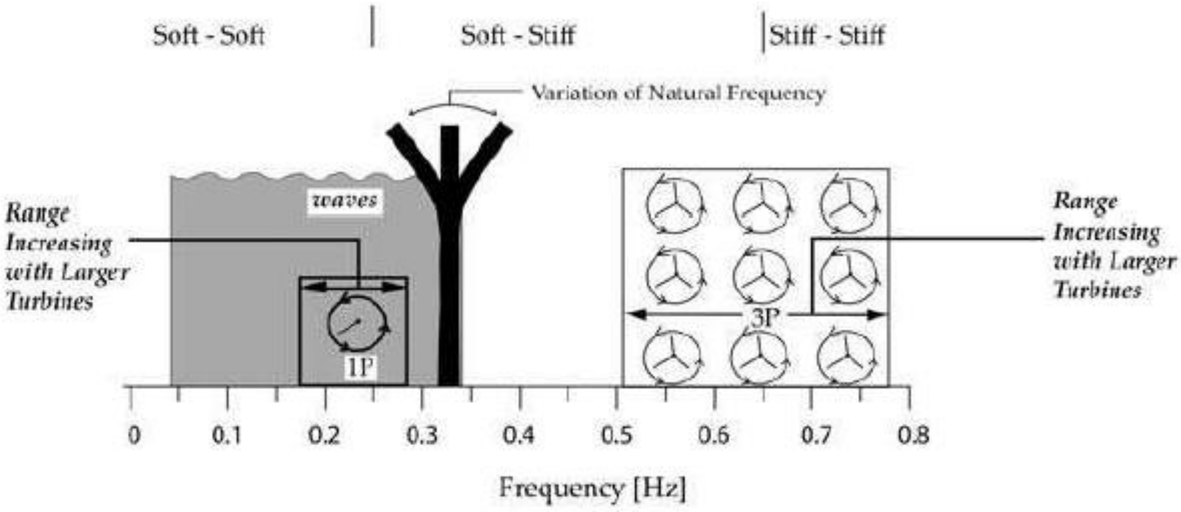


Figure 27 - General Ranges for Frequencies of Offshore Wind Farm Entities (Malhotra, 2011)

A larger the wind turbine diameter will result in taller tower designs and heavier nacelles, which means that the foundation will have to be appropriately designed with these aspects in the design as well. As the height of the tower increases the foundation’s design will proportionally change, as the physical demand of the foundation will increase. Most wind turbine towers are designed to be stiff in order to reduce the effects of vibration. The more stiff a tower is made to be the more materials will be required in the construction phase. It is up to the designers to plan the required amount of stiffness through turbine manufacturer information in order to balance the needed stiffness with the financial budget of the turbine.

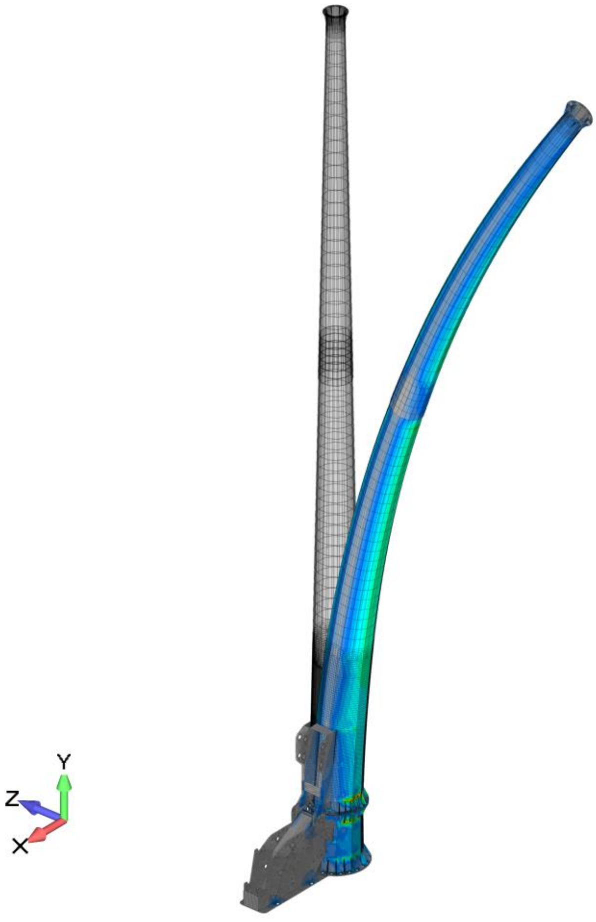


Figure 28 - Depiction of a Turbine's Tower stiffness model (PredictiveEngineering, 2015)

5. Bahamas Electricity Demand

The information gathered for this section of the report is to show the typical annual electricity consumption rate of the Bahamas. All of the numeral data from this section was found through a combination of research and assistance from Bahamas Electrical Corporation by Fichtner.

5.1. Domestic Demand

In the Bahamas around 40% of the electricity used is from the domestic sector. The information represented in this section was collected from previous audits done on 18 representative homes. The households were selected from the island of New Providence in which 4 main zones were designated by the government for the company Fichtner to perform the audits.

The methodology that was used to perform the audits were done based upon a combination of questionnaires and practical energy monitoring. The annual electricity consumption for the households were calculated with a combination of monthly electrical bills that most of the homeowners kept and also with the use of power meters.

The main estimations of domestic electricity consumption is seen in figure 29. Due to the amount of normal sized houses compared to smaller or luxury homes the majority of the electricity demand is resultant from the medium sized homes. (See Table 3).

Table 3 – Amount of Households & Inhabitants

Type	Households	Inhabitants
Luxury Homes	3,099	12,176
Normal Homes	63,888	265,344
Small Homes	20,755	54,772
Total	87,742	332,292

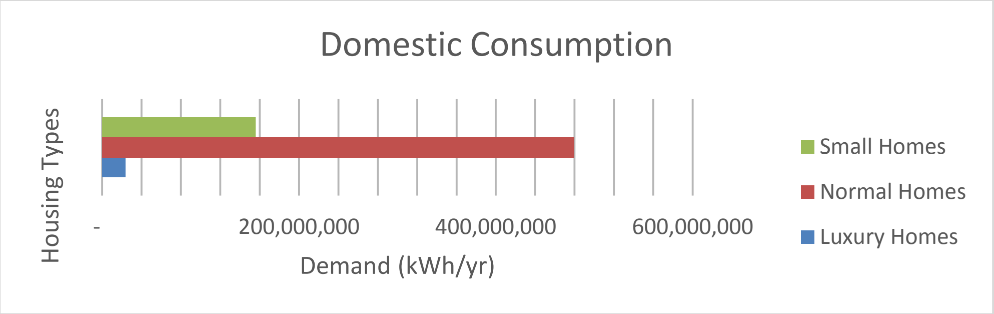


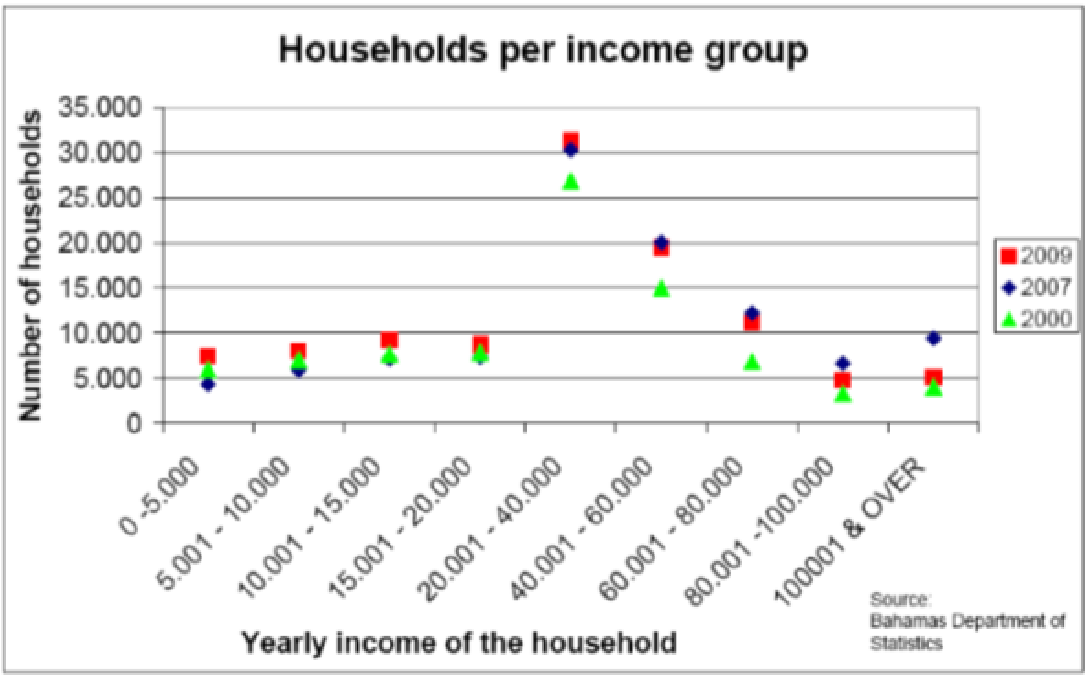
Figure 29 - Domestic Electrical Consumption in the Bahamas (Fichtner & BEC, 2010)

The annual electrical demand for the luxury homes was estimated to be 23,242,500 kWh while the annual demand for the normal homes and small homes were found to be 479,160,000 kWh and 155,662,500 kWh respectively. The total demand was calculated to be 658,065,000 kWh (See Table 4).

Table 4 - Domestic Electrical Demand Summation (Fichtner & BEC, 2010)

Type	Households	Calculated Demand (kWh/yr)
Luxury Homes	3,099	23,242,500
Normal Homes	63,888	479,160,000
Small Homes	20,755	155,662,500
Total	87,742	658,065,000

The average annual electricity consumption for a household was stated to be 7,500 kWh according to the Bahamas Electricity Corporation. The information stated cannot be the electrical demand for every household but the estimation is deemed to be accurate to be used for feasibility purposes. The demographic suggests that the majority of electrical demand comes from medium sized homes. These types of homes are owned by middle class families that have an estimated income of around $30,000-$45,000 (Fichtner, 2010).



Source:
Bahamas Department of Statistics

Figure 30 - Household income in The Bahamas (BDS & Fichtner, 2010)

5.2. Hotel Demand

The data that represents the electricity demand of the hotels in Bahamas were gathered through audits scheduled in partner with Bahamas Electrical Corporation and Fichtner. The audits were carried out using a combination of questionnaires and power monitoring. Also the larger hotels were able to give the monthly readings for the electrical consumption in most cases. The audit went into such detail that it took into account the electricity consumption per rented room but for the sake of this feasibility study the most important information is the overall consumption of the hotels in the Bahamas. The hotels were split into three categories, which were large, mid-sized and small (Shown in Table 5).

Table 5 - Hotel Size Classification used by Fichtner

Classification of Hotels	Number of Rooms
Large	350 +
Mid-sized	50 - 350
Small	<50

The energy consumption was analysed in kWh per year. According to the report produced by Fichtner 89% of the energy usage of hotels in the Bahamas is due to electricity requirements.

Around 40% of the total energy usage in the Bahamas comes from hotels so it is important to note that renewable energy in the Bahamas will have an obligation to facilitate a portion of that electrical demand.

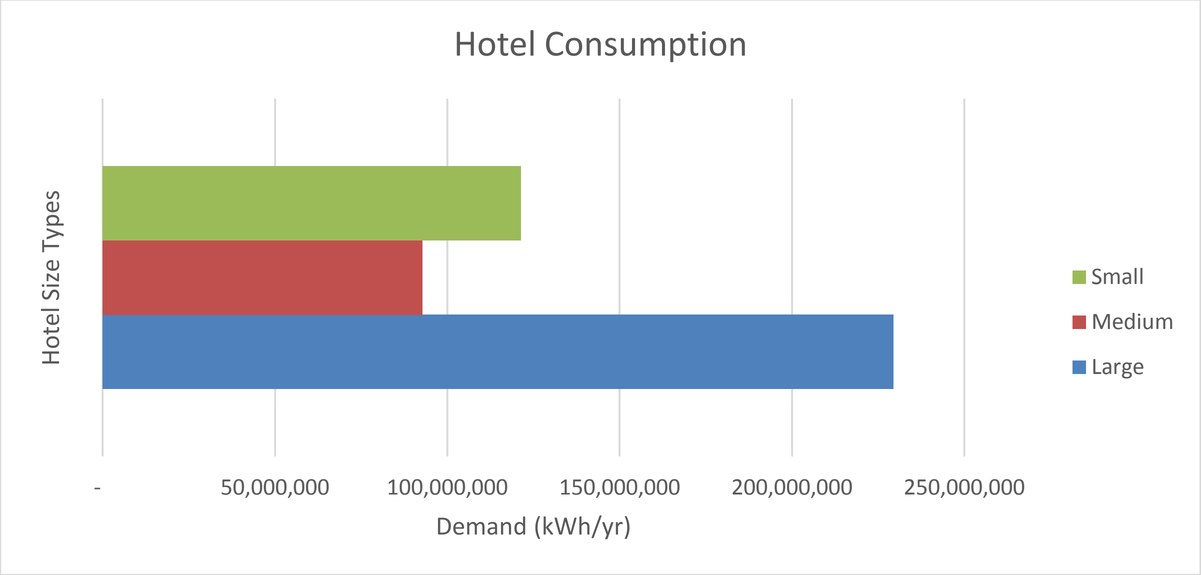


Figure 31 - Annual Electrical Demand of Hotels

The majority of the electricity used is from the large hotels, which contributes about 230,000,000 kWh a year. The second largest electrical demand came from the smaller hotels, which has an electrical consumption of about 120,000,000 kWh annually. The smallest electrical demand contribution was from the medium sized hotels that have an electrical demand of about 92,000,000 kWh a year (See Figure 31 & Table 6).

Table 6 - Total Electricity Consumption of Hotels (Fichtner, 2010)

Type	Average Electricity Demand Per Hotel (kWh/yr)	Number of Hotels	Total Electricity Consumption (kWh/yr)
Large	19,112,593	12	229,351,116
Medium	2,507,326	37	92,771,062
Small	529,427	229	121,238,783
Total	22,149,346	278	443,360,961

The electrical consumption from each hotel was reported to be from air conditioning, lighting, cooling, and other stand-by appliances. Although the use of liquefied petrol gas and diesel is used it is only for kitchen usage, water heating, and steam generation for laundry purposes. The majority of the electricity usage comes from air conditioning and ventilation to accommodate for the heat in the Bahamas.

As shown in Table 6 the total annual amount of electricity that the hotels in the Bahamas consume was calculated to be 443,000,000 kWh. As stated previously the hotels use around 40% of total electricity demand in the Bahamas.

Figure 32 - Example of a Hotel in the Bahamas (Atlantis, 2015)

5.3. Public Buildings Demand

According to the Bahamas Electrical Corporation (BEC) the public buildings account for about 10% of the electrical consumption. The most prominent buildings had their electrical consumption audited. The information provided by BEC allowed for proper visualization of the electrical consumption from the public sector. For the sake of this report it also helps in providing useful information for prospective companies or researchers interested in finding out the prospect future of sustainability in the Bahamas and also the demand requirements of the wind turbines.

The public buildings that were chosen were the most prominent in use in terms of electricity consumption. Any building that was below the Geriatrics Hospital's electrical was too low to be accounted for in this analysis. For the original analysis the information gathered was processed into kWh per square feet of the buildings but for this project that amount of detail is not necessary as it is mostly the accumulative data that is needed.

For the buildings that were analysed the one with the highest amount of electricity demand is the Ministry of Education, which has a demand rate of about 2,600,000 kWh a year. The second highest is the Main Port Office, which has an annual demand rate of about 1,800,000 kWh. The third highest is the Ministry of Works building, which has a yearly demand rate of around 1,250,000. The lowest is the Geriatrics Hospital, which has a demand rate of about 750,000 kWh annually.

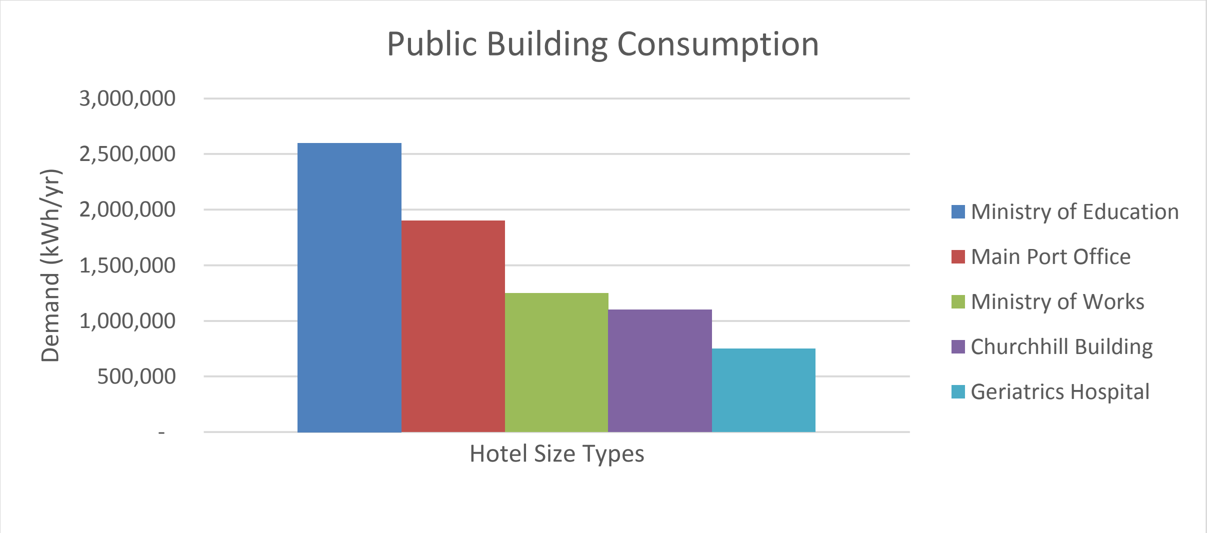


Figure 33 - Annual Electrical Demand from Notable Public Buildings (BEC & Fichtner, 2010)

The public buildings that were chosen in this procedure are the most active and also the largest in size. There are other public offices in the Bahamas but because of the low demand rate that they contribute to the country's overall electricity consumption it was seen for this project that only the more major participants in that percentile were to be mentioned. The total demand that the public buildings was found to be is around 7,600,000 kWh a year. This number will be larger by some degree due to the smaller demands that were left out but when looked at in the larger scale that amount does not change the total energy consumption of the country substantially.

Table 7 - Total Annual Energy Consumption for Notable Public Buildings

Types	Electricity Demand (kWh/yr)
Ministry of Education	2,600,000
Main Port Office	1,900,000
Ministry of Works	1,250,000
Churchill Building	1,100,000
Geriatrics Hospital	750,000
Total	7,600,000

5.4. Total Demand – Summation

The importance of this section of the report is to put into perspective the overall electrical demand of the Bahamas. The goal for an offshore wind farm is not to cover the entire electrical demand but to contribute up to 30% of the total demand shown in Table 8. As stated throughout this section the main contribution of the electricity demand comes from the domestic use of electricity. In the Bahamas the majority of electricity usage comes from air conditioning and lighting. The air conditioning comes from the high temperatures that the Bahamas can present especially during the summer season.

Table 8 and figure 34 both show that the major electrical demand is the one to be the most important in the society, which represents the needs of the people. The average total amount of electricity consumed in the Bahamas is 1100 GWh a year. The majority of this electricity usage comes from domestic use, which is shown to contribute nearly 60% of that demand. The majority of this demand could be facilitated by the use of a small to medium sized wind farm that could produce half or less of the needed domestic electricity demand.

Table 8 - Summation of Annual Electric Demand for the Bahamas

Type	Electricity Demand (kWh/yr)
Domestic	658,065,000
Hotel	443,360,961
Public	7,600,000
Total	1,109,025,961

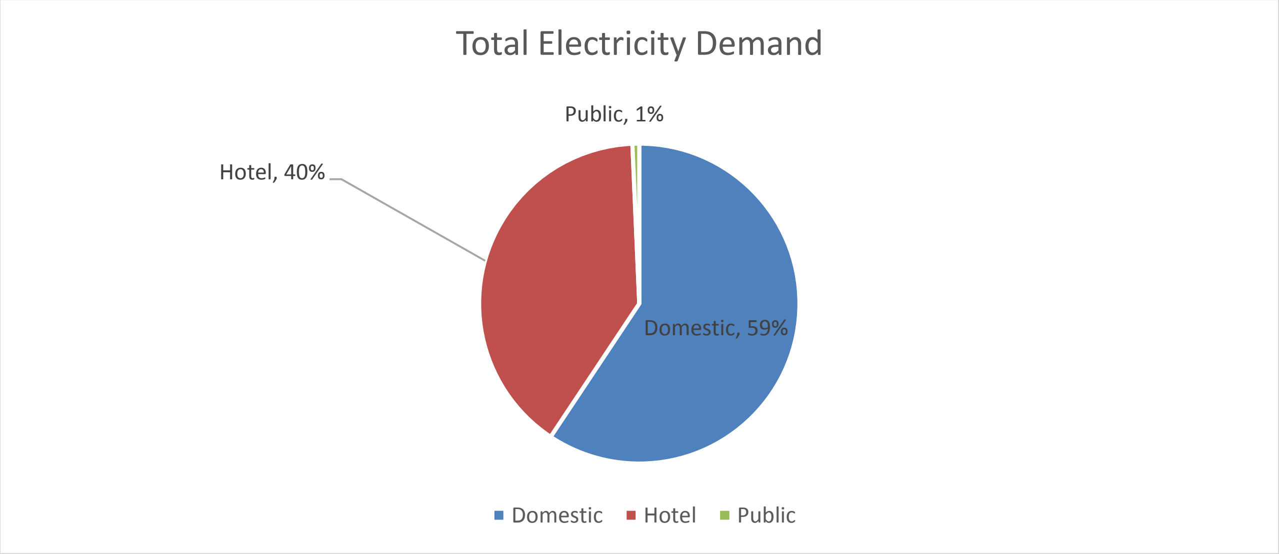


Figure 34 - Chart of Annual Demand Percentile of the Bahamas

6. Project Consenting

The purpose of this section of the thesis is to utilize environmental information about the Bahamas, and develop an environmental impact assessment guideline that can be used for the preplanning stage of an offshore wind farm. The information will begin with an explanation of all of the most important environmental aspects of the Bahamas and their position in the ecosystem/economy. The information will then be used to create an environmental assessment guide tailored for the Bahamas' environment.

6.1. State of Bahamas Environment

6.1.1. Geography

The Bahamas is an archipelago of over 700 low latitude islands and over 200 cays that collectively cover close to 260,000 km^2 in the Caribbean; they also include the county's Exclusive Economic Zone located in the Atlantic. The extent of the islands includes up to 50 km east of Florida and about 50 km northeast of Cuba; the collected landmass of the islands is about 14,000 km^2. The neighbours of the Bahamas include Haiti, Turks & Caicos, Cuba and the United States as shown in Figure 1.

Being that the islands of the Bahamas are located on low latitude grounds there are mostly flat lands for most of the islands, however the highest point is a location called Mt. Alvernia that is located on Cat Island that has a height of 63 meters. In most cases throughout the islands there are no rivers but there are large brackish lakes, which are connected by tidal creeks. These creeks are seen on Andros and Grand Bahama, where the creeks are large enough to be navigable by small boats.

Close by the islands are a variety of coral reefs that hold a multitude of marine life (See figure 35). Along with the coral reefs are a diverse range of banks and sea grass beds. The coral reefs that reside in the shallow oceans of the Bahamas provide one of the most extensive groups of marine organisms in the Atlantic/Caribbean (BEST, 2005). The collective size of the coral reefs in the Bahamas is estimated to about 10,000 km^2.

Figure 35 - Coral Reef in the Bahamas (V., 2014)

The overall landscape of the Bahamas is mostly rolling hills, ridges, flat rock lands, and large wetlands. Any areas that have not been cleared for settlement purposes have a large amount of vegetation, which usually consists of a natural forest of Caribbean pine, coppice vegetation, and other diversities. In the southern drier areas there is less diversity in terms of forestry vegetation.

Figure 36 - Forestry in the Bahamas (Barrett, 2015)

6.1.2. Population

In the Bahamas around 30 of the islands are inhabited; the population count as of 2015 is 384,397 (countrymeter.info, 2015). The growth rate of the Bahamas has been steadily decreasing since 1961; the information gathered shows the growth rate was at 5.1% in 1961 but declined to 0.92% in 2014. The population at this time was 109,526 but increased throughout the years as the birth rate became higher that the death rate. Currently 69.2% of the population is between 15 and 64 years of age, 24.4% of the population is under 15 years old, and 6.3% of the population is over the age of 64. The highest populated islands are New Providence and Grand Bahama.

6.1.3. Climate & Climate Variation

The Bahamas is stated to have a sub-tropical climate that is subjugated to warm water from the north Gulf Stream. In result the seasons of the Bahamas are split into two types, one being the drier winter season that spans from November to April, and the other being a hot rainy summer season that starts in May and ends in October. The mean rainfall ranges between 865mm to 1470mm. The yearly temperature ranges from 17^{o}C to 32^{o}C, which depends on the season and time of the month.

The country is prone to experiencing hurricanes and tropical storms during the hurricane season, which starts in June and ends in November. The high speed winds, heavy rainfall, and resultant flooding can cause a large amount of damage but the architectural structure of the homes built are designed taking into account the prospective storm seasons; the majority of destruction caused by hurricanes are usually to the roads and power lines. Due to the dry nature and high temperatures that create high evaporation means that a portion of the islands have to get their water imported from other islands such as Andros and other islands that have water desalination plants and other water purification systems.

Climate trends in the Bahamas has seen an average temperature rise of 1^{o}C; the most change occurred within the last 40 years (NEMAP, 2005). The average number of days in which the average minimum and maximum temperature went past the usual temperature range has increased from 4% in 1960 to 8% currently. The amount of heavy all day rainfall has also increased to 28% currently from 24% in 1960. The further effects of increasing greenhouse gases are expected to increase the effects of climate change.

According to Bahamian information the mean daily temperature for July is increasing by 2^{o}C every 100 years. The amount of rainfall is expected to increase gradually as well with the correlating temperature with an increase of draught in certain areas.

Figure 37 - Damage from Hurricanes in the Bahamas (Pydynowsky, 2012)

Coral reefs and other life that is depended on the coastal eco system rely on the temperature and other climate factors of the Bahamas. Any sudden shifts in the sea-temperatures can cause a correlating effect that can damage the lives of millions of marine life forms. The coastal ecosystem is not only important to the marine life but also to the local life as a large portion of the economy is depended upon the survival of the marine ecosystem.

6.1.4. Economy

The majority of the Bahamian economy is depended on tourism and the offshore financial industry. Tourism is responsible for about 50% of the country's gross domestic product and employs 40% or more of the labour force directly or indirectly. Overall tourism creates $1.5 billion annually for the country by which the tourists arrive via cruises and airplanes.

The financial sector of the Bahamas contributes around 15% of the gross domestic product creating around $300 million annually. The other sectors include, fishing, agriculture, and manufacturing. Agriculture was seen to create around 50 million in revenue for the Bahamas in 2002. Large-scale and commercial fishing creates around $70 million for the economy every year. Fishing and scuba diving also contribute to the tourism industry. The manufacturing industry is small and accounts for about 4% of the total gross domestic product (NEMAP, 2005).

A large part of the industrial industry of the Bahamas is located in Grand Bahama near Freeport Harbour. Most of these industries include cement bagging, oil bunkering, large carrier ship dry-docking and repair, and pharmaceuticals manufacturing (NEMAP, 2005).

Figure 38 - Grand Bahama Shipyard (Grand Bahama Shipyard, 2015)

6.1.5. Important Ecosystem Components

There are a variety of contributing components that make up the ecosystem of the Bahamas, of which a few of them have been categorised as highly important towards the overall success of the ecosystem. The following subsection will state these components and also explain their importance.

6.1.5.1. Quality of Air

The local ambient air quality throughout the islands of the Bahamas is mostly at an adequate level of quality due to a variety of reasons. First of all the atmosphere has prominent easterly trade winds throughout the year and multidirectional but still high levels of wind speed conditions through any remaining months of the year (NEMAP, 2005). Any emissions created from the industrial and domestic sector of the Bahamas is transported overseas by the winds allowing a lack of concentrated ozone emissions in the ambient air conditions. Secondly the Bahamas has a relatively low level of industrial activity creating small amounts of greenhouse gas emissions from the islands, in result the areas that do have industrial activity in most cases have an acceptable level of air pollutants. And lastly the overall population of the country is relatively small compared to other nations so in result the amount of pollutants created from the domestic, industrial, and agricultural sectors aren’t very high.

Table 9 - Green House Gases for the Bahamas - 2011 (CCCCC, 2012)

Green House Gasses Inventory 2011	
Sub-sectors	*Kg CO_2e for 2011*
Accommodations	3,281,131
Ferries	65,235
Local Air Traffic	1,994,562
Water Taxis	0
Tour Boats	0
Tour buses	0
Taxis	9,383
Car Rentals	93,526
Total	**5,443,837**

The small industrial industry and low population density means that the Bahamas is one of the smaller contributors to greenhouse gases globally. Two major sources of air pollutants are from electricity generation and transportation. Around 65% of the greenhouse gases that are created comes from burning of gas & oil by products for the production of electricity

(NEMAP). The use of damaged or poorly maintained air conditioning units also contribute to a small portion of greenhouse gas production.

The Bahamas is also deemed a major absorber of carbon dioxide due to its marine production and vegetation. The relatively large pinewood forests help to absorb some of the CO_2 in the area. Also the general marine vegetation use CO_2 in their biological processes helping to reduce the amount of greenhouse gases. "*An estimated 370 to 739 kg CO2 per year is sequestered over a 277 km2 area of shallow marine banks around Abaco*" (NEMAP, 2005). This estimation shows that carbon dioxide is used in an amount up to 240,000Gg over all of the shallow water areas that harbor marine vegetation.

6.1.5.2. Soil

Around 5% of the entire area of the Bahamas is land mass, this is one of the major reasons why there are competing industries that are demanding land resources.

The soil is a thin, fragile, and course in texture. This is why there have been many attempts at agriculture in the Bahamas but only a few that have succeeded. The majority of the land in the capital of New Providence has been used for road construction, domestic homes, business compounds and hotels. The large amount of forestry that was cleared to do such construction was made on crown estates, which around 80% belongs to the government. Due to a change in environmental regulations pine trees are now deemed productive towards the survival of the ecosystem in the Bahamas so they are now a protected species.

There are several threats towards the soil in the Bahamas. The first is in the form of infrastructure development, which includes roads, resorts, and domestic housing. The second type of threat comes from the pollutant by-products of the local industrial sector. The third type of threat is due to none-designated dumping in which individuals illegally dump trash in areas that have a small diversity of wildlife. The final form of threat type comes with miscalculated designated dumping in which the land areas that are chosen for dumping are not practically planned and so more land than what is needed is then ruined.

6.1.5.3. Resources of Freshwater

The main source of freshwater for the Bahamas comes from rainfall. As previously mentioned the yearly average of rainfall is from 865mm to 1470mm. There are no freshwater rivers or lakes of freshwater but during high amounts of rain the water moves through the limestone rocks and eventually is placed on top of dense seawater, which creates a layer of freshwater on top of these reservoirs.

Islands that are affected by heavy rainfall are Andros, Grand Bahamas, and Abaco. The rainwater from these islands are filtered and transported by the thousands of gallons to the main island of New Providence. Depending on the area and the rain consistency sometimes seasonal wetlands form. Wetlands, despite the size, often are an important factor in the balance of a much larger biophysical system that extends to the aquatic system that supports a variety of complex nutrient cycles which in turn help to sustain life. Despite their inconsistent frequency the importance of the wetlands goes past the confined area of its borders. These areas help to regulate water levels, improve the quality of water, reduce the chances of flooding and also provide life for a variety of marine organisms.

Due to the lack of research and awareness the management of such areas is often neglected. The wetlands are often unchecked and therefore no inventory is taken in order to gather information about them that is non-speculative. The legislations in the Bahamas do not cover wetlands so areas that are deemed attractive for development are sold and then excavated. In result the number of wetlands in the Bahamas has been declining (NEMAP, 2005).

Figure 39 - Wetlands in the Bahamas (US Embassy, 2012)

6.1.5.4. Marine Life & Resources

The marine environment covers the majority of the total area of the Bahamas. It is an important factor for the economy and ecosystem of the islands as both the tourism industry and the biological cycles depend on it. In the Bahamas there are four main categories of marine environments, which are the coral reefs, sea grass areas, pelagic ecosystems and the deep water areas (NEMAP, 2005).

Sea grass areas are common in shallow water tropical environments. These underwater grass beds can vary in length and types, which can grow in depths of up to 33m and can cover vast acres of underwater land. The grass beds usually form a small forest area that can provide shelter and food for a variety of marine life that are important for the ecosystem and economy. One of the reasons why the waters of the Bahamas are so clear is due to the natural filtration system that the sea grass provide. If destroyed the area can become an unstable environment for marine life, which can result in a less attractive environment for the tourism industry. There are a few threats to sea grass beds that come from careless boating practices, anchoring for long periods of time, jet skis, dredging areas, pollution from sewage or industrial by-products, silt created from on land construction, and the pollutants created from boats.

Coral reefs are one of the most important aspects of the Bahamian economy and ecosystem. The coral reefs not only house a variety of marine life but they are also the reason for the colour of the Bahamian beaches. These natural underwater vegetation farms also help to attract a multitude of tourists from all around the world, which in turn help to maintain the tourism industry.

The pelagic ecosystem is an area of the of deep water ocean that is located around 938 meters on top of areas that have large depths (see Figure 45). These areas are seen as a large food source for deep water fishes to thrive in. Larger mammals such as dolphins and whales often use these areas for protection during the winter seasons. Overfishing and illegal hunting are the greatest threats to these areas.

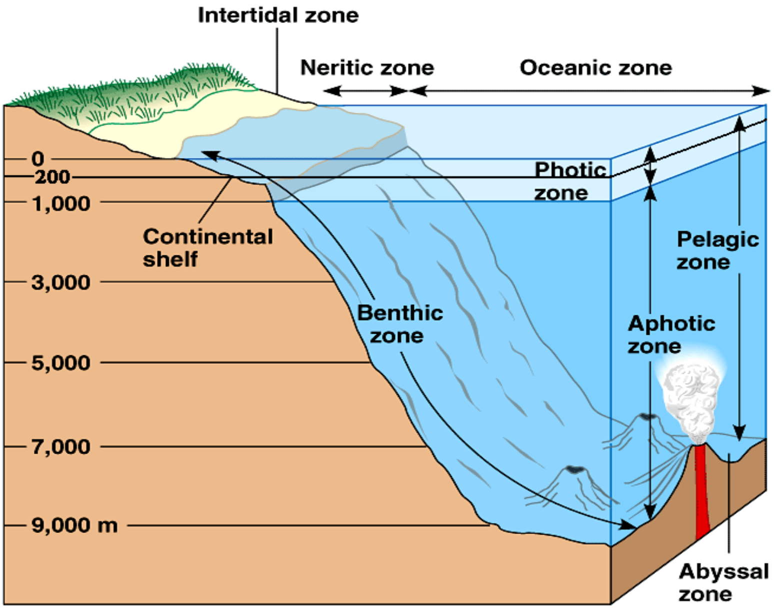


Figure 40 - Different Oceanic Zones (K.I.T.U., 2014)

Deep ocean environments are areas that are greater than 938 meters. These areas have submarine canyons and other yet to be discovered areas. The deep ocean houses a variety of animals of which most have yet to be discovered. The major threat to this area is illegal dumping of large unwanted items like cars and household units.

6.2. Environmental Impact Assessment Procedures

The information created here will utilise the general guidelines created by The Crown Estate, and apply them to the environmental factors that would be taken into account for the development and consenting stage of an offshore wind farm in the Bahamas. It should also be stated that this part of the project will solely focus on the environmental assessment procedures, and will not digress into the technical development procedures of an offshore wind farm.

6.2.1. Benthic Environmental Survey

The main purpose of the benthic survey is to create an inventory of the species that live in the surrounding seabed and sediment of the proposed wind farm confinements. A variety of sampled sites along the region of the Bahamas would be chosen in order to categorise and pick an area that the wind farm would have the least environmental impact on. This study would observe all of the surrounding land areas and also the small scale environmental features such as coral reefs and populated sea grass beds. One of the main goals of this study is to determine the size and importance of any coral types in the prospective area such as:

- Symmetrical Brain Coral (Diploria Strigosa)
- Grooved Brain Coral (Diploria labryinthiformis)
- Finger Coral (Porites porites)
- Boulder Star Coral (Montastraea annularis)
- Mountainous Star Coral Montastraea faveolata)
- Great Star Coral (Monstrastraea cavernosa)
- Massive Starlet Coral (Siderastrea siderea)
- Lettuce coral (Agaricia agaricites)

The methodology used to collect the information would include practical sampling, beam trawling, video analysis, and acoustic data of the seabed area. This type of survey is done with local fisheries allowing the company to retrieve information of the fishing routes and spots nearby. The interaction with the locals will allow for needed interaction necessary for a successful environmental impact study, this includes asking opinions on the idea of placing offshore structures in the area of question. Samples taken will be analysed in a laboratory.

6.2.2. Pelagic Environmental Survey

The pelagic survey can be done simultaneously with the benthic survey. This survey analyses the open sea life that surrounds the wind farm site; the goal of this is to search for fishes that reside or migrate through the site. These tests are done with local fisheries in the Bahamas using trawls in order to create an inventory of the types of marine life in the area. One of the main goals for this type of survey is to arrive at a conclusion of whether the area of question is spawning grounds for local fishes. The type of vessels used in this survey would be locally based fishing boats, the type of navigation and survey equipment needed for the analysis might have to be provided by the company doing the survey if the fisheries do not have it.

6.2.3. Ornithological Environmental Survey

Any Bahamian birds that are natural to the wind farm site have to be categorised and placed in a formal inventory. Offshore wind farms can cause a damaging change of habitat for the birds as the turbines can create a barrier of the flight path that may result in mortality through collision with the turbine blades or tower.

This type of survey will involve aircrafts and marine vessels as a part of the analysis equipment. For the data to reveal conclusive results the potential wind farm area will need 2 years' worth of data. Information that is gathered from this survey will take into account the following data of the birds in the area:

- Species variation
- Species population numbers
- Flight patterns
- Result of birds effect on the wind farm

The survey of the area has to take an inventory of the sea birds, resting birds and the migrating birds' interaction with the proposed site and also it has to come to conclusive effects that the wind farm will have on the birds. Also if there are a large amount of migrating birds within the site the data collected has to lead to the effects that the wind farms will have on their flight paths.

The use of aerial boat based visual recordings and radio tagging would be used to categorise the different types of birds and their flight paths. In order to fully access the risk of collision the flying height of the birds should be noted. Any data that comes from radio tagged birds that fly through an existing wind farm would be useful in order to predict the change in flight tactics that birds of the same species might use.

6.2.4. Sea Mammal Environmental Survey

Bahamian marine mammals, which include whales, dolphins, porpoises and seals in the area have to be observed, categorised, and the effect of the implementation of an offshore wind farm on their survival has to be concluded.

This can be done with the bird surveys in order to save costs but there has to be separate techniques used for the data collection. The individuals involved in the marine mammal survey should assess the acoustic impact during any offshore activities. The activities that should be observed in relation to the proposed area are:

- Hunting patterns
- Mating areas
- Resting areas
- Areas in which young are raised

This type of surveying should be done by qualified marine biologists, which have an existing knowledge of the types of species that will be analysed. All of the observing practices in result should not disturb the natural patterns and habits of the animals else that will jeopardise the quality of the data collected.

Figure 41 - Manatee Native to the Bahamas (Moon Travel Guides, 2013)

6.2.5. Ornithological & Mammal Surveying Craft

The mammal and bird surveys are to be done using a set of vessels and aircrafts that will provide a suitable platform for the observation and analysis to take place.

Survey vessels used should be chosen based upon the company’s requirements; the same vessels used for the bird survey would be used for the mammal survey to save costs. The weather has to be checked in advance for the area of study before the trip is planned. The most important aspect that should be noted when choosing an appropriate vessel is that it should provide a level of platform stability for the surveys to be completed accurately. Usually the vessels that are chosen for this type of work have a lower waterline or an elevated platform area for surveying operations. The use of aircrafts is also recommended for sites that have a large overall area. These aircrafts should be equipped with the following equipment:

- High resolution digital cameras
- LiDAR
- Video imaging and imaging spectrometers
- Autopilot capabilities for extensive surveying

A crew of appointed ecologists supplied by the environmental survey consultancy would perform a rotational shift of area observing, recording and video analysis. Techniques such as passive acoustic monitoring and physical observation should be performed by qualified marine biologists, that will efficiently utilise the allocated surveying time to create a detailed inventory of their retrieved results of Bahamian birds and mammals in the area.

Figure 42 - Example of Marine Craft Used in Bird & Mammal Surveying (Barnes Offshore Ltd, 2011l)

6.2.6. Onshore Environmental Survey

Environmental surveys that find the potential impact that the offshore wind farm will have onshore must be completed. Due to cable- laying and the construction of onshore substations the surveys have to be performed in order to satisfy environmental regulations of the Bahamas.

The wildlife survey and further data collection should be done in collaboration with ecological consultancies that understand the wildlife in the area. These types of companies will have qualified professionals that are specialised in ecology and also have background knowledge on the species that are categorised. The study that will be taken onshore should include the following factors:

- Species distribution
- Species population density
- Variety of species

The main focus of this survey to come to the conclusion of the areas that have the highest thriving ecosystems.

Figure 43 - Type of Land Reptiles in the Bahamas (Shedd, 2012)

6.2.7. Sea Bed Survey

The purpose of the seabed survey is to analyse the sea floor of the wind farm area and to take an inventory of its condition, characteristics, and marine life. The seabed survey has two main parts that are conducted in order to gain conclusive information about the site:

- Geophysical survey of the bathymetry of the sea bed
- Geotechnical survey, which takes into account the factors that make up the characteristics of the sea bed

This part of the environmental survey is important as the information gained from this section can help with a variety of other development procedures of the offshore wind farm, such as:

- The design process of the offshore wind turbine foundations
- The layout of the entire wind farm
- The risk assessment of the installation procedure

Depending on the size of the site there will be a variety of specialized marine vessels in order to complete the survey.

6.2.8. Geophysical Survey

To establish information about the sea bed a geophysical survey has to be done; this survey will research and categorize the following factors:

- Sea floor bathymetry
- Sea bed features
- Depth of the water
- Stratigraphy
- Hazardous areas

Techniques that are used for creating data of the sea floor bathymetry are arrived at by using the following types of analysis:

- Bathymetry mapping with beam echo soundings
- Swathe bathymetry
- Sea floor mapping with the use of side scan sonar
- Magnetometer readings

- Acoustic seismic profiling
- Airgun high resolution surveying

These surveys will run within the proposed wind farm area and also across boundary areas of the farm site. The information gathered should include any data relevant to the movement of seabed sediments. Data that is gathered for geophysical surveys will not only help to categorise important sea bed life for the proposed area but also aid the information gathered from the geotechnical surveys; this will be done during the beginning of the design and planning process. Charts and maps of the proposed area will be produced from the collected information that will in turn also help with the design stage of the project in terms of foundation and site layouts. A thorough survey can reveal non-activated marine weaponry such as mines that could prove hazardous during the construction process. Marine archaeology could be discovered, which would have to be dealt with by a specialist archaeologist that will be provided by the consultancy in charge of the survey.

6.2.9. Geophysical Survey Vessels

Specialized marine vessels will be utilized to perform the needed tasks of the geophysical survey. These vessels, like the ones stated in previous surveys, must have a stable platforms that can maintain stability during rough sea weather. The crew of these vessels must come from a variety of specialized backgrounds specifically designated for the operation of the equipment on the ships. Most of the sea in the Bahamas is relatively close to islands so there will be no need of staying offshore for long periods of time so no cabins are necessary. In order to establish efficient functional data collection it is recommended that a crew rotational scheme is added to the surveying operation.

Figure 44 - Example of Geophysical surveying vessel (Tesla Offshore, 2014/)

6.2.10. Geotechnical survey

Soil strata data of the site has to be collected in order to fully analyse the sea floor features. This survey takes place after the geophysical survey as it uses data collected to target any recent changes in the sea floor. The types of equipment used in this survey will be specialized and the individuals involved will need experience with the equipment so that the operation can go through successfully.

The goal of the survey is dependent on the type of wind turbine foundation that will be used and the varying characteristics of the seabed. The type of tests that will be done for this type of survey are:

- Borehole test that drills from 50m to 70m depending on the size of the turbines
- Cone penetration tests that investigates the sea bed’s physical characteristics

The data that is collected from these tests along with the information gained from the geophysical survey will be analysed in a laboratory to aid the development of a geological model of the area. This test will be used for the design of the turbine’s foundation as well as for the acquisition of information needed for the consenting of the project.

6.2.11. Geotechnical Survey Vessels

As stated previously this survey will require vessels that are specialized for the task. The type of marine vehicles used in this will be large enough to have the following equipment:

- Drilling rigs
- Cranes
- Possible offshore laboratories if the analysis takes place over a long period of time

The vessel must have the ability to position itself in a specific position in order to create borehole samples during a multitude of possible weather conditions. The individuals on this ship must be able to operate the requested machinery for the specific purpose of data collection. Usually these ships are used for situations that involve long periods of time being offshore but due to the distance between islands in the Bahamas this won’t be necessary.

6.2.12. Human Impact Study

The assessment of the impact that the project will have on the local community living on the coastal areas have to be surveyed. This assessment will take into account human impact factors such as visual and noise implications of the offshore wind farm. Also it will analyse the socio-economic impact that the wind farm will have on ports and ocean navigation.

Visual assessments of the prospective wind farm will include using photomontages from a variety of viewpoints that will give the public an idea of wind farm’s design.

Along with the visual assessment there will be a noise assessment that will analyse the potential noise impact that the wind farm will have on the community. This will involve using a set of machinery noise tolerance guidelines and coming to a conclusion of whether or not it will affect the lives of the Bahamians nearby.

One of the most important aspects of this study is to find out the impact that this will have on the socio-economics of the community nearby. This will take into account whether or not the offshore wind farm will affect the following factors:

- Employment rates of nearby ports
- Transportation rates of nearby docks and associated ports
- Aesthetic value of nearby lands that may be changed

A socio-economic study will gather a mix of subjective and objective information. The subjective information is created through surveys and designated observations, while the object information is found from general statistics of the local population such as age, sex, average income, ethnicity, mortality, education, and housing types. Both types of information will be used to produce systematic estimations of the level the local community will react to their socio-economic environment and the resultant impact of the change of environment.

The impact on the local society will not purely be measured on the socio-economics but also the bio-geophysical effects that the offshore wind farm can cause on the coastal area.

6.3. Grid connection

The electricity output of a large wind farm requires that the transmission system is adjusted to the settings of the Bahamas' grid. Knowledgeable operators and proper development plans can result in a successful grid connection but in order to do this there are some general technical facts that must be known before the design plans can take place. The objective of grid connections is to create steady state power production in a safe environment, which would continue to maintain its reliable environment even during fault scenarios. This part of the paper will discuss the general guidelines needed in an efficient grid connection for a large offshore wind farm in the Bahamas for both AC and DC outputs.

6.3.1. National Grid Code Requirements

Other than the requirements for overloading there are also a set of additional specifications that are accustomed for connection to the Point of Common Coupling, which are set in the country's national grid codes that in result are a combination of dynamic and steady state reactions during and after a fault scenario (Wensky, 2006).

Despite the small variety in the infrastructure of national grid codes the main goal of all of them is to maintain support from an adjacent power generation system. One of the main standardizations of most national grids is that the electricity produced from the energy system must be cohesive with the voltage levels of the main grid. This precondition is due to the grid's intention of maintaining stability and also to reduce the amount of dynamic voltage deviations that may occur. In most cases the variation of stability that wind farms are known to exhibit have been allowed to proceed but that doesn't mean that there aren't techniques and equipment available to reduce such voltage alterations.

The energy market of the past has shown that the implementation of small wind farms do help to provide extra power to needed areas, but with the development of much larger farms the potential electricity production has increased. The level of energy generated from larger farms means that there is more dependency on the electricity output and in result there is a higher demand for voltage level stability. If a fault is said to happen the dysfunctional component will be disengaged, which means that if it is a feeder connected to a wind turbine the turbine in result will disconnect. In situations where the faulty component is not connected directly to a turbine; the desired function would be for it to continue production so once the faulty connection is resolved the overall operation shall resume. If there is a prolonged period of disconnection it will usually result with a system shutdown.

It is a requirement that consistent operation of a wind farm continues even during situations that require the voltage to be disconnected for maintenance purposes. In order to achieve this there has to be management of the reactive power produced by the system. Synchronous generators have the operational capacity to achieve such controls via the exciter system (Wensky, 2006). Static Var Compensators (SVC) or High Voltage Direct Current transmission systems (HVDC) could be placed at the connection point between the wind farm feeder and the national grid that would operate as a central exciter that would control the reactive power even during inactive power generation.

The distribution system that an offshore wind farm is connected to is the component that delivers power to the distribution company's customers through the main grid. These sort of systems are designed with low tolerances of volatile voltage levels. Due to the variation of wind speeds; the usual techniques for compensating voltage level changes through usage of reactive power compensation will result in expensive components. The use of an SVC for a wind farm scenario can be chosen as a cost efficient option for several smaller components.

The use of a HVDC or SVC can also be used to mitigate such phenomena that are connected with the wind speed variability. The changes of wind speeds can create a situation of which the power generated is produced in intervals of stopping and starting. An active device like the SVD or HVDC can control these effects.

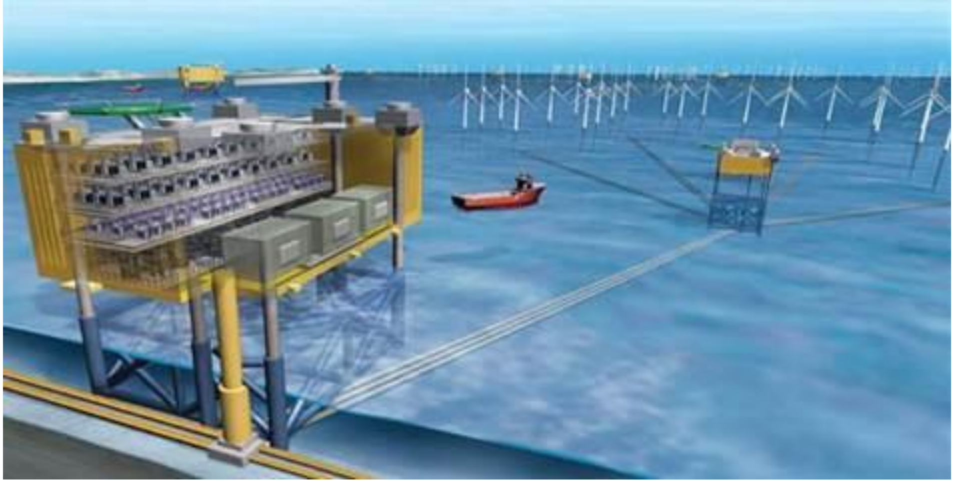


Figure 45 - Example of Grid Connection Configuration (Roberts, 2011)

6.3.2. DC Requirements & Solutions

DC transmission is one method in which the energy generated from the wind turbines can be transferred to the national grid. Newer high voltage direct current transmission systems can be utilized for systems that have cables that cover a long distance to and from the wind farm.

The transmission system is based off of voltage source converter technology, which has the ability to control the valves and in result the current, these type of systems are self-commutated meaning that they can convert DC to AC via components that can be activated or deactivated at the user's or system's request.

High converting frequency technology such as insulated-gate bipolar transistors is also auspicious when coupled with pulse width modulation equipment. The rapid switching causes the two fixed voltages to produce AC voltage levels. "*The desired fundamental frequency voltage is created through low pass filtering of the high frequency pulse modulated voltage*" (Wensky, 2006).

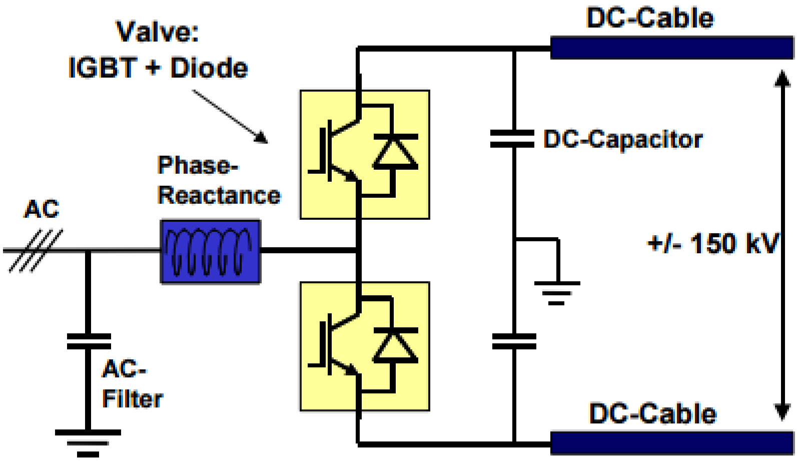


Figure 46 - Voltage Source Converter Diagram (Wensky, 2006)

The pulse width modulators can create an array of phase angles by changing the modulator's pattern, which is an instant process. The use of the two separate controlled factors can be regulated with active and reactive power control loops. In order to achieve fast independent control of the active and reactive power flows; the communication between the two converter stations is limited. This creates voltage, power, and current characteristics shown in figure 47.

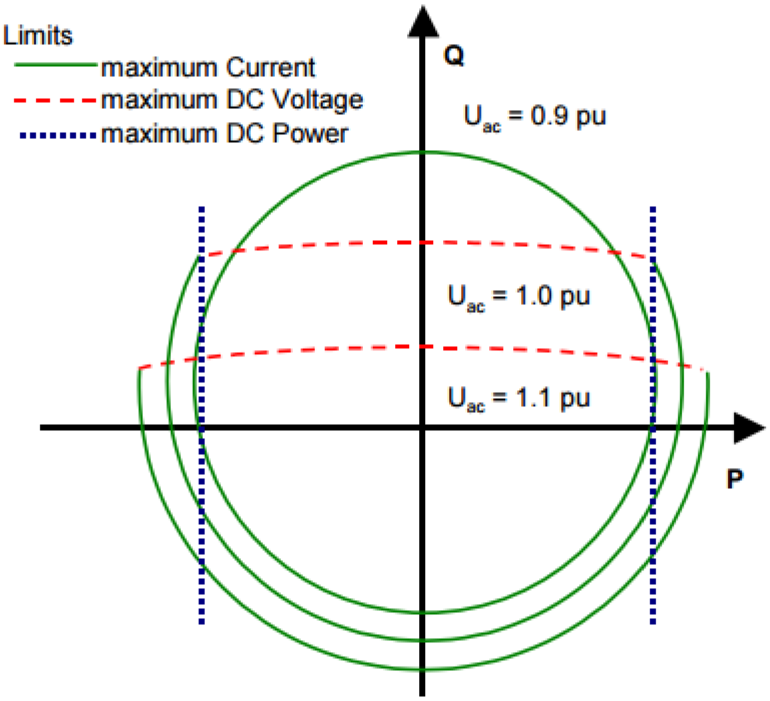


Figure 47 - DC Voltage, Current, Power Characteristics of a Voltage Surge Converter (Wensky, 2006)

One of the components that determine the state of a HVDC transmission is the maximum current going through the insulated-gate bipolar transistors, which leads to a peak MVA within the power plane. This is when the peak current and AC voltage are aggregated. The MVA levels are dependent on the AC voltage, if the voltage increases so will the MVA and vice versa. The second factor is dependent upon the level of the DC voltage. Reactive power depends on the different voltage levels for the AC. This is produced by the voltage server converters by the grid. Depending on the level of the grid's AC voltage the difference between the DC voltage and AC voltage levels will vary, if the AC voltage levels are high then the difference will be low and vice versa. Reactive power will increase if the AC voltage is decreasing; if there are low voltage levels then the system will need reactive power. The final limiting factor is the peak direct current flowing through the cable.

A voltage surge converter transmission (VSC) system can function at a variety of frequencies acting as a rectifier or inverter while simultaneously absorbing or supplying reactive power to the alternating current system. This in a sense means that the VSC transmission system can provide a similar role to that of a generator or a zero-inertia motor allowing the system to manage active and reactive power on demand. An AC filter will need to be installed to be used as a reactive power compensation support. The generation of reactive power and the consumption of a high voltage direct current transmission system can be used to compensate the requirements of the connected system, while staying within the rating levels that a converter would have. Converter rating levels depends on the maximum voltage and current, also any reactive power capacities can be alternated against the capacity of the active power.

In an offshore windfarm the HVDC transmission system can be used to transmit AC voltage to non-activated areas during system electrification while also gathering power from the turbine, and simultaneously taking or supplying reactive power to and from the wind turbine generators. The frequency of the transmission system can change, which can create a higher efficiency in terms of power output from the offshore wind farm.

An isolated wind farm that has a VSC transmission system gathers the active power created by the wind turbines and transfers it to the VSC system in the receiving network via a DC cable (Wensky, 2006). The VSC system manages the DC voltage by infusing the received DC power into the AC network. The AC voltage can be controlled onshore to a pre-defined power factor established by the Bahamas' national grid code by the HVDC reactive power controller, without negatively changing the active power management. The use of a VSC transmission system can create an advantageous condition that is due to the increased active and reactive power control speed, which is because of the VSC system frequency and AC voltage control.

The VSC transmission system can allow for power reversal due to the system's ability to change DC current direction without affecting the DC polarity. The use of a cross-linked polyethylene cable has the ability to sustain current reversals. It is advised that if there are any limitations in the peak power alternation limits these should be noted (Wensky, 2006).

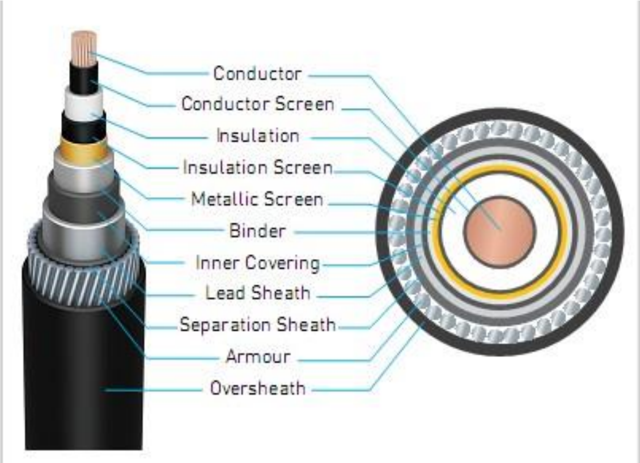


Figure 48 - XLPE Cable Configuration Illustration (tradeKorea, 2015)

The HVDC transmission system is an asynchronous system link, which has the ability to disconnect the power system from the fluctuations created from the wind power generation. This can work with the onshore inverters that supply reactive power support to the AC system that is on the receiving end.

One of the dynamic properties of a VSC transmission system is that it can be applied to projects that produce a large amount of wind energy to the main networks; this can be done without upgrading the short circuit power at the connection points. Even during black networks the VSC has the ability to support the offshore wind farm and grid with active and reactive power during such high afflicted scenarios.

Using a DC link to the wind farm it will isolate the farm from the AC network which means that the farm's voltage is not influenced by any alternating voltages that the AC network may produce from switching actions and unpredicted system faults. The quick system response for AC voltage control means that the AC bus voltage may maintain system stability during transitions and unpronounced system changes. Any flicker effects and other faults that may be in the AC network, during situations when it has low voltage levels, cannot be transmitted into the AC system network. Any active power that is created via the wind turbine generators can be temporarily stored in the turbine's generators by increasing the rotor speed. Once the fault has been fixed the stored wind power can then be transferred to the AC system network and the normal rotor speeds can continue. Frequency management is not limited by boiler dynamics during grid reclamation as it would in a standard power plant; the HVDC transmission system can quickly recover after an unexpected fault. If there are any non-balanced grid conditions, power quality problems, or harmonic issues the voltage surge converter can positively influence the outcome of each of the previously stated issues to a degree, if handled knowledgeably. Constant operation will continue in an event that causes the turbine generators to fail until they are restarted and normal operation can continue.

The major financial costs of offshore installation are due to space and weight. The use of any HVDC transmission systems can be an advantage as the converters and filters are generally small and the overall system can be designed compact.

6.3.3. AC Requirements & Solutions

One of the issues associated with a collaborative network of sea cables is that there will be a higher need of reactive power management. The main goal of reactive power control is that it takes into account the sea cables and wind farm collectively, which would provide the demand associated with the regulation for reactive power.

Any limitations that are due to the sea cables' capacity should be noted with added allowance, which would allow the charging current to flow through the cables at maximum load.

The use of a static var compensator (SVC) could be used as a source for reactive power, which would bring a set of advantages. One being that the device would help to supply reactive power throughout the entire wind farm depending on the size. Any voltage that is present at the connecting points would be stable due to influence from the voltage controller. Another advantage is that the amount of flicker created from variations of wind speed and tower shadow effects will be reduced. The basic layout for such a system is shown in figure 49 provided from research papers by Dorman Wensky at ABB AG.

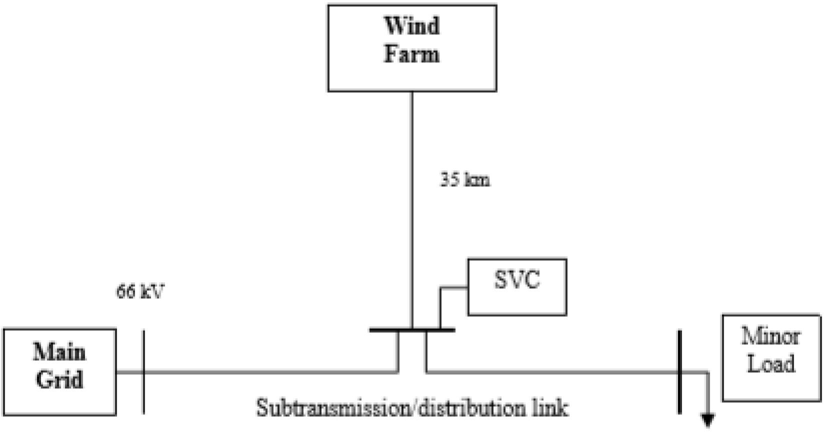


Figure 49 - Generic Block Diagram of Grid Connection with SVC (Wensky, 2006)

The constant initiating and halting of a system can create a series of errors and wearing of a power generating system. Usage of an induction machine has the capacity to draw an ample amount of reactive currents once a stator is electrified, which would happen even if the turbine begins to rotate at synchronous speed before grid connection. This creates a resultant decrease in voltage.

When using SVCs to improve recovery rates from network faults the induction generators will be quickly magnetized when the voltage is brought back after a network issue. If there is a factor that for some reason causes a delay in the magnetization speed the generator will increase speed levels, which will cause a reduction of the slip levels that would create difficulties when it is needed to be close to zero. In situations such as these the mechanical turbine blade angle control system must be used to reduce the speed. The longer that this error is not dealt with will shorten the time constraints eventually causing the wind turbine's generator to require a restart so that normal power generation operation can resume. To compensate for any fault or weakness in the electrical network there will need to be reactive power support to improve the behaviour of the offshore wind farm.

There are two types of SVCs available in the present market. The first type's design is based off of standard capacitor banks that are linked parallel to thyristor managed inductive branches that are able to gather any extra reactive power that is produced from the capacitor bank. Components such as these can be connected directly to an intermediate voltage bus that will be annexed to the wind generators up to limits of 36 kV. A more expensive approach is to utilize a dedicated transformer to adjoin the SVC to the network. The second type of design uses the power electronic voltage source or voltage surge converter (VSC), which uses semiconductors that have the ability to switch off. The purpose of the converter is to collect or transfer reactive power to or from the voltage bus. "*This application of VSC technology is usually referred to as STATCOM (Static Compensator)* (Wenksy, 2006). The advantage of this type of converter is that there will be less space used as the larger air-cored inductors will not be a part of the design, and also the small size of the parallel capacitor bank has the capacity to be utilised as a converter, which can also provide reactive power to the system. If used simultaneously the two design types can result in a cost-efficient dynamic compensator being created that would be useful for short timed high dynamic yields and steady-state operation that would create a low yield for the system.

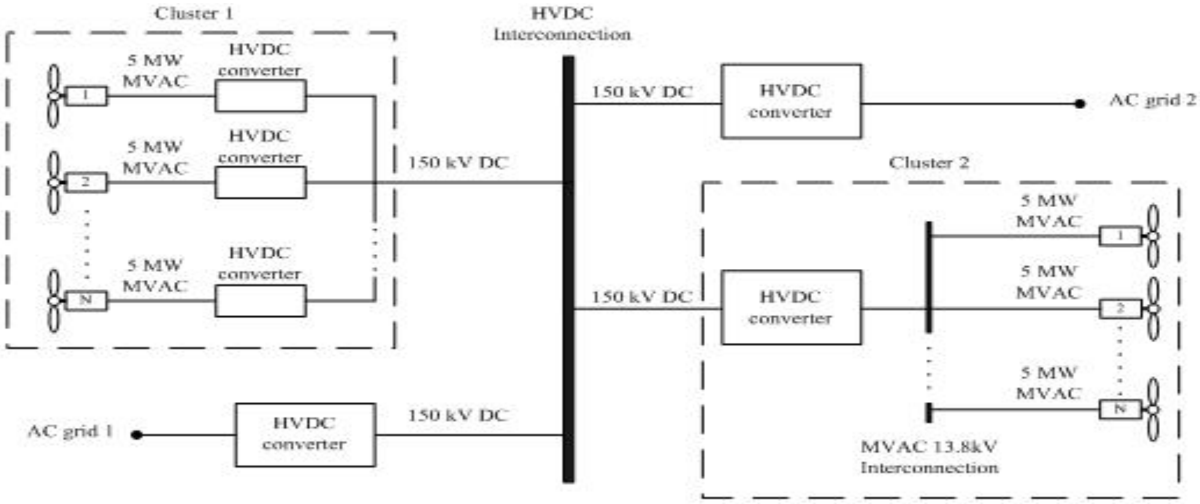


Figure 50 - HVDC Interconnected System Scheme (Ludois, 2010)

6.3.4. Summation

This section of the project was used to layout the technical issues of general grid connection and provide possible solutions through information gathered through cited research. In the Bahamas the national grid is based off of US technical design. The information here is to be utilised by professional engineers who understand the importance of undertaking and understanding research of the grid code in the Bahamas before using such data as reference. The information gives basic guidelines for AC and DC requirements for an offshore wind farm's grid connection. The technical suggestions here are taken from industry cited research but due to the time frame of this project all of the possible techniques used in offshore grid connection were not explored.

6.4. Ocean Navigation Mitigation

The purpose of this section of the thesis is to state the importance of ocean navigation mitigation in the Bahamas; with regards to proposing an offshore wind farm project through stating the economic importance of the commercial fishing industry. Also this section will utilise researched data and information to produce a general guideline that should be taken into account before mitigation methods are planned.

6.4.1. Overall Fishery Sector

The main areas of the Bahamas that contribute to the commercial fishing industries are the Great Bahamas Bank and also Little Bahama Bank, which are shown in figure 51. There are other areas that contribute to the active fishing industry of the Bahamas but these two sites support the largest diversity of species.

Figure 51 - Detailed Map of The Bahamas (www.maps.com, 1997)

The type of fish that are the most popular to catch are the following:

- Spiny Lobster (Panulirus argus)
- Snapper
- Queen Conch (Strombus gigas)
- Nassau Grouper (Epinephelus striatus)
- Jack

According to data presented by the Food & Agriculture Organization of the United Nations the live weight of spiny lobsters caught in 2007 was 6,977 tonnes. Around 99% of the lobsters brought to land were in the forms of tails. Also around 84% of the totals landed weight of caught marine sea creatures were spiny lobsters.

Areas that are used as landing sites are placed through the Bahamas. The most prominent sites are New Providence, Abaco, Grand Bahama, Long Island and Eleuthera. Although there are other sites that facilitate full time fisheries, small vessels, and boats the sites previously stated house the majority of them.

The Bahamas has 9,500 (+) full time fisheries, over 4,000 small vessels and boats that participate in the fishing industry. The majority of these boats fish for spiny lobster as they bring in the highest revenue.

The size range for commercial fishing vessels can range from 3.35 meters to 30.5 meters, which usually has a main ship that coordinates the other smaller vessels. There are some vessels that have the capacity to stay out to sea for up to 5 weeks in order land up to 18,000kg of fish and 9,000kg of lobster tails; most of the lobsters caught are landed in tail form. The processing of the lobsters are done at sea, which the rest of the lobster are discarded or used for the further baiting purposes. The main types of gear that are used for fishing are spears, lobster hooks, compressors, lobster traps, fish traps, and casitas.

Abundance and price play a large part for what is caught in the commercial fishing industry. This is the main reason why the spiny lobster is often the main target of most fisheries in the Bahamas. Out of the $80 million made in 2007 around $70 million was from lobsters. The second most valuable forms of landed product is the queen conch (See Table 10).

Table 10 - Landings of Commercial Fisheries 2007 (F&AOUN, 2009)

Resource	**Live Weight (tonnes)**	**Value (USD)**
Spiny Lobster	6,976.74	70,366,282
Snappers	568.56	2,848,370
Queen Conch	378.98	3,051,282
Nassau Grouper	157.44	1,592,827
Jacks	83.50	619,452
Other Grouper	59.01	401,214
Grunts	39.25	102,967
Stone Crabs	30.97	582,527
Grouper Fillet	6.67	64,3374
Turtle (loghd)	1.07	3,880
Other	28.62	114,235
Total	**8,330.81**	**79,747,410**

In order to efficiently manage the fisheries the government of the Bahamas has established defined economic zones that are allowed to be only used by Bahamian nationals. This means that in order to establish a commercial fishing company or vessel it has to be owned by a Bahamian if it wishes to be used in the Bahamas. The allocation of foreign investment is allowed within the processing sector and aquaculture of the fishing industry, but the actual company has to have some percentage of Bahamian ownership, or the Bahamian National Economic Council must preapprove it before it can create revenue.

6.4.2. Mitigation Guidelines

The guidelines created in this section were done some using general guidelines created by COWRIE Ltd and applying them to an offshore wind farm project effort in the Bahamas. The guidelines created are not to be used as definitive rules but instead to be considered as the foundation guidelines set for projects of this type. Depending on the developer or designer involved in the project their expertise can be used to add to the information written in this thesis.

The basic type of mitigation efforts created are:

1. Time dedicated for pre-construction and mid-planning options to reduce any possible impacts on commercial fisheries.

   To make sure that the impacts caused on the fishing industry are minimized there are a number pre-research techniques that can be implemented in the planning stage. These can include (but are not limited to) taking into account substrate type, water depths, grid connection availability, and interests of nature conservation, visual impacts and shipping routes. In order to further reduce the impacts caused by the construction efforts of an offshore wind farm in the Bahamas is best to keep in consultation with the government, local commercial fisheries, and developers.

2. Allocate resources to enhance stocks of species and habitats in the designated area.

   One way of maintaining the vitality of the fishing industry is to take an inventory of the fish stocks of the prospective area. Once this is done the next step would be to promote the activity of fishing within the wind farm site by stating through researched facts that the site will allow the existing marine life to continue to flourish upon completion.

3. Allocate resources to support existing fishing activities in the prospective site.

   Other than the amount of fish to catch and the area in which they reside; there are several other important factors that are a part of the fishing industry. These include the cost associated with fishing operations, the amount of ground available in which to fish, and the value of the landed fish. The company involved in the wind farm project should make it a project goal to increase performance, enhance access, reduce costs, and increase marketability or product price.

4. Reserve time and funds to help develop new fisheries and other non-fishery opportunities for the companies involved.

If the fishing grounds of a particular fishing company is lost this will likely result in a loss of income for the fishermen involved. This is especially true for the smaller businesses that use inshore vessels that have a variety of restraints that the larger vessels do not have. In scenarios such as these there might not be an alternative ground available so a transfer to a new fishery ground could be plausible. There might be less financial benefit to the businesses and locals who are influenced by the efforts of the fisheries, so a switch in activities that require experienced seamen could be also an option.

6.5. Challenges

There are a variety of challenges that will accompany a construction of an offshore wind farm in the Bahamas, other than the need for environmental impact assessment, and appropriate planning. These challenges have been found as the following:

1. Law & Regulation Legislation

The types of laws that govern and guide the standards for preparation of an offshore wind farm are absent in the Bahamas. The best way to overcome this is through constant communication with the government, particularly the Ministry of Agriculture, Marine Resources and Local Government.

2. Guidelines & Policies

There are EIA guidelines for particular sectors of nature but there is not a dedicated EIA guideline for the construction of an offshore wind farm. There are academic references, such as this thesis, that utilise researched information to create a collective document but other than that there is no government approved body of work that can be used as a guideline.

3. Institutions

Although there is not a government institution that is responsible for the production of EIA guidelines, environmental planning or protection; there are subsidy companies such as The Bahamas Environment Science & Technology Commission that are responsible for coordinating such plans upon request.

4. Institutional Financial Resources

Due to the lack of government incentive there are little funds allocated for offshore wind farm projects. This would mean that it would be difficult for the government to participate in training staff and that would solely be the responsibility of the company invested in the project. This can be stated until the company involves the government of the Bahamas in some way, which could result in the allocation of funds for certain areas of the project.

5. Human Resource Management

There is a shortfall of staff members in certain government areas of the Bahamas, which can result in certain legislations and procedures taking longer to complete.

6. Services For The Family Islands

Environmental management services that can include nature monitoring, data collection, and enforcement are only seen to be focused on the capital island of New Providence. This can prove to be an issue if the project wishes to extend farms nearer to the other family islands. A solution to this challenge would be to involve the government in any extension proposals so needed information can be researched.

7. Information Management

There isn't a system set up in the government sector that allows the procurement of information between institutions. This then leads to slow information processing. The majority of the information that is collected for governmental purposes are gained from the Internet as there is no institutional libraries that have a collection of the needed information.

8. Compliance & Enforcement

There seems to be lack of incentive in the staff as in result some of the requirements that are set by international standard have not been set up. The lack of trained field officers in the needed areas of investigation and enforcement means that if there is an issue or fault in the internal system; there is no one to find the issue and in result acknowledge the solution; this can be coupled with the lack of needed hardware that would be used by such investigators.

7. Feasibility Study

This section will help to support the plausibility of an offshore wind farm in the Bahamas with the use of supporting research in a similar environment (Canary Islands, Spain), and also through the data found from a sensitivity analysis performed using information from RETScreen. This sensitivity analysis helped to identify the types of conditions that should be met in order to establish a successful project in the Bahamas.

7.1. Financial & Risk Assessment Methodology (Sensitivity Analysis)

RETScreen Software is a free program created by the Government of Canada in order to acknowledge the potential effects of climate change. The purpose of RETScreen is to identify potential energy projects and calculate the estimated costs of the desired project. The power output, development costs, and engineering costs are all includes in the software.

The wind energy model of RETScreen was used for this project, which includes an energy model, equipment data, cost analysis, financial summary. There are other options available such as the greenhouse gases analysis sheet but due to the time constraints of this project these were not used for this thesis. The sensitivity worksheet was mainly used in order to give insight into the financial parameters that affect the lifespan of the project and also the amount of energy produced from the farm. One of the substantial limitations of this model is that wind energy projects that include energy storage cannot be analysed (CANMET Energy Technology, 2004).

Unadjusted energy production of the wind turbines were analysed as a part of the sensitivity analysis. These calculations are derived from energy production curves of each wind turbine and on the average wind velocity at the hub height of the selected farm site.

Wind velocity distribution is an important factor in the calculations involved with wind energy engineering. The advantage of the values is the mean wind speeds for a variety of sites can be observed for the long-term. The use of the Rayleigh wind speed distribution is used in some cases as it is a special form of the Weibull distribution; this is usually used in cases where the shape factor is equal to 2 (CANMET Energy Technology, 2004).

The following formulae is the Weibull probability density function that expresses the probability ‘ρ (χ)’, which ‘χ’ is the annual wind speed:

I. $$\rho(\chi) = \left(\frac{k}{C}\right)\left(\frac{\chi}{C}\right)^{k-1} \exp(-(\frac{\chi}{C})^{k})$$

This formulae is used when $k > 1, \chi \geq 0,$ and $C > 0$. The denotation ‘k’ is the shape factor that is designated by the user. The typical range for the shape factor is from 1-3. A low shape factor means that there is a wide wind speed distribution for the average wind speed, while a higher shape factor means that there is narrow wind speed distribution. The lower the shape factor the higher the energy production will be for the average wind velocity. The shape factor is denominated by ‘C’, which is shown by the following formulae (CANMET Energy Technology, 2004):

II. $$C = \frac{\bar{X}}{\Gamma(1+\frac{1}{k})}$$

, where ‘Γ’ represents the gamma function and ‘$\bar{X}$’ is the average wind speed.

Certain scenarios require that the wind power density at the site be used to calculate the wind speed distribution. The wind power density, ‘WPD’, and wind speed, ‘$\bar{v}$’, are related through the following formulae:

III. $$WPD = \sum_{x=0}^{x=25} 0.5\, \rho\, x^{3}\, p(x)$$

IV. $$\bar{v} = \sum_{x=0}^{x=25} x\, p(x)$$

, where ‘ρ’ is the density of air and ‘$p(x)$’ is the annual wind speed probability, ‘x’.

The use of the energy curve data tool in RETScreen is an essential part of the feasibility analysis. In RETScreen it is possible to calculate the power production at incremental points of 1m/s over the range of 0m/s to 25m/s of the annual average wind speed. The calculation utilizes the wind probability density function shown in formulae ‘**I**’, where each point is presented by ‘$E_{\bar{v}}$’ and is calculated by the following equation:

V. $$E_{\bar{v}} = 8760 \sum_{x=0}^{x=25} P_{x}\, p(x)$$

, where the mean wind speed,'$\bar{v}$', considers ($\bar{v} = 3m/s, 4m/s, 5m/s, \ldots, 15m/s$); the turbine power at the wind speed 'x' is represented by 'P_x'.

Another calculation included in the feasibility analysis utilised the unadjusted energy production, which is the energy generated by the turbines during standard temperature and atmospheric pressure conditions. This calculation uses the average wind speed at hub height for the site, which is usually higher than the wind speed measured at anemometer height. The following power law equation is used to calculate the average wind speed at hub height (CANMET Energy Technology, 2004):

VI. $$\frac{\bar{V}}{\bar{V}_0} = (\frac{H}{H_0})^a$$

, where the average wind speed at hub height is '$\bar{V}$' and the hub height is represented by 'H'. The wind speed at anemometer height is '$\bar{V}_0$' with the anemometer height being 'H_0' and 'a'represents the wind shear exponent. The user chooses all of these values except for the average speed at hub height.

The unadjusted energy production 'E_U' is calculated by interpolating the energy curve for each of the annual average wind speeds at hub height.

Gross energy production represents the total annual energy generated by the wind farm equipment, at the wind speed, before any losses, at atmospheric pressure, and at the temperature conditions at the farm site. RETScreen utilizes this to find the renewable energy delivered from the system; the gross energy production is represented by 'E_G' and is found through the following formulae:

VII. $$E_G = E_U \, c_H \, c_T$$

, where 'c_H' and 'c_T' are the pressure and temperature adjustment coefficients and are calculated by:

VIII. $$c_H = \frac{P}{P_0}$$

IX. $$c_T = T_0/T$$

, where ‘T’ is the annual average absolute temperature at the farm site, and ‘T_0’ is the standard absolute temperature of 288.1 Kelvin. ‘P’ represents the annual average atmospheric pressure at the farm site, and ‘P_0’ is the standard atmospheric pressure of 101.3 kPa.

The renewable energy delivered to the electricity grid, with various losses added, are an important factor in the overall sensitivity analysis. RETScreen allows the calculations to take into account the amount of energy absorbed by the grid or the load. The total renewable energy gathered is equal to the net amount of energy generated by the wind farm as the following formulae demonstrates:

X. $E_C = E_G\, c_L$

, where ‘c_L’ is the losses coefficient and ‘E_G’ is the gross energy production. The losses coefficient is calculated with the following formulae:

XI. $c_L = (1 - \lambda_a)(1 - \lambda_{s\&i})(1 - \lambda_d)(1 - \lambda_m)$

, where ‘λ_m’ is the miscellaneous losses, ‘λ_d’ is the downtime losses, ‘$\lambda_{s\&i}$’ is the air foil soiling and icing losses, and ‘λ_a’ is the array losses.

Wind energy absorption rate is taken into account in the calculations performed in RETScreen. One of the formulae used in the calculation steps is the wind energy delivered, ‘E_D’, which is found as the following:

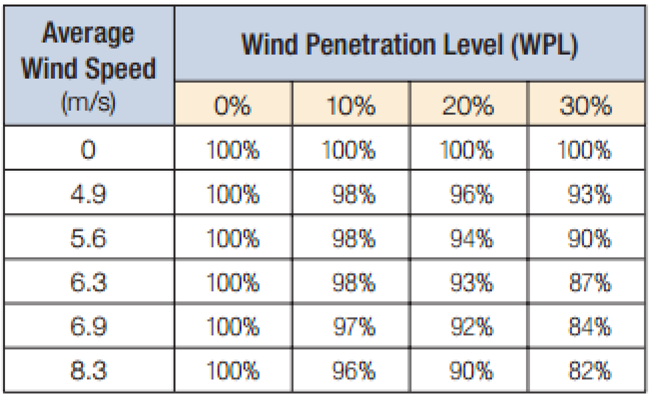
XII. $E_D = E_C\, \mu$

, where ‘μ’ is the wind energy absorption rate and ‘E_C’ is the renewable energy collected as shown in equation ‘**X**’.

To calculate the suggested wind energy absorption rate for isolated-grid and off-grid scenarios the following formula is used to calculate the wind penetration level, ‘WPL’, along with the interpolation of the values shown in figure 52:

XIII. $WPL = \left(\frac{WPC}{PL}\right) 100$

, where ‘PL’ represents the peak loads and ‘WPC’ is the wind plant capacity.



Average Wind Speed (m/s)	Wind Penetration Level (WPL)			
	0%	10%	20%	30%
0	100%	100%	100%	100%
4.9	100%	98%	96%	93%
5.6	100%	98%	94%	90%
6.3	100%	98%	93%	87%
6.9	100%	97%	92%	84%
8.3	100%	96%	90%	82%

Figure 52 - Wind Energy Absorption Rate for Isolated-Grid & Off-Grid Scenarios (CANMET Energy Technology, 2004)

The values in the previous figure shows the wind energy absorption rate varies according to the wind penetration level and average wind speed at the turbine hub height. Figure 52 shows the values that were calculated from simulations that were done to derive the amount of energy delivered from wind farms installed for isolated-grid and off-grid scenarios.

Excess renewable energy available is represented by 'E_X' and calculated from the difference between any wind energy collected, 'E_C' and any wind energy that is delivered, 'E_D':

XIV. $$E_X = E_C - E_D$$

Specific yield, which is represented by 'Y' is calculated by dividing the renewable energy collected, 'E_C', by the swept area of the turbines. The formulae is shown as the following:

XV. $$Y = \frac{E_C}{N * A}$$

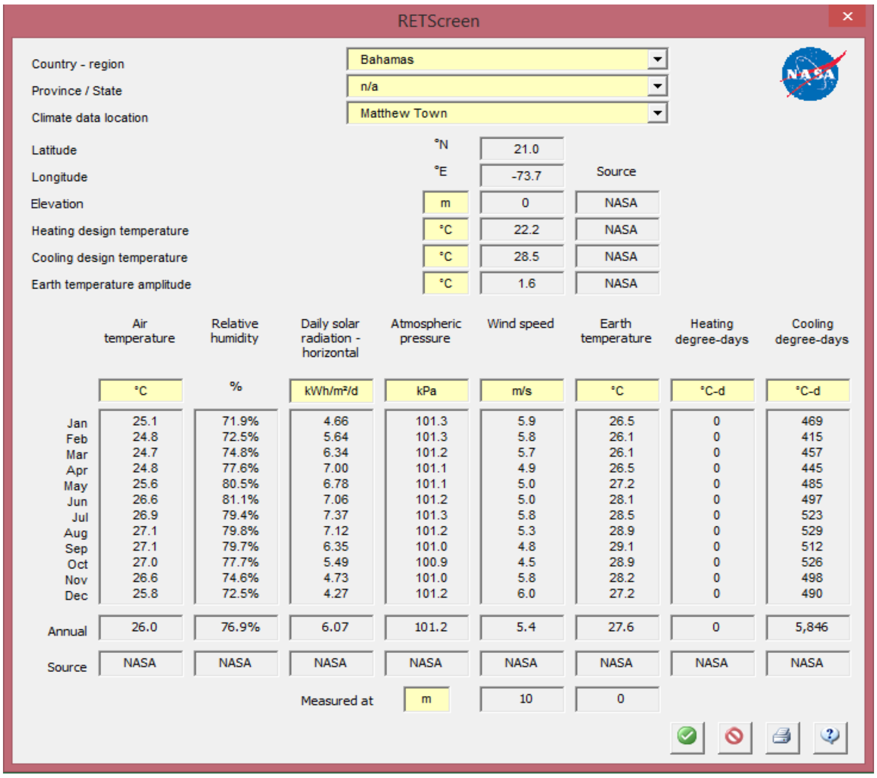
, where 'A' is the area that is swept by the rotor and 'N' is the number of turbines in the farm.

The last formulae that is included in the wind energy worksheet of RETScreen is the wind plant capacity factor that is represented by 'PCF', and is the ratio of the average amount of power produced by the plant over a year relative to its rated power capacity (CANMET Energy Technology, 2004). The formulae is the following:

XVI. $$PCF = \left(\frac{E_C}{WPC\ h_Y}\right) 100$$

, where 'h_Y' is the number of hours in a year.

To calculate the results needed for the sensitivity analysis a series of steps were done in RETScreen. The first state involved choosing the appropriate site from the given list in RETScreen (See Illustration 1).

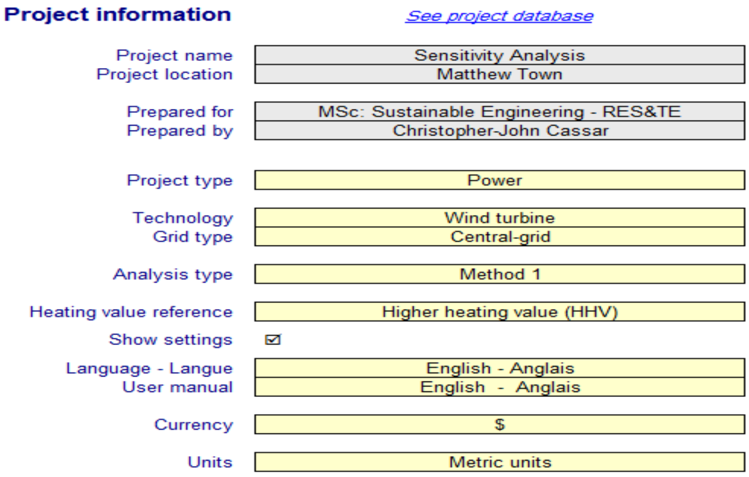


Country - region	Bahamas		
Province / State	n/a		
Climate data location	Matthew Town		
Latitude	°N	21.0	
Longitude	°E	-73.7	Source
Elevation	m	0	NASA
Heating design temperature	°C	22.2	NASA
Cooling design temperature	°C	28.5	NASA
Earth temperature amplitude	°C	1.6	NASA

	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
Jan	25.1	71.9%	4.66	101.3	5.9	26.5	0	469
Feb	24.8	72.5%	5.64	101.3	5.8	26.1	0	415
Mar	24.7	74.8%	6.34	101.2	5.7	26.1	0	457
Apr	24.8	77.6%	7.00	101.1	4.9	26.5	0	445
May	25.6	80.5%	6.78	101.1	5.0	27.2	0	485
Jun	26.6	81.1%	7.06	101.2	5.0	28.1	0	497
Jul	26.9	79.4%	7.37	101.3	5.8	28.5	0	523
Aug	27.1	79.8%	7.12	101.2	5.3	28.9	0	529
Sep	27.1	79.7%	6.35	101.0	4.8	29.1	0	512
Oct	27.0	77.7%	5.49	100.9	4.5	28.9	0	526
Nov	26.6	74.6%	4.73	101.0	5.8	28.2	0	498
Dec	25.8	72.5%	4.27	101.2	6.0	27.2	0	490
Annual	26.0	76.9%	6.07	101.2	5.4	27.6	0	5,846
Source	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA
			Measured at	m	10	0		

Illustration 1 - Selection of Site

The next was to select the project type and the type of technology used for the analysis. This was then followed by the selection of the grid type, currency of the analysis, and the type of units used (See Illustration 2).

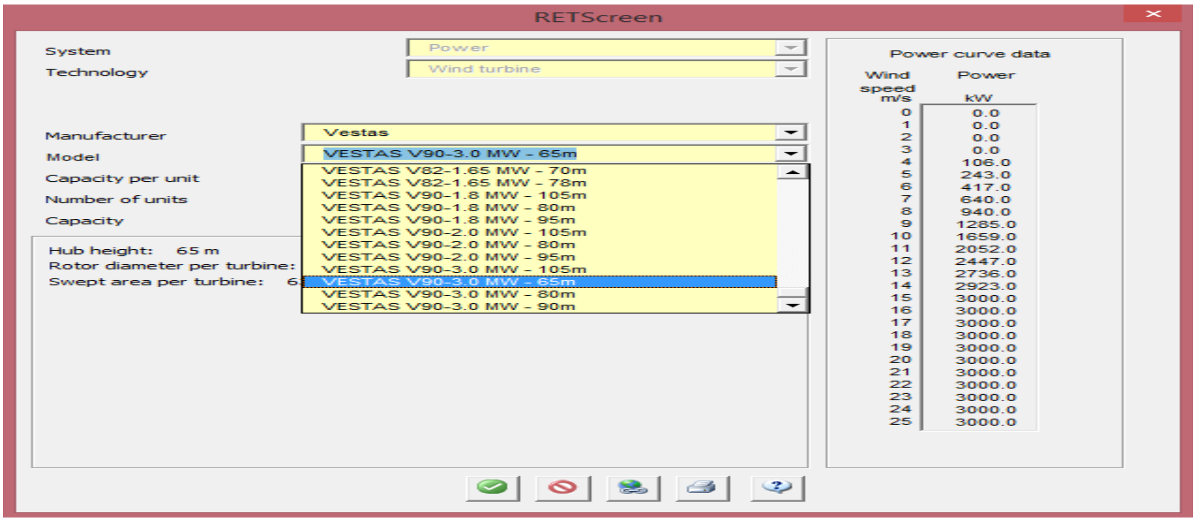


Project information

Project name	Sensitivity Analysis
Project location	Matthew Town
Prepared for	MSc: Sustainable Engineering - RES&TE
Prepared by	Christopher-John Cassar
Project type	Power
Technology	Wind turbine
Grid type	Central-grid
Analysis type	Method 1
Heating value reference	Higher heating value (HHV)
Show settings	☑
Language - Langue	English - Anglais
User manual	English - Anglais
Currency	$
Units	Metric units

Illustration 2 - Initial Information Input

After the initial information was inputted in RETScreen the next stage was to choose the type of wind turbine that would be utilized for the analysis. This meant going through all of the listed turbine types and choosing an appropriate sized wind turbine that would deliver the highest possible power output for the environmental wind resources that the Bahamas offered (See Illustration 3).



System Power
Technology Wind turbine
Manufacturer Vestas
Model VESTAS V90-3.0 MW - 65m
Capacity per unit
Number of units
Capacity
Hub height: 65 m
Rotor diameter per turbine:
Swept area per turbine: 6

Power curve data

Wind speed m/s	Power kW
0	0.0
1	0.0
2	0.0
3	0.0
4	106.0
5	243.0
6	417.0
7	640.0
8	940.0
9	1285.0
10	1659.0
11	2052.0
12	2447.0
13	2736.0
14	2923.0
15	3000.0
16	3000.0
17	3000.0
18	3000.0
19	3000.0
20	3000.0
21	3000.0
22	3000.0
23	3000.0
24	3000.0
25	3000.0

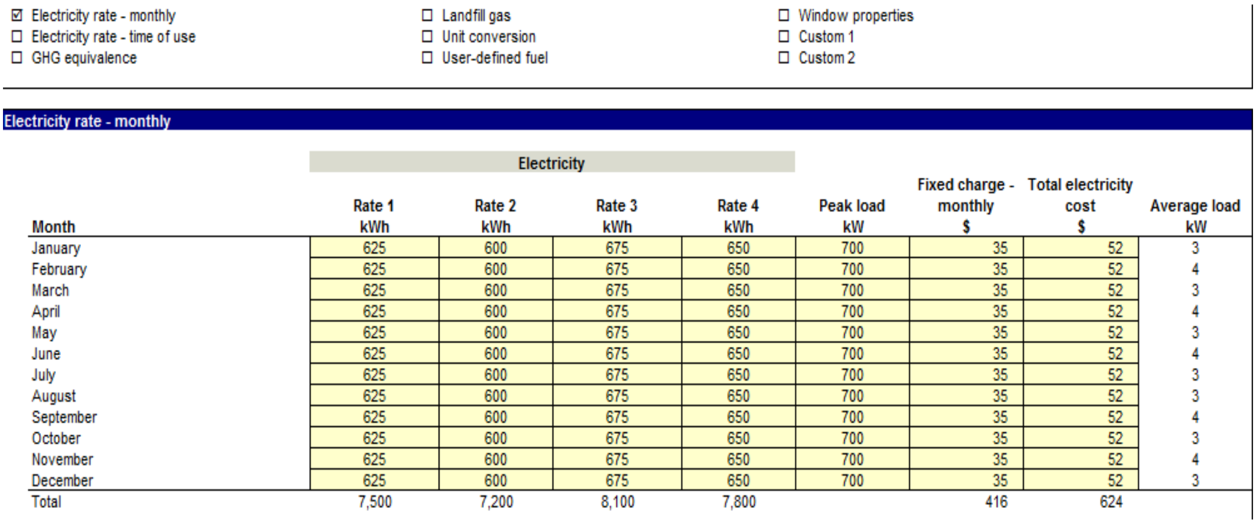
Illustration 3 - Choosing Turbine Type

After reading through a variety of turbine types by different manufacturers the model type that was chosen was a Vestas V90-3.0 MW – 65m (See Table 11).

Table 11 - Turbine Technical Details

Wind turbine			
Power capacity per turbine	kW	3000	
Manufacturer	Vestas		
Model	VESTAS V90-3.0 MW - 65m		
Number of turbines		15	
Power capacity	kW	45000	
Hub height	m	65	7.0 m/s
Rotor diameter per turbine	m	90	
Swept area per turbine	m²	6361.73	
Energy curve data		Standard	
Shape factor		2	

Finally before the actual sensitivity analysis would begin the last preparation step was to input the electricity demand for a typical household in the Bahamas (See Illustration 4).



☑ Electricity rate - monthly
☐ Electricity rate - time of use
☐ GHG equivalence
☐ Landfill gas
☐ Unit conversion
☐ User-defined fuel
☐ Window properties
☐ Custom 1
☐ Custom 2

Electricity rate - monthly

Month	Electricity Rate 1 kWh	Rate 2 kWh	Rate 3 kWh	Rate 4 kWh	Peak load kW	Fixed charge - monthly $	Total electricity cost $	Average load kW
January	625	600	675	650	700	35	52	3
February	625	600	675	650	700	35	52	4
March	625	600	675	650	700	35	52	3
April	625	600	675	650	700	35	52	4
May	625	600	675	650	700	35	52	3
June	625	600	675	650	700	35	52	4
July	625	600	675	650	700	35	52	3
August	625	600	675	650	700	35	52	3
September	625	600	675	650	700	35	52	4
October	625	600	675	650	700	35	52	3
November	625	600	675	650	700	35	52	4
December	625	600	675	650	700	35	52	3
Total	7,500	7,200	8,100	7,800		416	624	

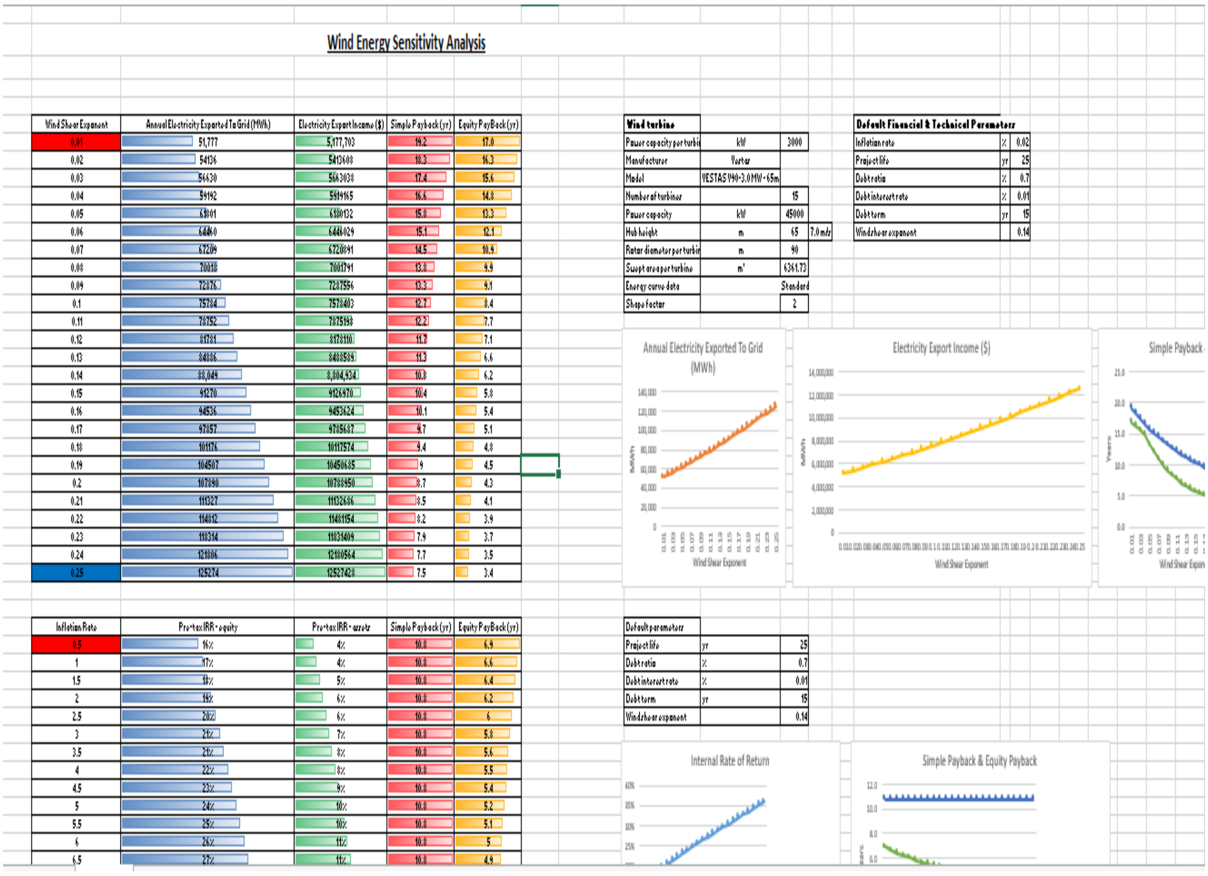
Illustration 4 - Monthly Electricity Rate Input

After the initial data input was completed the next step was to start the sensitivity analysis. This involved changing the parameters shown in table 12.

Table 12 - Financial & Technical Parameters

Default Financial & Technical Parameters		
Inflation rate	%	**0.02**
Project life	yr	**25**
Debt ratio	%	**0.7**
Debt interest rate	%	**0.01**
Debt term	yr	**15**
Wind shear exponent		**0.14**

The sensitivity analysis involved taking each of the parameters show in Table 12 and changing them in incremental amounts in order to identify changes throughout certain important financial and technical factors involved in an offshore wind farm project (See illustration 5).



Wind Energy Sensitivity Analysis

Wind Shear Exponent	Annual Electricity Exported To Grid (MWh)	Electricity Export Income ($)	Simple Payback (yr)	Equity PayBack (yr)
0.01	51,777	5,177,703	19.2	17.0
0.02	54136	5413608	18.3	16.3
0.03	56630	5663038	17.4	15.6
0.04	59192	5919165	16.6	14.8
0.05	61801	6180132	15.8	13.3
0.06	64460	6446029	15.1	12.1
0.07	67209	6720891	14.5	10.9
0.08	70018	7001791	13.8	9.9
0.09	72876	7287556	13.3	9.1
0.1	75784	7578403	12.7	8.4
0.11	78752	7875198	12.2	7.7
0.12	81781	8178110	11.7	7.1
0.13	84886	8488589	11.3	6.6
0.14	88,049	8,804,934	10.8	6.2
0.15	91270	9126970	10.4	5.8
0.16	94536	9453624	10.1	5.4
0.17	97857	9785687	9.7	5.1
0.18	101176	10117574	9.4	4.8
0.19	104507	10450685	9	4.5
0.2	107890	10788950	8.7	4.3
0.21	111327	11132686	8.5	4.1
0.22	114812	11481154	8.2	3.9
0.23	118314	11831409	7.9	3.7
0.24	121806	12180564	7.7	3.5
0.25	125274	12527428	7.5	3.4

Wind turbine			
Power capacity per turbi	kW	3000	
Manufacturer	Vestas		
Model	VESTAS V90-3.0MW - 65m		
Number of turbines		15	
Power capacity	kW	45000	
Hub height	m	65	7.0 m/s
Rotor diameter per turbin	m	90	
Swept area per turbine	m'	6361.73	
Energy curve data		Standard	
Shape factor		2	

Default Financial & Technical Parameters		
Inflation rate	%	0.02
Project life	yr	25
Debt ratio	%	0.7
Debt interest rate	%	0.01
Debt term	yr	15
Windshear exponent		0.14

Inflation Rate	Pre-tax IRR - equity	Pre-tax IRR - assets	Simple Payback (yr)	Equity PayBack (yr)
0.5	16%	4%	10.8	6.9
1	17%	4%	10.8	6.6
1.5	18%	5%	10.8	6.4
2	19%	6%	10.8	6.2
2.5	20%	6%	10.8	6
3	21%	7%	10.8	5.8
3.5	21%	8%	10.8	5.6
4	22%	8%	10.8	5.5
4.5	23%	9%	10.8	5.4
5	24%	10%	10.8	5.2
5.5	25%	10%	10.8	5.1
6	26%	11%	10.8	5
6.5	27%	11%	10.8	4.9

Default parameters		
Project life	yr	25
Debt ratio	%	0.7
Debt interest rate	%	0.01
Debt term	yr	15
Windshear exponent		0.14

Illustration 5 - Sensitivity Analysis Structure

7.2. Sensitivity Analysis Results

The full table and results of the sensitivity analysis can be viewed in the appendices section of this report. This section will explain the main finding of the sensitivity analysis.

The results shown in Table 13 show that under the default conditions of the chosen offshore wind turbine type the feasibility of an offshore wind farm of 15 turbines is possible. The equity payback found was 5.8 years with the Internal Rate of Return (IRR) equity at 20% and the assets at 6%.

Table 13 - Default Case Simulation Results

Default Case Scenario Results

Wind Shear Exponent	Inflation Rate	Project life	Debt ratio	Debt interest rate	Debt term	O&M (savings) costs
0.14	**0.02**	**25**	**0.7**	0.01	15	500000
Pre-tax IRR - equity	Pre-tax IRR - assets	Simple Payback (yr)	Equity PayBack (yr)			
20%	**6%**	**10.8**	**5.8**			

Table 14 shows the results for the best case results, which shows an equity payback period of 5 months. Of course this type of scenario is impossible in a real world scenario, due to some parameters being out of the developers' control, but the importance of this and the worst case scenario is to show the impact that the certain factors have on feasibility of such a project in the Bahamas.

Table 14 - Best Case Simulation Results

Best Case Scenario Results

Wind Shear Exponent	Inflation Rate	Project life	Debt ratio	Debt interest rate	Debt term	O&M (savings) costs
0.25	**12.5**	**50**	**0.95**	**0.005**	**25**	**350000**
Pre-tax IRR - equity	Pre-tax IRR - assets	Simple Payback (yr)	Equity PayBack (yr)			
240%	**26%**	**7.4**	**0.4**			

As stated before the worst case scenario shown in Table 15 shows that under harsh financial conditions and technical factors the payback period of the project would take up to 25 years. The use of these tables is to illustrate that in order to have a successful project in the Bahamas it relies not only on the present wind resources but also on the financial deal that the company that is investing in the Bahamas is able to arrange for the wind farm.

Worst Case
Scenario Results

Wind Shear Exponent	Inflation Rate	Project life	Debt ratio	Debt interest rate	Debt term	O&M (savings) costs
0.01	**0.5**	**5**	**5%**	**13%**	**5**	**1550000**
Pre-tax IRR - equity	Pre-tax IRR - assets	Simple Payback (yr)	Equity PayBack (yr)			
-43%	**-43%**	**24.8**	**> project**			

A brief technical analysis was done for the electrical load of the total amount of homes in the Bahamas, which was found to be around 88,000 collectively. This information is based off of the data simulation efforts of RETScreen and electricity information collected from a few personal contacts in the Bahamas. This information can be used as the basis of further research if need be. The full monthly electricity rate can be viewed in the appendices of this paper.

Table 15 - Electrical Load Data of Bahamian Homes

System peak electricity load over max monthly average		**18347%**
Peak load - annual	kW	**61419400**
Electricity	kWh	**2684905200**
Electricity difference	%	**3.27124183**
Electricity correction factor	h	
Electricity rate - base case	$/kWh	**0.020392157**

7.3. Comparable Wind Farm Study – Canary Islands

An environment with similar environmental sensitivity as the Bahamas is the Canary Islands near Spain. A study produced by the University of Las Palmas de Gran Canaria states there are areas that have the capacity to install a 324 MW farm that utilizes 90 m diameter blades (Martinez, 2009).

Another paper analysed the wind resource availability for the Canary Islands to come to a conclusion of which island is the most feasible. The information gathered utilised prevailing wind data that showed the main wind directions found were north and northeast. The months that were found to have the highest wind speeds were in summer months June and August. Las Palmas was found to have the highest mean wind speed compared to the other islands; the speeds found for Las Palmas were 7.19 m/s and 8.7 m/s (Hill, 2003).

The areas that do have onshore wind farms in the Canary Islands are often sparsely populated due to nearby noise pollution from airports and heavy local industries. The areas that were chosen did not have any nature regulations that could have stopped the construction process of the project. The advantages of these onshore systems are the well build roads and the established high voltage grid connection. The mountains of Gran Canaria intensify the wind velocity that that are projected onto the east coast of the island; the north winds are intensified from the coast that provide a natural funnelling for the wind path.

On the 21st of October 2013 the first offshore wind turbine was activated in Arinaga Quay in Gran Canary Island by Gamesa. The turbine is a 5 MW offshore platform wind turbine that has a rotor diameter of 129 meters couple with a height of 154 meters (Gamesa, 2013). The turbine has produced 1GWh from July 2013 to October 2013 that is deemed enough electricity to power up to 7,500 homes a year. The procedures needed for mass production has begun to take place.

8. Conclusion & Discussion

8.1. Conclusion

The purpose of this project was to determine the feasibility of an offshore wind farm in the Bahamas through academic research and also a sensitivity analysis that gave the basic value of such a project. One of the goals of the project was also to develop a series of project consenting guidelines that could be used as reference for the development of an offshore wind farm. The purpose of the sensitivity analysis was to produce data that could support the possibility of such a project in an environment as the Caribbean specifically the Bahamas.

Overall the project's goals were achieved as the project consenting guidelines were created for the Bahamas, and also the data proved that such a project is financially and technically possible. To make sure that the data was viable an analytical background check was done on the formulae used in RETScreen's wind data sheet, which is shown in the methodology. This gave an insight into the calculation that is involved within the technical aspect of the wind farm analysis. Information obtained from the sensitivity analysis was able to show that a wind farm of 15 wind turbines had an equity payback period of 5.8 years, which is seen as an adequate long-term investment. Such a project should start off with the researched amount of turbines and once the payback period is passed there could be the possibility of expansion, which at that point portions of the wind farm's annual income could allocate funds dedicated for such a reason. Although RETScreen does not have the capability to perform an analysis of a wind farm that includes an energy storage unit; the data suggests that the efficiency of the system would increase as it would allow the system to function as a dispatchable system.

8.2. Discussion

As stated previously the intention of the project was to perform a feasibility analysis that would address the lack of renewable energy awareness in the Bahamas despite it having such an abundance of resources. The Bahamas does have certain measures already in place that would allow certain environmental assessment procedures to go through. There is an evident lack of communication between the different sectors of government but once the appropriate investment makes itself known the information needed would be able to be procured.

Project consenting guidelines were created utilising a variety of reports and research reports for different countries. The creation of the guidelines was done by utilising a combination of environmental sensitivity information of the Bahamas and general offshore wind farm guidelines, to come to a dedicated set of guidelines that could be used for a pre-development process.

The wind resources in the Bahamas are enough for the operation of an offshore wind turbine, it was found that the average monthly wind speeds taken from a 10 meter height is 5.4 m/s. The minimum wind resource for the installation of a wind farm is 4 m/s. A 3MW wind turbine was chosen for the simulation due to the power efficiency of the turbines with a higher capacity. All of the data found that the Bahamas does have a suitable environment for wind farm functionality. This information also found that the financial profitability of an offshore wind farm is positive, showing an equity payback period of 5.8 years. The data, when compared to the information gathered about the Canary Islands, proves that the Bahamas has viable wind resources to fully facilitate the energy production of an offshore wind farm of 15 turbines.

One of the difficulties with this report was the lack of information available about the Bahamas in terms of its environmental sensitivity and sustainability efforts. The data that was available was used in a collective effort in order to create the information presented in this paper. One of the major issues that were discovered from this project was the lack of sustainable efforts in the Bahamas despite the amount of renewable resources available. Due to the population size, grid connection type, and number of homes in the domestic section, the country has the possibility to operate completely on renewables. This would make the Bahamas the perfect place to begin the trend of sustainable power dependability.

9. Recommendations

Due to time constrain and lack of information there was a few areas of research that was not focused on in this report that could be done through further research. One of the recommendations is that further research into grid connection loses in the Bahamas should be analysed. This information would increase the accuracy in the sensitivity analysis and it would also give insight into the operation efforts of the local national grid. Another recommendation is that further wind turbine types should be tested for the environment of the Bahamas; the turbine types and functionality were looked at but only in basic depth. The final recommendation regards the information gathered for the environment assessment section of the project consenting chapter of this paper. In order to gain accurate insight in the variety of marine life in the Bahamas an onsite investigation should be performed.

10. Future Work Proposals

The purpose of this section is to describe the areas of this thesis that could be improved through further work. One of the major areas that would increase the analysis of this project is with onsite data. This information would be used to solidify the EIA guidelines made in this project for the Bahamas. Also further validation of the wind energy data could be completed through the use of different wind energy software and actual site performance data. The feasibility of grid connection should be analysed further using software such as MERIT or HEM in order to fully understand the compatibility of the offshore wind farm and the national grid.

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12. Appendices

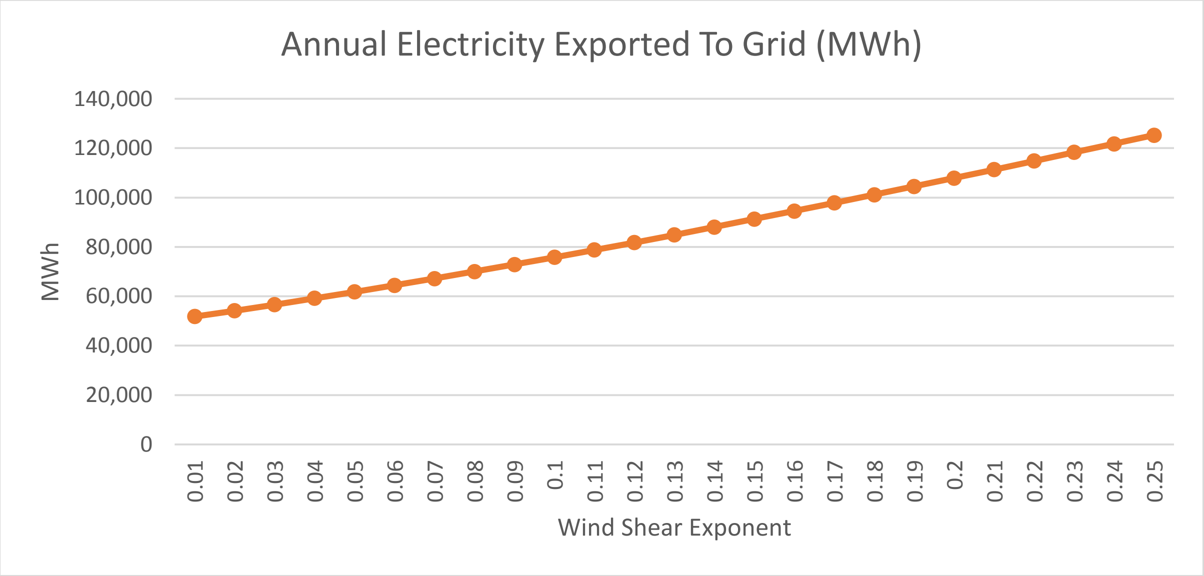
12.1. Default Conditions

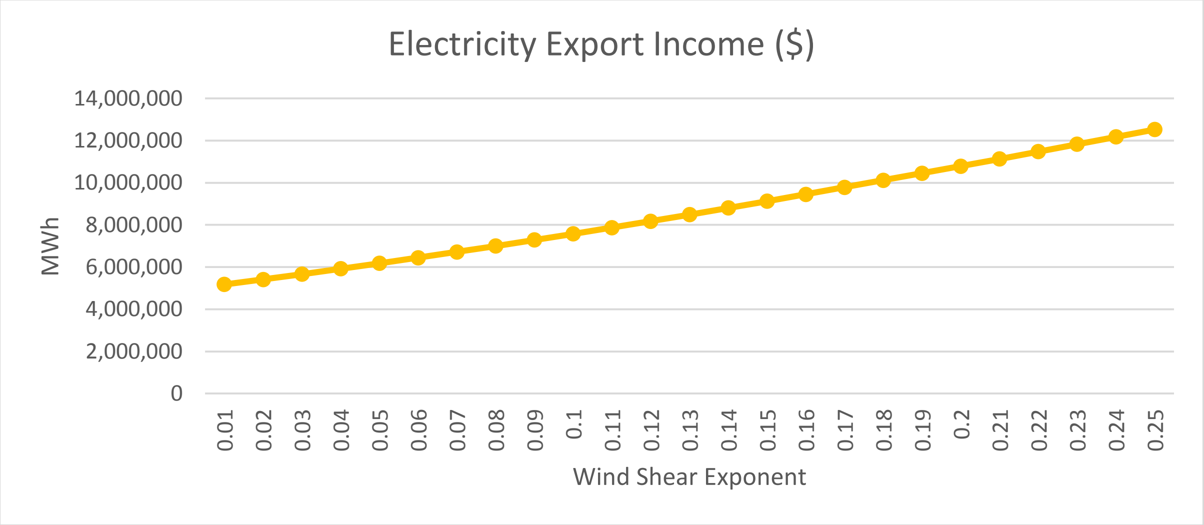
Default Financial & Technical Parameters

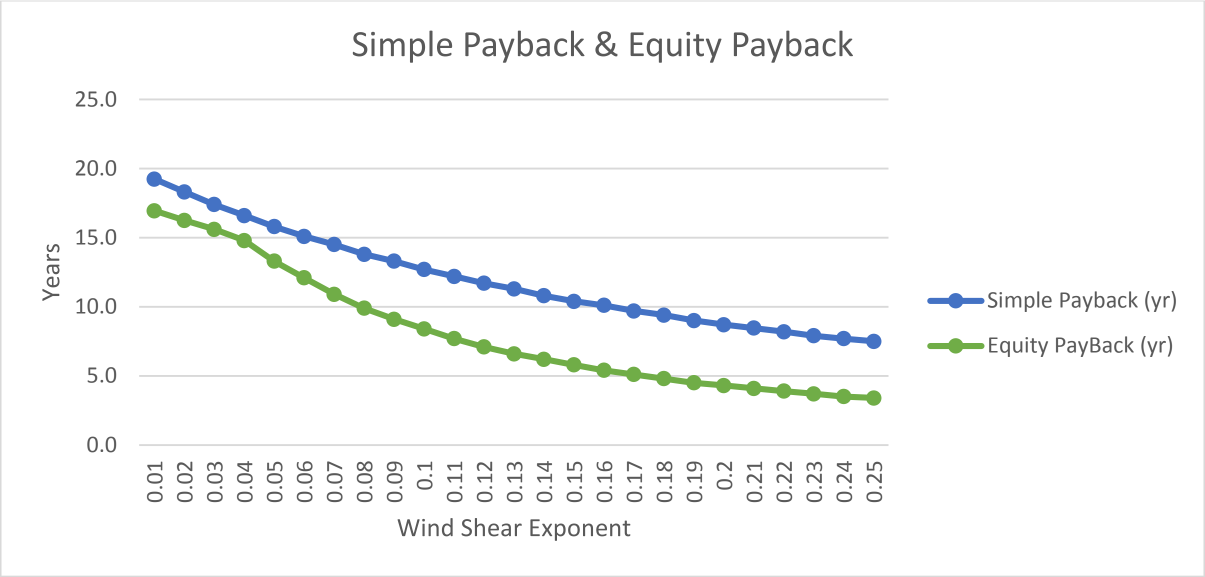
Inflation rate	%	0.02
Project life	yr	25
Debt ratio	%	0.7
Debt interest rate	%	0.01
Debt term	yr	15
Wind shear exponent		0.14

12.2. Full Results

12.2.1. Wind Shear Sensitivity Analysis Results







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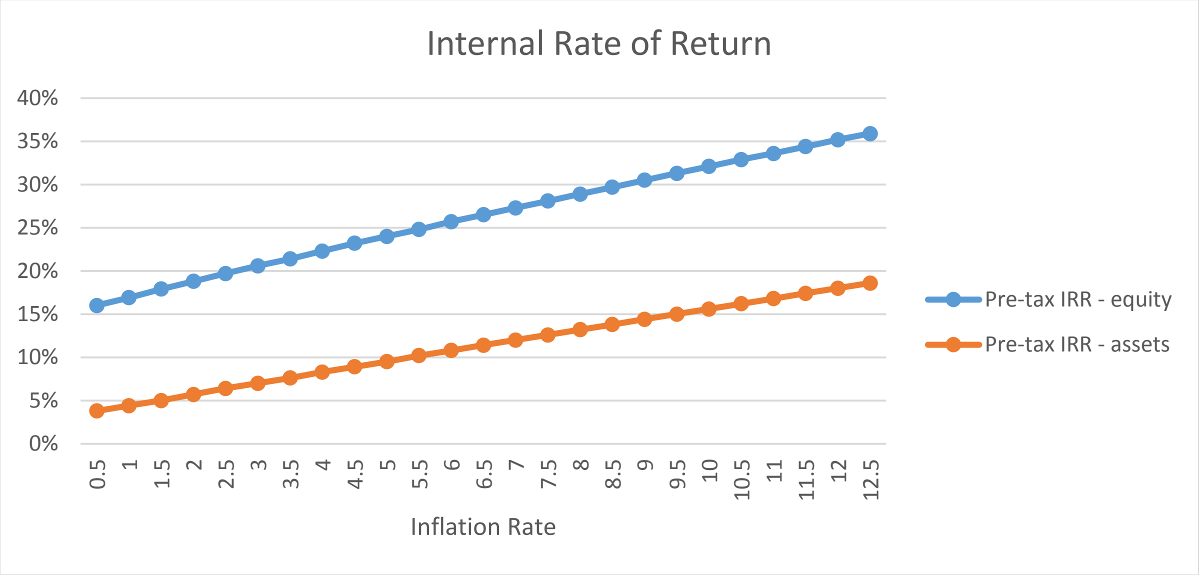
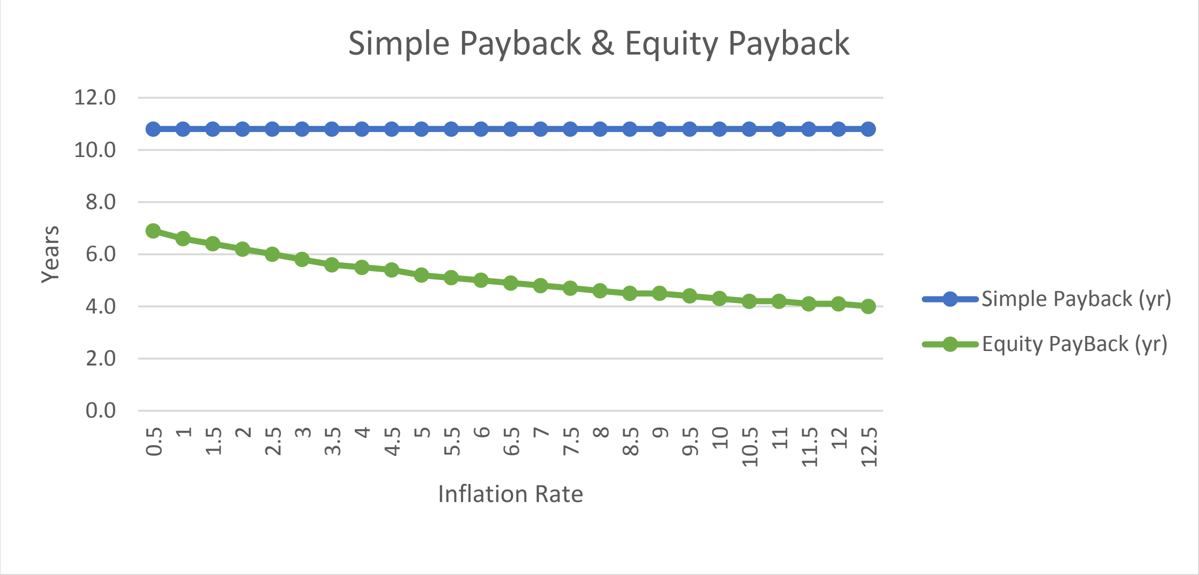
0.07	67209	6720891	14.5	10.9
0.08	70018	7001791	13.8	9.9
0.09	72876	7287556	13.3	9.1
0.1	75784	7578403	12.7	8.4
0.11	78752	7875198	12.2	7.7
0.12	81781	8178110	11.7	7.1
0.13	84886	8488589	11.3	6.6
0.14	88,049	8,804,934	10.8	6.2
0.15	91270	9126970	10.4	5.8
0.16	94536	9453624	10.1	5.4
0.17	97857	9785687	9.7	5.1
0.18	101176	10117574	9.4	4.8
0.19	104507	10450685	9	4.5
0.2	107890	10788950	8.7	4.3
0.21	111327	11132686	8.5	4.1
0.22	114812	11481154	8.2	3.9
0.23	118314	11831409	7.9	3.7
0.24	121806	12180564	7.7	3.5
0.25	125274	12527428	7.5	3.4

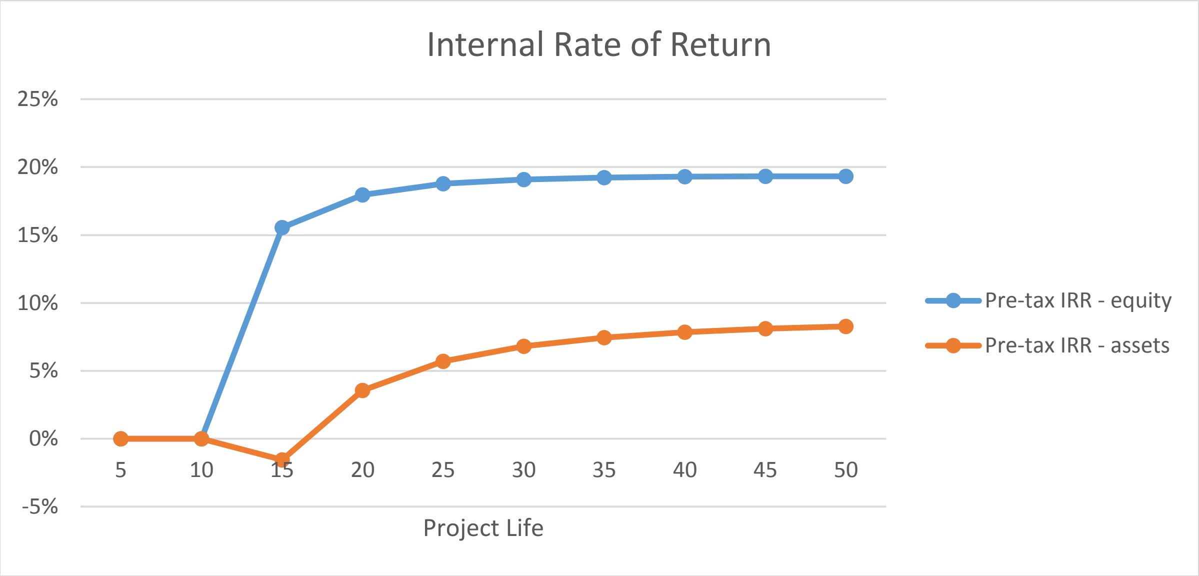
12.2.2. Inflation Rate Sensitivity Analysis Results

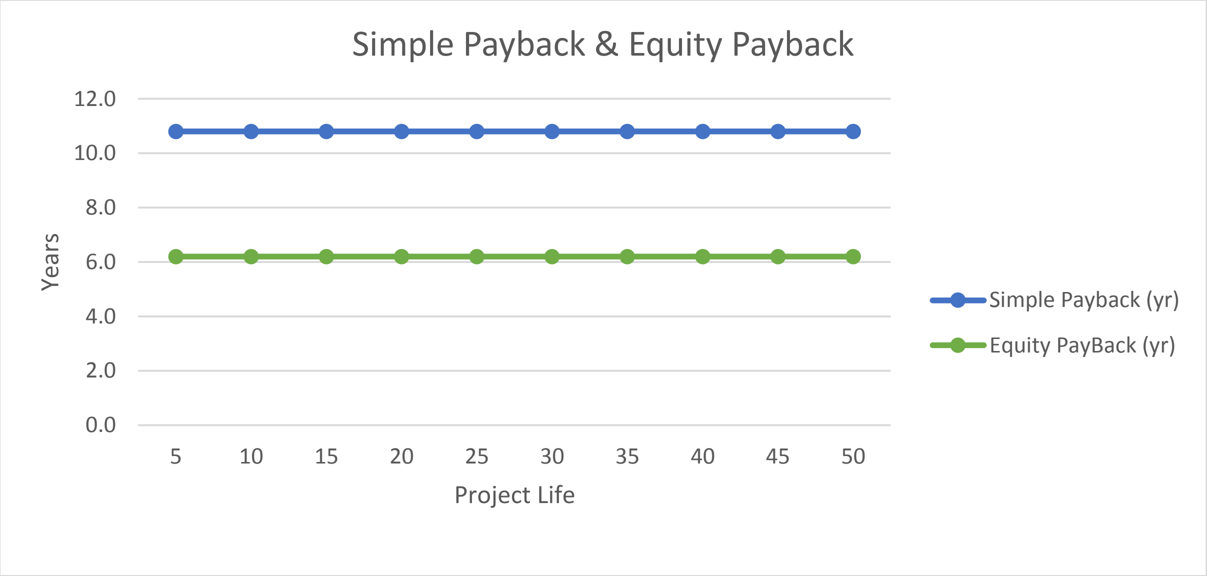




Inflation Rate	Pre-tax IRR - equity	Pre-tax IRR - assets	Simple Payback (yr)	Equity PayBack (yr)
0.5	16%	4%	10.8	6.9
1	17%	4%	10.8	6.6
1.5	18%	5%	10.8	6.4
2	19%	6%	10.8	6.2
2.5	20%	6%	10.8	6
3	21%	7%	10.8	5.8
3.5	21%	8%	10.8	5.6
4	22%	8%	10.8	5.5
4.5	23%	9%	10.8	5.4
5	24%	10%	10.8	5.2
5.5	25%	10%	10.8	5.1
6	26%	11%	10.8	5
6.5	27%	11%	10.8	4.9
7	27%	12%	10.8	4.8
7.5	28%	13%	10.8	4.7
8	29%	13%	10.8	4.6
8.5	30%	14%	10.8	4.5
9	31%	14%	10.8	4.5
9.5	31%	15%	10.8	4.4
10	32%	16%	10.8	4.3
10.5	33%	16%	10.8	4.2
11	34%	17%	10.8	4.2
11.5	34%	17%	10.8	4.1
12	35%	18%	10.8	4.1
12.5	36%	19%	10.8	4

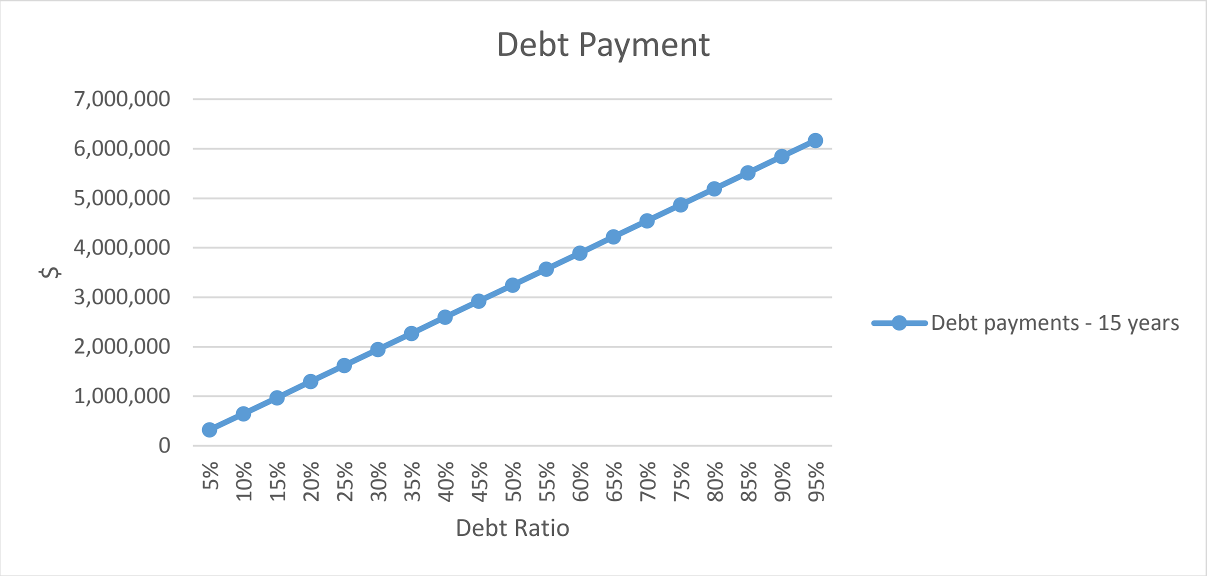
12.2.3. Project Life Sensitivity Analysis Results

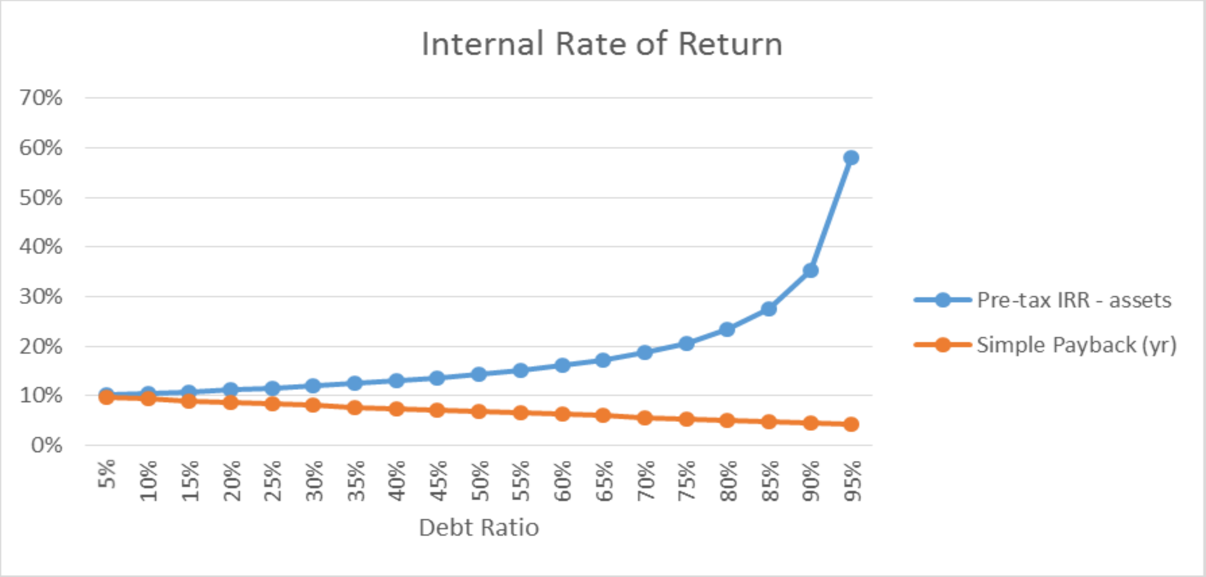


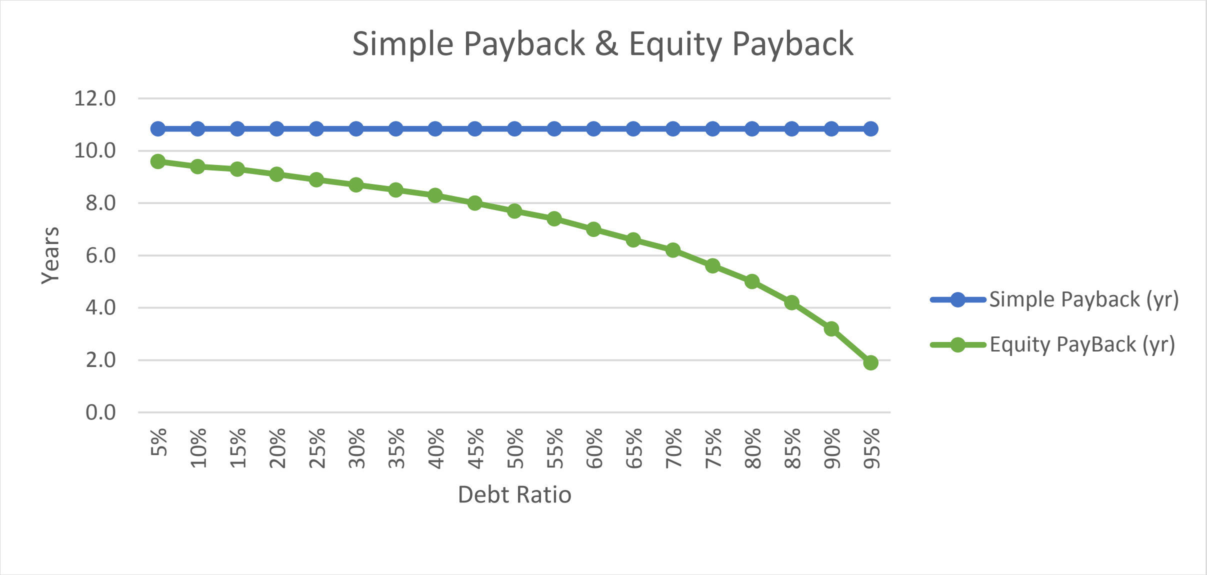


Project life	**Pre-tax IRR - equity**	**Pre-tax IRR - assets**	**Simple Payback (yr)**	**Equity PayBack (yr)**
5	negative	negative	10.8	6.2
10	negative	negative	10.8	6.2
15	16%	-2%	10.8	6.2
20	18%	4%	10.8	6.2
25	19%	6%	10.8	6.2
30	19%	7%	10.8	6.2
35	19%	7%	10.8	6.2
40	19%	8%	10.8	6.2
45	19%	8%	10.8	6.2
50	19%	8%	10.8	6.2

12.2.4. Debt Ratio Sensitivity Analysis Results

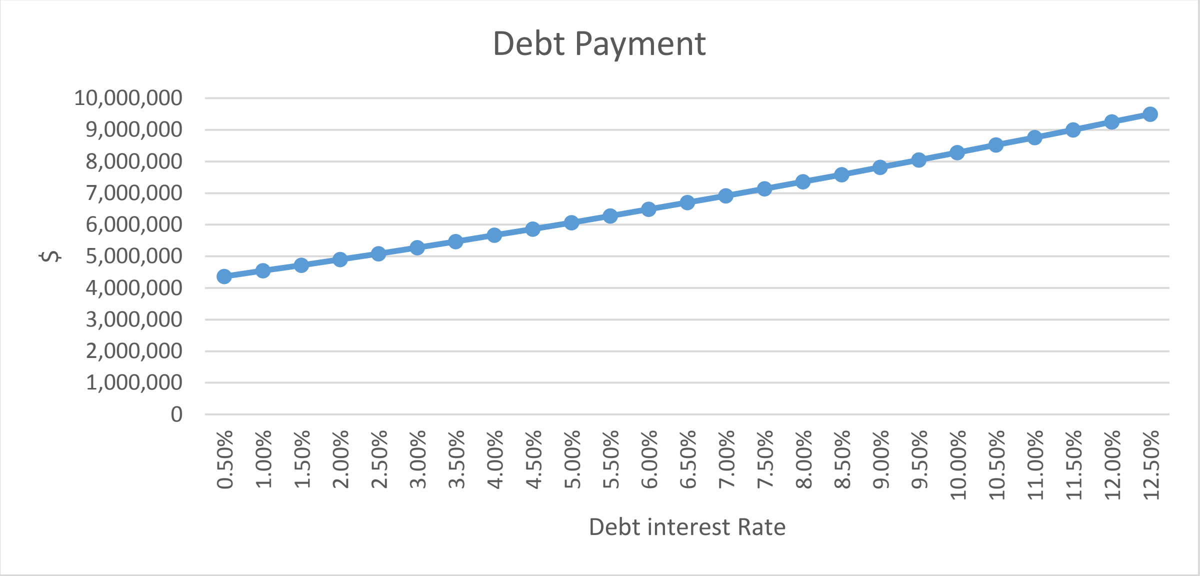


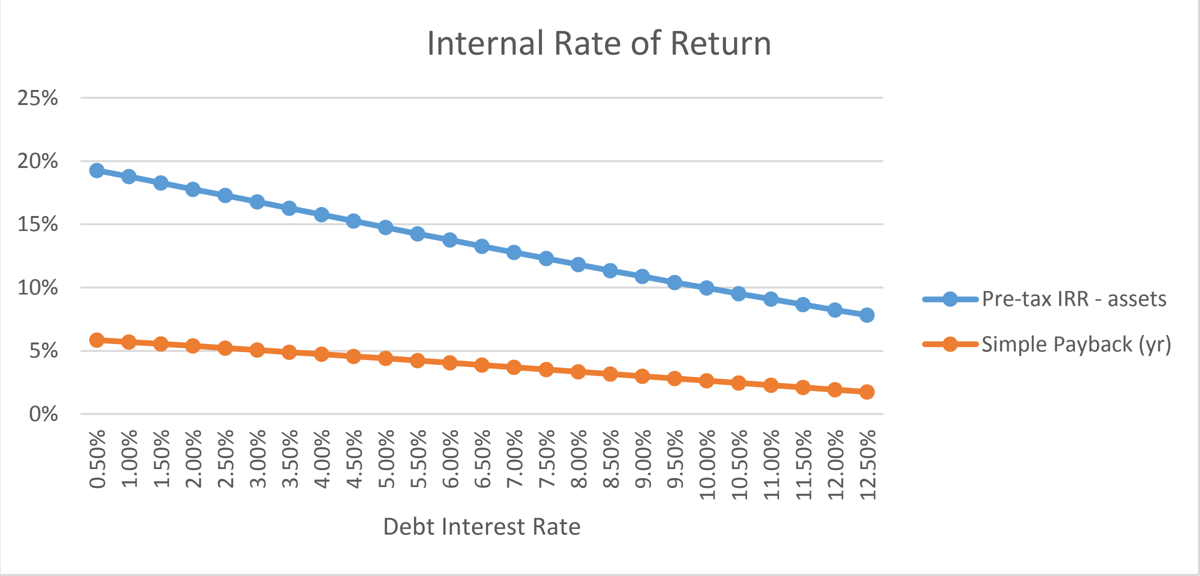


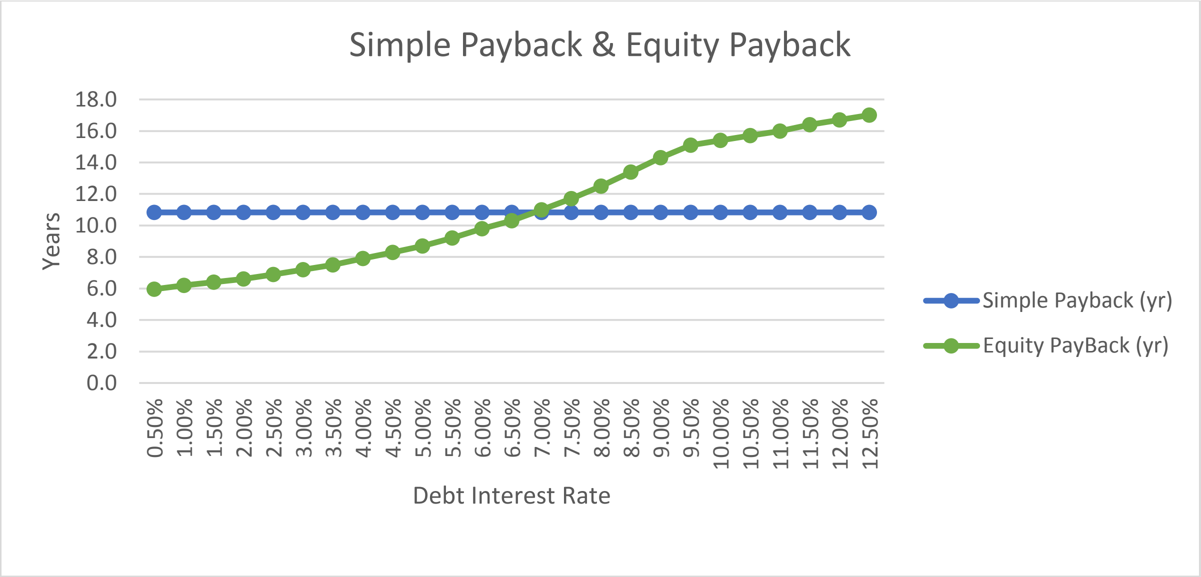


Debt ratio	Debt payments - 15 years	Pre-tax IRR - equity	Pre-tax IRR - assets	Simple Payback (yr)	Equity PayBack (yr)
5%	324,557	10%	10%	10.8	9.6
10%	649,114	11%	9%	10.8	9.4
15%	973,671	11%	9%	10.8	9.3
20%	1,298,228	11%	9%	10.8	9.1
25%	1,622,785	12%	8%	10.8	8.9
30%	1,947,342	12%	8%	10.8	8.7
35%	2,271,899	13%	8%	10.8	8.5
40%	2,596,456	13%	7%	10.8	8.3
45%	2,921,013	14%	7%	10.8	8
50%	3,245,570	14%	7%	10.8	7.7
55%	3,570,127	15%	7%	10.8	7.4
60%	3,894,684	16%	6%	10.8	7
65%	4,219,241	17%	6%	10.8	6.6
70%	4,543,798	19%	6%	10.8	6.2
75%	4,868,355	21%	5%	10.8	5.6
80%	5,192,912	23%	5%	10.8	5
85%	5,517,469	28%	5%	10.8	4.2
90%	5,842,026	35%	5%	10.8	3.2
95%	6,166,583	58%	4%	10.8	1.9
100%	6,491,140	positive	4%	10.8	0
105%	6,815,697	positive	4%	10.8	0
110%	7,140,254	positive	4%	10.8	0
115%	7,464,811	positive	3%	10.8	0
120%	7,789,368	positive	3%	10.8	0
125%	8,113,925	positive	3%	10.8	0

12.2.5. Debt Interest Rate Sensitivity Analysis Results

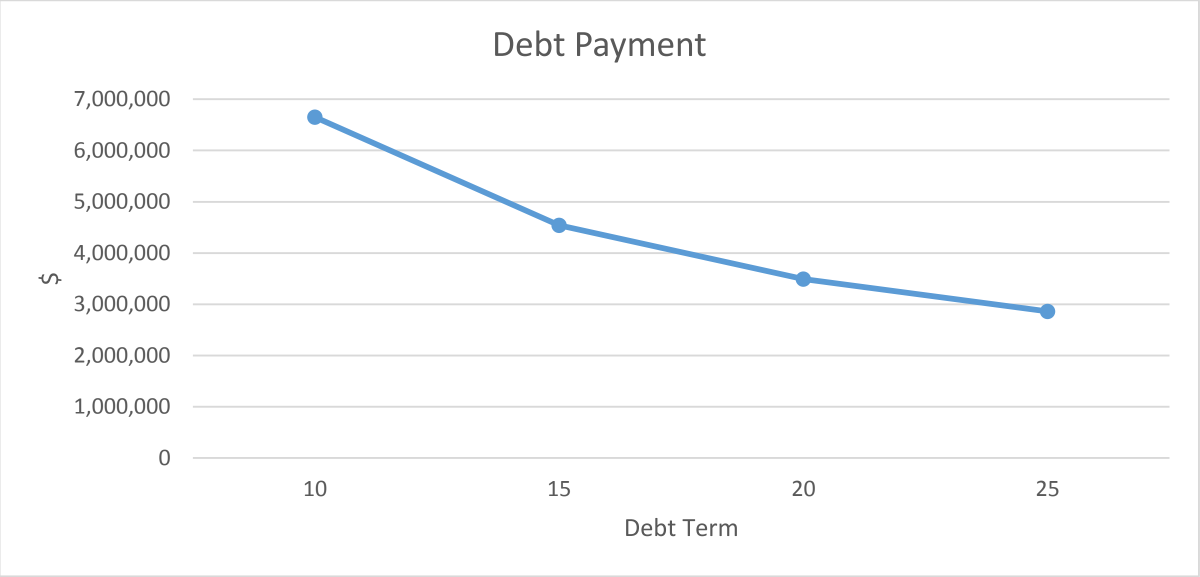


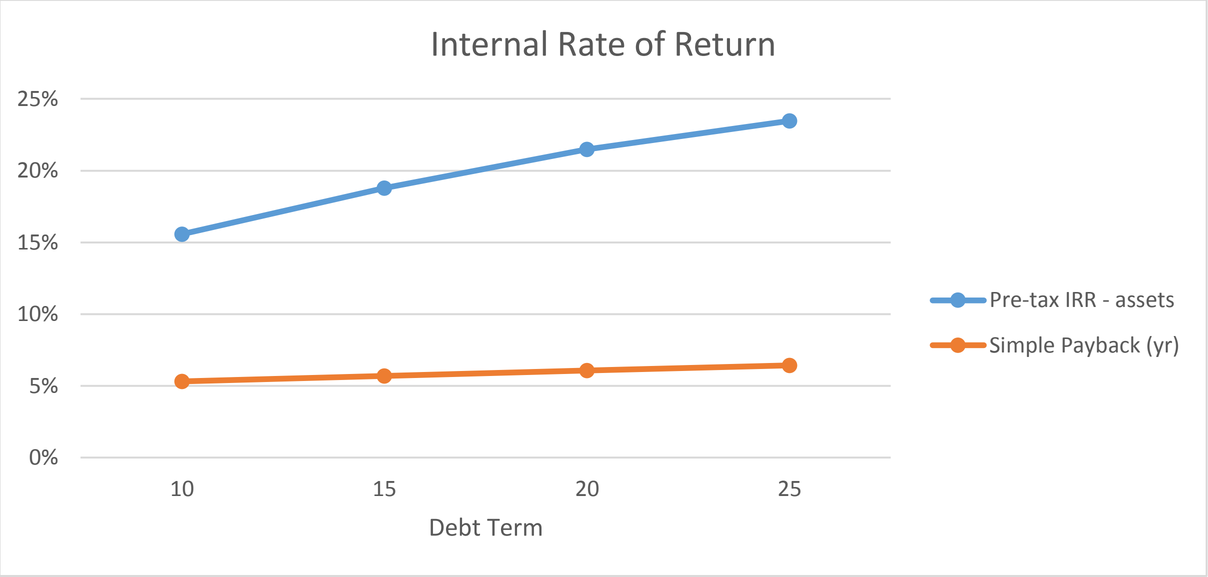


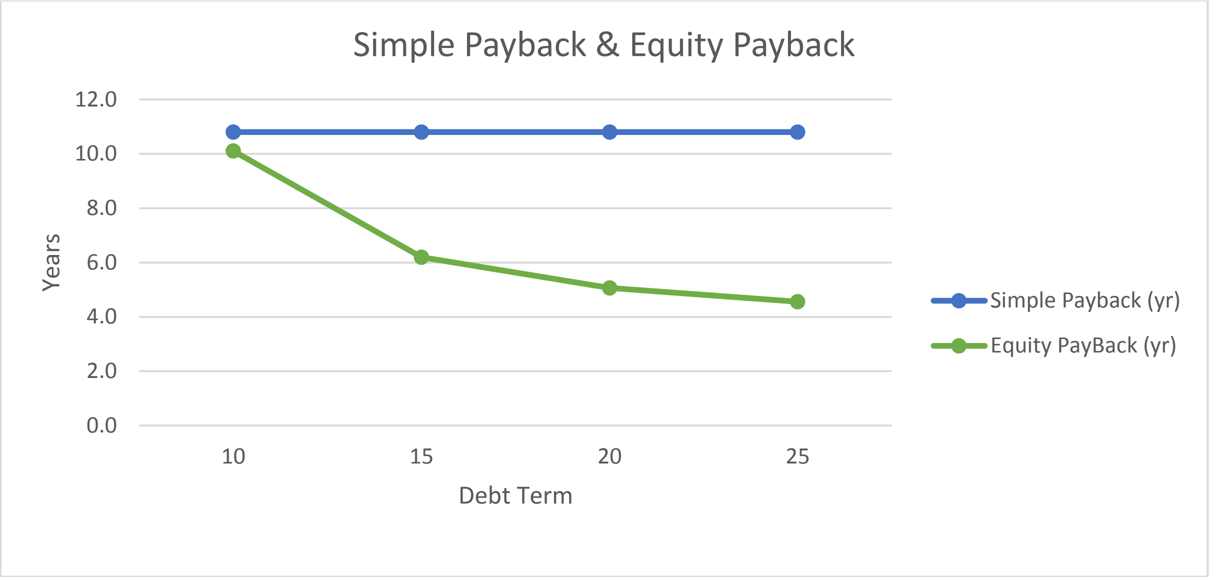


Debt interest rate	Debt payments - 15 years	Pre-tax IRR - equity	Pre-tax IRR - assets	Simple Payback (yr)	Equity PayBack (yr)
0.50%	4,369,955	19%	6%	10.8	6.0
1.00%	4,543,798	19%	6%	10.8	6.2
1.50%	4,721,494	18%	6%	10.8	6.4
2.00%	4,903,005	18%	5%	10.8	6.6
2.50%	5,088,287	17%	5%	10.8	6.9
3.00%	5,277,295	17%	5%	10.8	7.2
3.50%	5,469,979	16%	5%	10.8	7.5
4.00%	5,666,289	16%	5%	10.8	7.9
4.50%	5,866,170	15%	5%	10.8	8.3
5.00%	6,069,564	15%	4%	10.8	8.7
5.50%	6,276,413	14%	4%	10.8	9.2
6.00%	6,486,654	14%	4%	10.8	9.8
6.50%	6,700,225	13%	4%	10.8	10.3
7.00%	6,917,061	13%	4%	10.8	11
7.50%	7,137,096	12%	4%	10.8	11.7
8.00%	7,360,261	12%	3%	10.8	12.5
8.50%	7,586,489	11%	3%	10.8	13.4
9.00%	7,815,710	11%	3%	10.8	14.3
9.50%	8,047,853	10%	3%	10.8	15.1
10.00%	8,282,848	10%	3%	10.8	15.4
10.50%	8,520,624	10%	2%	10.8	15.7
11.00%	8,761,110	9%	2%	10.8	16
11.50%	9,004,235	9%	2%	10.8	16.4
12.00%	9,249,927	8%	2%	10.8	16.7
12.50%	9,498,116	8%	2%	10.8	17

12.2.6. Debt Term Sensitivity Analysis Results

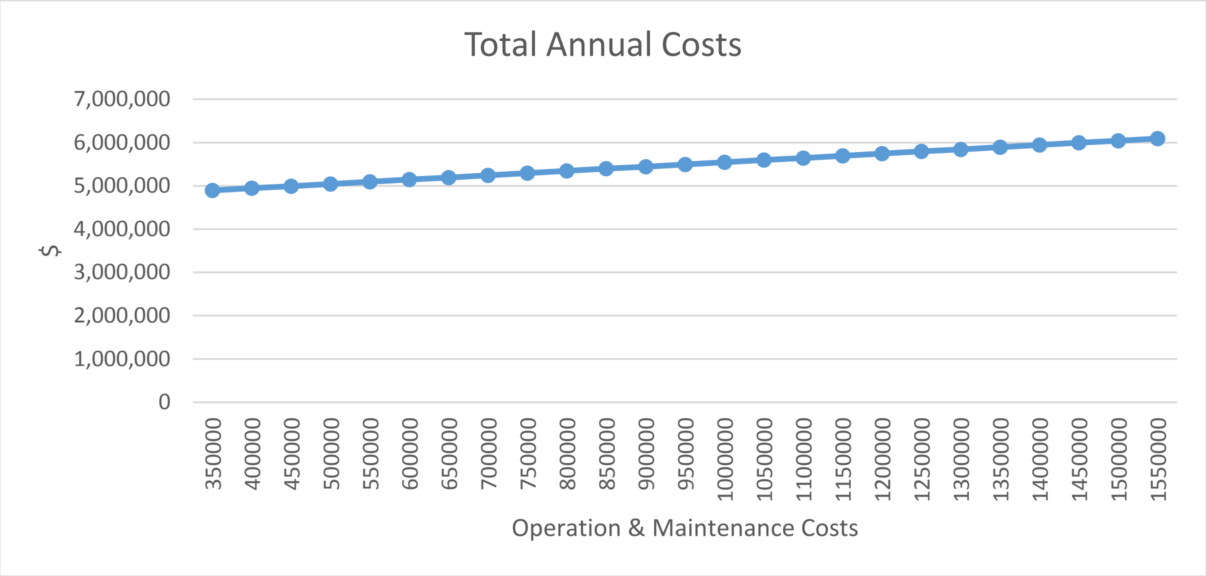


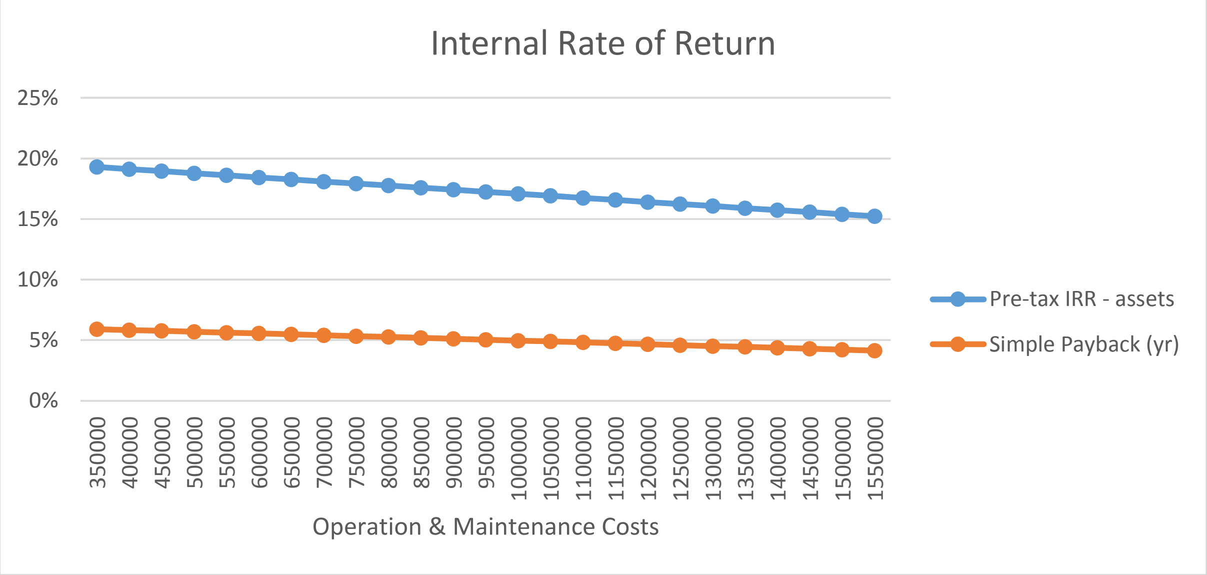


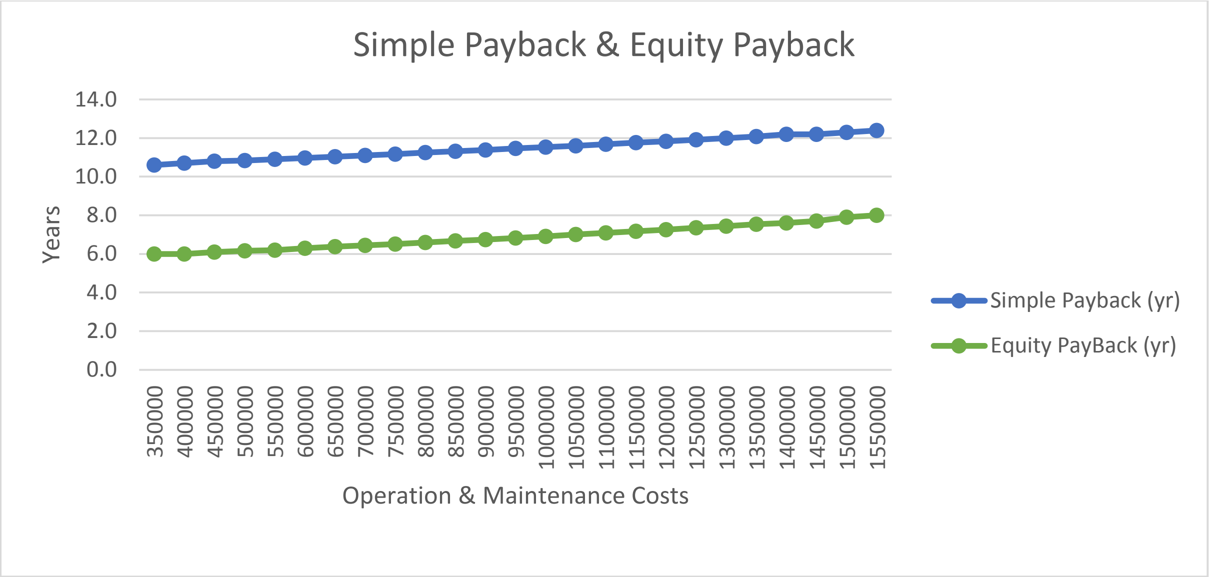


Debt term	Debt payments	Pre-tax IRR - equity	Pre-tax IRR - assets	Simple Payback (yr)	Equity PayBack (yr)
10	6,651,671	16%	5%	10.8	10.1
15	4,543,798	19%	6%	10.8	6.2
20	3,491,165	21%	6%	10.8	5.1
25	2,860,625	23%	6%	10.8	4.6

12.2.7. Operations & Maintenance Costs Sensitivity Analysis Results







O&M (savings) costs	Total Annual Costs (Including Dept Payment @ 15 years	Pre-tax IRR - equity	Pre-tax IRR - assets	Simple Payback (yr)	Equity PayBack (yr)
350000	4,893,798	19%	6%	10.6	6.0
400000	4,943,798	19%	6%	10.7	6.0
450000	4,993,798	19%	6%	10.8	6.1
500000	5,043,798	19%	6%	10.8	6.2
550000	5,093,798	19%	6%	10.9	6.2
600000	5,143,798	18%	6%	11.0	6.3
650000	5,193,798	18%	5%	11.0	6.4
700000	5,243,798	18%	5%	11.1	6.4
750000	5,293,798	18%	5%	11.2	6.5
800000	5,343,798	18%	5%	11.2	6.6
850000	5,393,798	18%	5%	11.3	6.7
900000	5,443,798	17%	5%	11.4	6.7
950000	5,493,798	17%	5%	11.5	6.8
1000000	5,543,798	17%	5%	11.5	6.9
1050000	5,593,798	17%	5%	11.6	7.0
1100000	5,643,798	17%	5%	11.7	7.1
1150000	5,693,798	17%	5%	11.8	7.2
1200000	5,743,798	16%	5%	11.8	7.3
1250000	5,793,798	16%	5%	11.9	7.4
1300000	5,843,798	16%	5%	12.0	7.4
1350000	5,893,798	16%	4%	12.1	7.5
1400000	5,943,798	16%	4%	12.2	7.6
1450000	5,993,798	16%	4%	12.2	7.7
1500000	6,043,798	15%	4%	12.3	7.9
1550000	6,093,798	15%	4%	12.4	8.0

12.2.8. Electrical Analysis Results

Electricity rate - monthly	**Rate 1**	**Rate 2**	**Rate 3**	**Rate 4**	**Peak load**	**Fixed charge - monthly**	**Total electricity cost**	**Average load**
Month	kWh	kWh	kWh	kWh	kW	$	$	kW
January	54838750	52645200	59225850	57032300	61419400	3041137.72	4562584	300728.629
February	54838750	52645200	59225850	57032300	61419400	3041137.72	4562584	332949.5536
March	54838750	52645200	59225850	57032300	61419400	3041137.72	4562584	300728.629
April	54838750	52645200	59225850	57032300	61419400	3041137.72	4562584	310752.9167
May	54838750	52645200	59225850	57032300	61419400	3041137.72	4562584	300728.629
June	54838750	52645200	59225850	57032300	61419400	3041137.72	4562584	310752.9167
July	54838750	52645200	59225850	57032300	61419400	3041137.72	4562584	300728.629
August	54838750	52645200	59225850	57032300	61419400	3041137.72	4562584	300728.629
September	54838750	52645200	59225850	57032300	61419400	3041137.72	4562584	310752.9167
October	54838750	52645200	59225850	57032300	61419400	3041137.72	4562584	300728.629
November	54838750	52645200	59225850	57032300	61419400	3041137.72	4562584	310752.9167
December	54838750	52645200	59225850	57032300	61419400	3041137.72	4562584	300728.629
Total	658065000	631742400	710710200	684387600		36493652.64	54751008	