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WIND POWER PLANT POTENTIALS IN GHANA

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ABSTRACT

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This thesis studies the wind energy technology and the wind technology transfer to Ghana. The thesis analyses some market achievements of wind energy in the world, types and components of the wind energy technology, cooperation involved in manufacturing of the component of the wind turbine, best areas for wind turbine, types of the wind energy construction, applications of wind energy, arrangement of wind farm, environmental impact of the technology and assessment of wind energy resources in Ghana.

However this thesis work focuses mainly on two questions: what are the potentials of wind energy generation in Ghana? Secondly, what are the barriers in implementing wind energy technology in Ghana? This research questions was selected based on the aim of this thesis work, which is to identify some general issues relevant for wind energy technology transfer to Ghana such as pinpointing some areas in Ghana with good wind flow for wind energy generation and the barriers in implementing the wind energy technology. Also the thesis presents some investment analysis of wind energy technology transfer to a selected location in Ghana.

The thesis concluded with dates indicating that the expected energy that can be generated from the wind speed in Ghana is adequate for wind energy farm. From the data it was found that the accumulation of power generated from Ghana wind was about 5.64GW which is adequate for reducing the energy crises in Ghana. The cash payback period for the wind energy setup observed in Nkwanta by this thesis was estimated to be 5.5year, which is objectively very good for wind energy investment. The final recommendation was addressed as Nkwanta been selected as the best area for wind energy generation due to the data observed for the thesis but further investigations needs to be than before starting the project in the area.

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1 INTRODUCTION

The focus of this thesis is on Ghana and the wind energy potential in the country. Several new projects for energy producing are being developed all over the world due to an increase in the energy demand. The continent Africa is not an exception to the increase in the energy demand but there have only been a few new projects for energy production. To address the potential of wind energy in Ghana, we first take a brief look at the African continent.

Data collected by the FAO Corporate Document Repository show that in Africa the electricity is inaccessible to most residents, entangling people into poverty. Statistics gathered from the world African monitor show that about 15% of the world’s total population live in Africa but the consumption of energy is just about 3% of the world’s energy output that leaves about 587 million Africans without electricity by means of the national grids. During the past few years, there has been 64 major discoveries in Africa that provides potential areas for new fuel supply of mostly gas and oil deposit, 13 of these deposits were found in the first eight months of 2012 alone. About 84% of Kenyans, 65% of Sudanese and 81% of Ugandans are not connected to a national electricity supply. Energy in Africa is mostly derived from kerosene and charcoal at home. This source of energy causes many ailment and premature deaths especially respiratory infections. The charcoal is acquired from trees by chopping them down, which has a bad environmental impact, while businesses determine to operate a purchased power generator to help as a standby for the unreliable electricity available despite the fuel cost causing them to have shorter working hours. Clinics also find it very challenging to operate due to unreliable electricity supply since they usually do not have enough funds to purchase a generator or the fuel for the generator. On the other hand students in Africa find it problematic to study when it gets dark. There is no thought that the continent´s developmental growth cannot be enhanced without solving the energy supply crises. (Agriculture and Consumer Protection Department 1995; CIA 2013; Pflanz Mike 2013)

1.1 Brief History about Ghana

The country Ghana was formerly called Gold Coast. The country was colonised by the British and it gained independence in 1957. The country is located in Western Africa and has it territory bordering the Gulf of Guinea, Cote D'Ivoire, Burkina Faso and Togo. The country has 800N, 200W as it geographic coordination. (CIA 2013)

Ghana had a Gross domestic product GDP of about $83.18 billion in 2012, $76.89 billion in 2011 and $67.22 billion in 2010 accumulating to a GDP growth rate of about 8.2% in 2012. Ghana had an official exchange rate of $40.12 billion and a GDP per capital (PPP) of $3,300 in 2012. Ghana had a labour force of about 11.67 million and unemployment rate estimated at about 11% in 2012. The investment fixes gross in Ghana was about 25.1% of GDP in 2012 and had taxes about 20.9% of GDP. The central bank discount rate in Ghana was about 18% in December 2009 and commercial bank rate of about18.2% in December 2011 and about 25.1% in December 2012. Ghana had an electricity production capacity of about 8,764 GWh and an electricity consumption of about 6,122GWh in 2009. Ghana exported about 752GWh of the electricity produced and imports about 198GWh in 2009. Ghana had an installed generation capacity of about 1,985MW in 2009 and was hoping to increase installed generation capacity to 5,000MW by 2015 due to the increase in demand of electricity. Ghana had a total capacity of about 40.6% of energy generated from fossil fuels and 59.4% from hydroelectric plant in 2009. Ghana plans to increase their use of renewable energy sources by 2020, so there is really good opportunity for renewable energy companies to setup in totally new markets hence the need for this research. The approved rates that exist for renewable energy feed in tariffs for Ghana fixed and applicable for 10 years but subjected to review every 2 years is Wind 0.16 cent/kWh, Solar 0.20 cent/kWh, Hydro10MW or less 0.13, Hydro10MW-100MW 0.11 cent/kWh, Landfill Gas 0.15 cent/kWh, Sewage Gas 0.15 cent/kWh and Biomass 0.15 cent/kWh. (CIA 2013; ECOWREX 2011; Admin 2013)

2 PROBLEM STATEMENT

The energy demand in the world is growing, as a product of economic, developmental and population growth. Developing countries need reliable energy to accelerate their economic, educational and social growth. Due to these issues, many developing countries have set energy problems as their main concern. These countries are turning their focus on renewable energy, unlike other forms of electrical generation where fuel is expensive, rare and dangerous. Ghana as a developing country is facing the same energy crises. The Ghanaian government aims at increasing their renewable energy by 2020. The information needed to attract renewable energy investors to Ghana for solving these energy crises is dispersed and not clearly defined.

2.1 Objective

This thesis aims at gathering and identifying all the necessary information and specific elements needed to attract wind energy investors to Ghana. The focus of the work has been separated into two areas, the main objective and the sub-objective.

The research main objective is to investigating the potential of wind energy in Ghana. By identifying some general issues relevant for wind energy technology transfer to Ghana such as detecting some areas with good wind flow for wind energy production and the barriers in implementing the technology. The thesis analyses why investors in wind energy should consider Ghana as the new potential market for energy transfer.This thesis will also analyse some market achievements of wind energy in the world, types and components of the wind energy technology, some cooperation involved in manufacturing of the components of the wind turbine, best areas for wind turbine, types of the wind energy construction, applications of wind energy, arrangement of wind farm and environmental impact of the technology so we can have a better understanding of the technology.

2.2 Research Questions

The research was based on the review of past research articles based on significant issues surrounding wind energy technology transfer. For the research, the following questions were selected to help in achieving the aim of the thesis.

1) What are the potential of wind energy generation in Ghana?

2) What are the barriers in implementing wind power plants in Ghana?

The result of some recently completed field study on the possibility of wind power in Ghana will provide information to Question 1.

A recent event in Ghana and some wind energy implementation in other countries will help provide information on Question 2 and also provide additional insights into Question1.

3 METHODOLOGY

In this chapter the methods and material used in the thesis are explained. Exploratory research design was chosen because the problem that this thesis aims to address about the potential of wind energy in Ghana is dispersed and has not been clearly defined. The fundamental nature of the issue requires an investigation to identify areas in Ghana with adequate wind flow to generate electricity and the barriers in implementing wind power plants in Ghana.

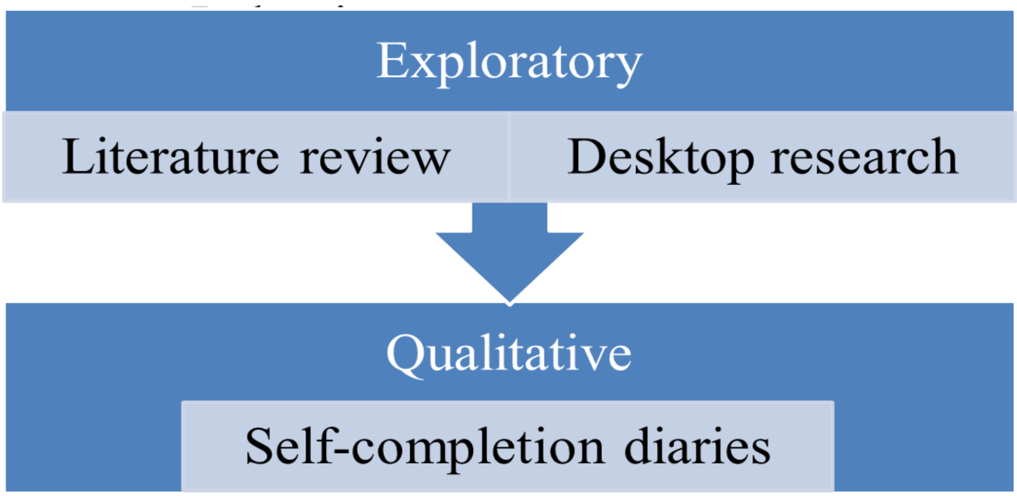
A qualitative method was selected as the best research method of collecting data for this thesis, because the area this thesis aims to address has already been researched by different organisation but the data is dispersed and was not clearly defined. The qualitative method was used to select theories and articles pertaining to the research problem and the data was sampled through evaluation and analysis.

The process of gathering data was very essential to the method chosen because it helped to provide the fundamental links between the wind flow data in Ghana and the wind energy that can be produced by the turbine and also the energy demand in Ghana and the wind energy that could be supplied to yield an impartial result. Due to the nature of the exploratory research used, we employed secondary source of collecting data along with argument and justifications. The secondary data used was gathered by reviewing available literature data and article from the internet. This was because most of the data needed for this thesis could not be collected in person by the researcher due to the distance and the lack of funding.

3.1 Research Methods – Approach

Table 1 shows the approaches observed for this thesis during the gathering of the research data.

Table 1. The steps involved in the research approach used for this thesis



- Literature Review: To track issues and changes in relations to wind energy generation

- Desktop Research: To identify articles, issues and changes in a wind power plant

- Self-Completion Diaries: Self-selection and sampling through data by evaluation and analysis

Source of Data: The majority of the information used in writing this thesis was originally congregated from articles acquired from the internet. Most of the sources used in this thesis are reliable, but some are more reliable than others. The overall accuracy of the material in this thesis work is objectively clear-cut.

4 WIND ENERGY

Wind energy has over the years become the easiest energy to acquire and use. The wind energy as a fuel have served man for centuries during which it has been used for propelling ships, driving wind mills for grinding grains and for sky diving. Based on our study of introducing wind energy technology to Ghana, we are going to follow a background research on the wind power plant technology which we believe will help to gain a better understanding of the technology and for the selection of the right type of wind turbine for a specific area in Ghana. The wind energy produced is accounted for by the mechanical, aerodynamics and electrical conversion therefore we will look at such areas in this chapter.

4.1 Types of Wind Turbines

Man has found a way to produce electricity by harnessing the kinetic energy from the wind. This source of renewable energy has a significantly promising potential in areas with high winds speed. The technology used to harness the wind energy is known as a wind turbine. The energy captured by the wind turbines efficiency depends on the wind speed of the area where the turbine is placed and the type of wind turbine been used. Over the years the wind technology has been researched and a more effective, high efficiency and reliable ways of harnessing the energy to produce electricity has been found. Various researches into the wind energy technology have provided several types of wind turbines. Some of the types of wind turbines are presented in the following. (Canadian Wind Energy Association 1996)

Vertical Axis Wind Turbines

Vertical Axis Wind Turbines shortened to VAWTs have been in existence for centuries but recently they are not as common as horizontal axis wind turbine, because the vertical axis wind turbines do not take advantage of the greater wind speeds at upper elevations above the ground unlike horizontal axis turbines. During 1000 BC. the Persian used the principle in vertical axis wind turbine systems in constructing their windmill to turn grindstone for grinding spices and grains. They blocked the wind blowing on half of it blades. The blades exposed to the wind are pushed and this causes the windmill to rotate. Figure 1 illustrates the image and operating system of an early vertical axis windmill. (Teacher Geek 2006)

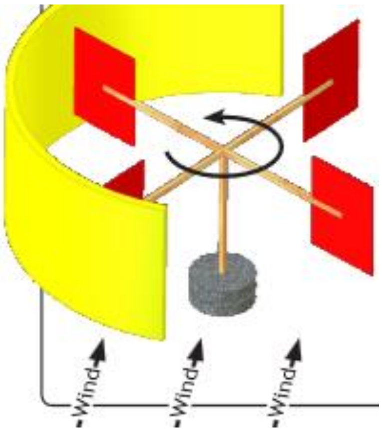


Figure 1. Early Windmill (Teacher Geek 2006)

The vertical axis wind turbine has a vertical rotor shaft so it is good for areas where the direction of the wind changes rapidly. Another advantage is that the generator and some other components can be positioned closer to the ground making maintenance of the generator and other components easier. But the blades generally cause drag when it rotates into the direction of the wind. It is very challenging to mount the turbines on towers, and so it is usually installed at lower altitude where slow wind flow causing the turbine to generated less energy. Other objects and air flowing near the ground around the turbine can cause turbulence, which can increase the noise and vibrations causing bearing wear which increases the regularity of maintenance or shortens its service life. But it is better when the turbine is fixed on a rooftop, the building redirects most of the wind over the roof and often doubles the wind speed and directed the wind flow toward the turbine. According to the research, if the height of the rooftop that the turbine was mounted on is approximately 50% of the height of the building, then the wind energy generated will be at its maximum and will have the turbulence to be at it minimum. Figure 2 shows the images of an example of a vertical axis wind turbine. (Bracken Meyers 2013)

Figure 2. Vertical axis wind turbine (Bracken Meyers 2013)

Flapping Panel or Lollipop Style Wind Turbine is another kind of vertical axis wind turbine with the blades of the turbine forced to spin by the wind, regardless of the direction the wind is flowing due to the spinning of the blades in half revolution with the wind and the other half revolution into the wind but has a diminished efficiency. Figure 10 illustrates the way a flapping panel wind turbine operates. (Teacher Geek 2006)

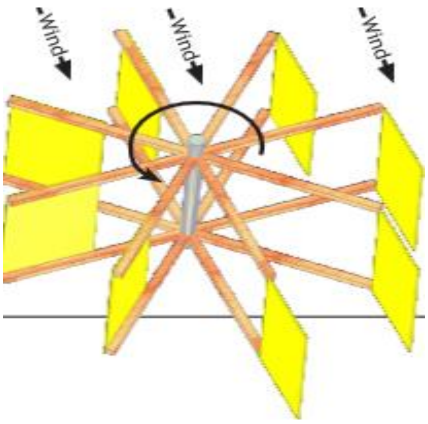


Figure 3. Flapping Panel Wind Turbine (Teacher Geek 2006)

Darrieus Wind Turbine is commonly known as an Eggbeater turbine, because it resembles the shape of a giant egg. It is the one of the most popular vertical axis wind turbines and is characterised by it C-shaped rotor blades. It is usually built with two or three blades resulting in higher solidity, having good efficiency but yields great torque ripple and cyclic stress on the tower, contributing to low consistency. Figure 4 is the illustration of some examples of a Darrieus wind turbine and the way it operates. (Teacher Geek 2006)

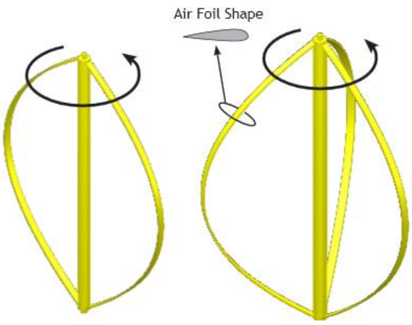


Figure 4. Darrieus Wind Turbine (Teacher Geek 2006)

The Darrieus turbine requires an external power source to start turning because it starting torque is very low. Figure 5 is an example of a Darrieus wind turbine and illustrates the position of some component. (Castellano 2012)

Figure 5. Darrieus Wind Turbine (Teacher Geek 2006)

A Giromill Wind Turbine is a type of vertical axis wind turbine where the blades of the turbine are attached to the central mast by horizontal supports. The giromill turbine is commonly built with two or three vertical aerofoils which work well in turbulent wind conditions areas. Figure 6 is an illustration of a giromill wind turbine and the direction of the shaft rotation. (Teacher Geek 2006)

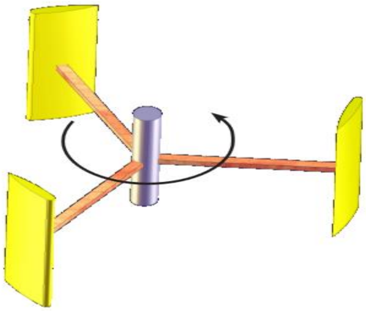


Figure 6. Giromill wind turbine (Teacher Geek 2006)

A Savonius Wind Turbine is type of turbine which has a sort of S-shape when viewed from above with no barriers. The Savonius wind turbine is one of the varieties of vertical axis wind turbine which turns rather slowly but produces a high torque and therefore a high reliability. Figure 7 is an illustration of a Savonius wind turbine. (Teacher Geek 2006; Bracken Meyers 2013)

Due to the slow rotation speed of the system it is not used to generate electricity on a large-scale. The system is suitable for places with turbulent wind and self-stating.

Figure 7. Savonius Wind Turbine (Renewable Energy UK 2010)

A Wind Spire is a vertical axis wind turbine about four feet wide and thirty feet tall with three blades. The technology is a new innovation of a vertical axis wind turbine. Figure 8 is an example of a wind spire farm. (Markham 2012)

Figure 8. Wind spire farm (Markham 2012)

An Eddy Turbine is a new technology innovation of a vertical axis wind turbine that is intended to be combined with solar energy as an energy booster. The technology can be installed in an hour with about 20years life span. Figure 9 is shows an example of the Eddy turbine. (Markham 2012)

Figure 9. Eddy Turbine (Markham 2012)

Horizontal Axis Wind Turbines

A Horizontal Axis Wind Turbines, generally shortened as HAWT, is the most common recorded type of wind turbines design. The HAWT is similar to the design of a general windmill and has it blades parallel to the ground. The blade commonly resembles a propeller that spin on the horizontal axis and has it rotation parallel to the wind flow. Massive tower construction is usually required to support the blade and other components in the nacelle making maintenance difficult. There have been several researches on this system where two or more blades have been used but the type that commonly comes to mind when we speak of wind turbine is the HAWT with three blades. Figure 10 is an example of a horizontal axis wind turbine. (Teacher Geek 2006; Bracken Meyers C 2013)

Figure 10. HAWT with three Blades

The system has it main rotor shaft and electrical generator on top of a tower. The research yielded two ways of dragging the blades.

An up-wind turbine has the rotor hub facing the direction of the wind flow and operates in an upwind mode. A large wind turbine usually changes the direction of the rotor axis to face the wind flow by using a motor-driven mechanism. A smaller wind turbine commonly has a tail vane to keep the hub directed towards the wind. Figure 11 illustrates an example of an up-wind turbine. (Teacher Geek 2006)

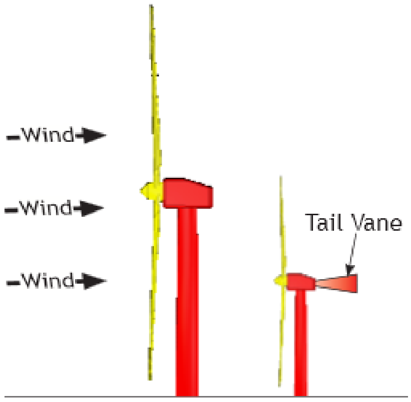


Figure 11. Horizontal axis up-wind turbine (Teacher Geek 2006)

The **down-wind turbine** operates in a downwind way so that the wind passes the tower before striking the blades. This system does not use a tail vane for smaller turbines to track the flowing wind because it tracks the flow naturally. Figure 12 shows an illustration of a down-wind turbine.

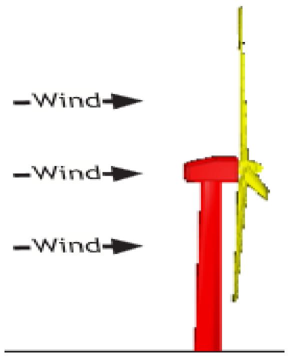


Figure 12. Horizontal axis Down-wind turbine (Teacher Geek 2006)

A wind lens or shrouded wind turbine is a horizontal axis wind turbines with an additional structure termed as lens because the added structure works similarly to a magnifying glass just like when the lens intensifies light from the sun except the wind lens is intended to intensify the wind flow. The added structure focuses the airflow to increase the pressure of the wind passing through the blades and greatly reducing turbulence. The system can be used in areas with low wind speed, it produces less noise and can have a protective rim for preventing bird strikes. According to a research on the wind turbine, the shrouded wind turbine increases the peak power by a factor of 2.8, as shown in the Figure 13. Another research shows that the increase in speed is based on the lens diameter. (RIAM Division 2011)

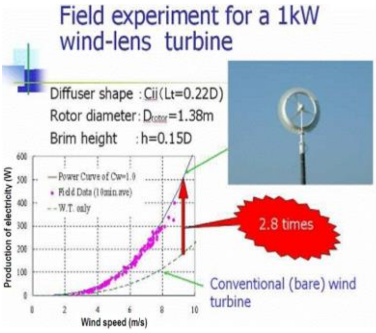


Figure 13. Output of shrouded wind turbine (RIAM Division 2011)

An eco-whisper turbine is another form of horizontal axis wind turbines but has more blades than the conventional wind turbine and is said to be nearly silent. The technology consists of about 30 exceptional blades connected to the rotor at an angle. Figure 14 gives an example of an Eco whisper turbine. (Designboom 2012)

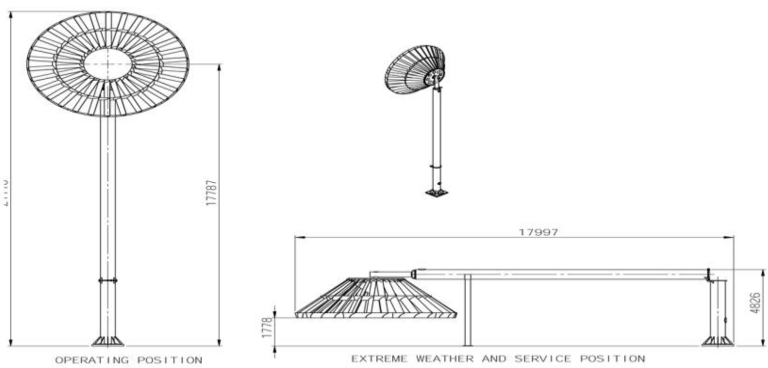


Figure 14. Eco Whisper Turbine (Designboom 2012)

A catching wind power turbines is a bladeless (covered) wind turbine that consist of an enclosed wind turbine about 20kg in weight, 30cm in diameter and surrounded by a wind sock measured 78cm at it widest point. The prototype has safely housed horizontal axis wind turbine to make it bird friendly. Figure 15 shows an example of a catching wind farm. (Buczynski 2012)

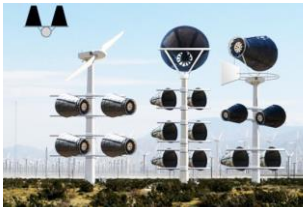


Figure 15. Catching Wind farm (Buczynski 2012)

An airborne wind turbine is one of the latest research constructions of wind turbine. There have been several designs of the technology researched. The aim of the airborne wind turbine was to harness the wind energy at high altitudes, This is because there is a stronger wind flow high above the sea level when the measurement taken from both low and high altitudes were compared. (Horton 2013)

One of the airborne wind turbines developed is by a float fluffy power generation firm, which has a similar design of a wind lens turbine. Just like a wind lens turbine this airborne wind turbine has a horizontal axis. The propeller of the wind turbine rotates with an additional structural around it in a form of a balloon filled with helium or any fluid lighter than air, similar to an airship or a floating balloon. This technology makes little noise and maintenance can be performed easily by descending the turbine to the ground. Figure 16 shows an example of a floating fluffy airborne wind turbine setup in the sky. (Kimura 2012)

Figure 16. Airborne Wind Turbine (Kimura 2012)

Magenn**,** has also developed another type of airborne wind turbine that is made up of a floating air rotor and a tether that transfers the electricity generated to the ground. They call the technology Magenn Air Rotor System, MARS for short, and manufacturing was started in 2010. The rotor is filled with helium to make the device float.The Magenn air rotor system floats in the sky and generates electrical energy by rotating about a horizontal axis when wind passes on the system. The cost of maintaining MARS is low and can be easily done. Figure 17 illustrates an example of a Magenn airborne wind turbine and the way it operates. (Kansainväliset Uutiset 2010)

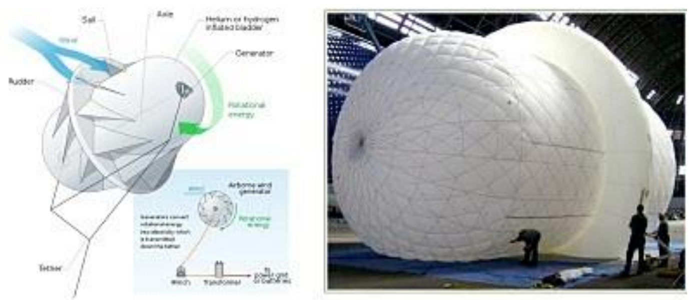


Figure 17. Magenn Air Rotor System (MARS) (Kansainväliset Uutiset 2010)

Joby Energy has also developed another kind of airborne wind turbine which will operate in upper altitude layer. The technology arrangement supports multiple arrays of wind turbines and has a vertical take-off. The turbines are connected to a motor which provides thrust during take-off and produces electricity during crosswind flight. This system transmits electricity through the tether but a computer system drives the aerodynamics of the wings like a kit and the rotor speed. The structure can handle multiple failures and still remain airborne. Figure 18 shows an example of a Joby airborne wind turbine. (Joby Energy 2013)

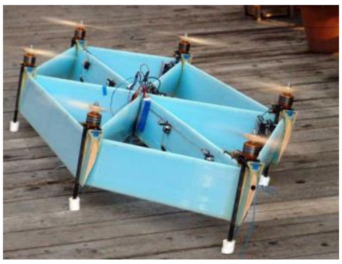


Figure 18. Airborne Wind Turbine, Rana 2 prototype (Joby Energy 2013)

Sky Wind Power Corporation has also developed a similar technology just like that of Joby Energy. The Wind Airborne Tethered Turbine System, shortened to WATTS, uses FEGs (Flying Electric Generators) to convert high altitude wind energy. The rotor of a FEG is for both lifting the device into the sky and generating electricity by converting the kinetic energy from the wind. Figure 19 shows an example of a sky airborne wind turbine. (Sky Wind Power Corporation 2012)

Figure 19. Wind Airborne Tethered Turbine System (Sky Wind Power Corporation 2012)

The Makani airborne wind turbine is made of hybrid rotors that help the system to take-off from the ground and generate electricity in high altitude when the force from the wind pushes the rotor. The system is in a form of an airplane with wing of the size of a conventional turbine blade and tethers to transmit the power been generated to the ground. Figure 20 gives an illustration of the example of The Makani airborne wind turbine. (Makani Power 2013)

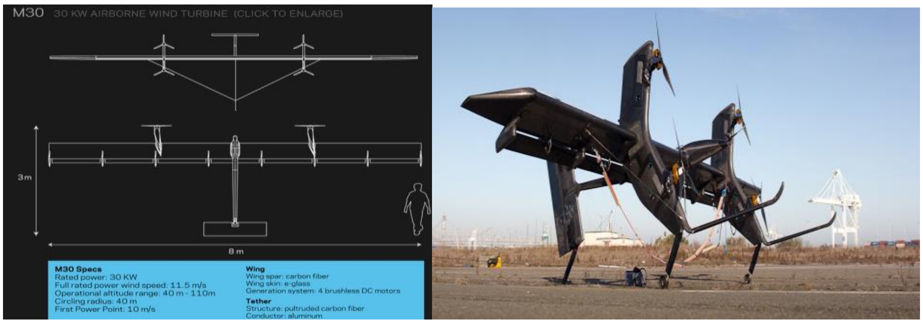


Figure 20. The Makani Airborne Wind Turbine (Makani Power 2013)

The wind harvester system was developed by Heath Evdemon and can be installed anywhere and is almost noise free. The turbine consists of a one meter horizontal blade and needs only half a meter off the surface of the ground to operate. The principle of the technology was based on reciprocating motion similar to those used on aeroplanes where the aerofoil is raised till it hits a certain point after which the blade's angle changes and is forced downward. The process repeated at the same speed. Figure 21 shows an example of a wind harvester. (Markham 2012)

Figure 21. Wind Harvester (Markham 2012)

A saphon energy wind turbine is a new kind of wind turbine that works without blades. The wind turbine resembles a regular satellite dish. The technology generates electricity by oscillating back and forth when the wind pushes the surface of the part of the technology that looks like a satellite dish. The movement, back and forth drives small pistons that are connected to hydraulic system that generates the electricity. The device harvests about 80% of the winds energy, which is estimated to be about 2.3 more effective than a conventional wind turbine. Figure 22 shows an example of a Saphon energy wind turbine. (Ackerman2012)

Figure 22. Saphon Energy Wind Turbine (Ackerman 2012)

A wind stalk is a bladeless wind turbine that produces no noise and is easy to install relative to a conventional wind turbine. The technology was designed by Atelier DNA in New York. The wind stalk comprises of layers of electrodes and ceramic discs which produce electricity when the stalk is under pressure. When the wind blows the wind stalk, it causes them to swing forcing the discs to compress and thereby producing electricity. Figure 23 shows an illustration of a wind stalk farm. (Hall 2012)

Figure 23. Wind Stalk (Hall 2012)

4.2 Components of Conventional Wind Turbine

The wind turbine consists of blade (with a pitch controller and a blade joint), rotor hub, nacelle (with generator, brake, shafts, sometimes a gearbox and electrical circuitry), a wind speed measuring instrument and tower (the tower contains yaw drive and motor) and is assisted with a transformer. When wind passes by the blade of the wind turbine, the wind force causes the blade to move when the brakes are inactive and the blade pitch is in the right angle, which then starts to turn the rotor hub shaft. The rotation force is then directed to a gear box, if the turbine has any, then to a generator usually in the nacelle. The generator turns the rotating force into electricity which then goes to a transformer which converts the electricity to a higher voltage required by the grid. Figure 24 shows an illustration of all the components of a wind turbine and how it works together to generate electricity. (Canadian Wind Energy Association 1996; Bracken Meyers 2013; U.S. Department of Energy 2013)

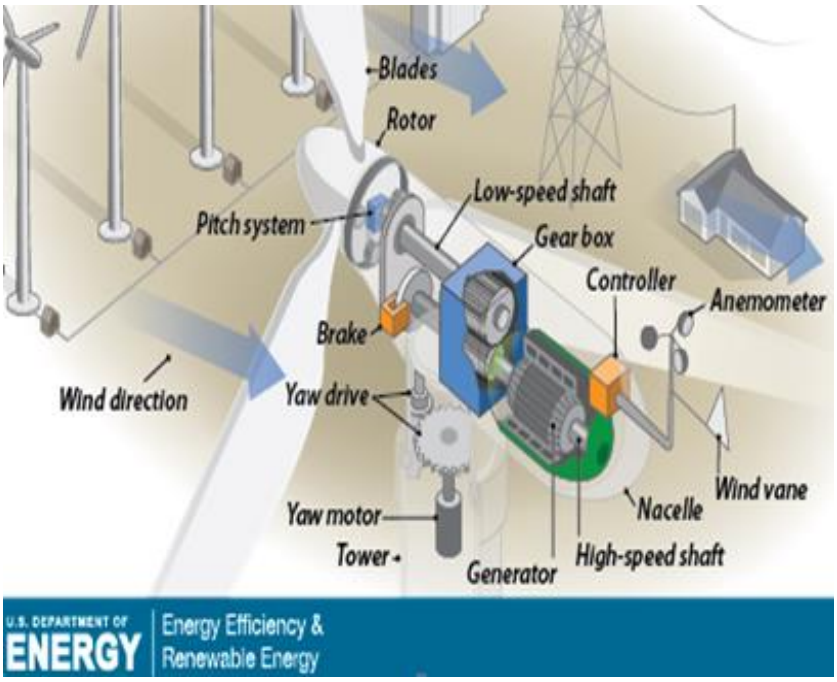


Figure 24. Components of the wind turbine (U.S. Department of Energy 2013)

The tower is made from rolled steel, or from concrete. A scaffold pole is a cheaper alternative. The tower holds and supports the wind turbine into a suitable position. Because high altitude has stronger wind speeds the tower is usually made very tall, ranging from 40-100m height or more. The total cost percentage of the tower in a regular onshore project is about 26.3% including the transportation, foundation, labor and other cost. (U.S. Department of Energy 2013)

The blades are usually made from glass fibre and polyester. The blade is simply the propeller of the device. The blades vary in length, and most wind turbine has two or more blades. The blade acts as barriers to the wind and transfers some of the wind's energy to the rotor shafts when the wind blows over them. The total cost percentage of the blades in an onshore project is about 22.2%. (U.S. Department of Energy 2013; Layton 2013; Pacella 2010)

The pitch system adjusts the angle of the blades to control the rotor speed and the use of the prevailing wind that is too high or too low for the generator to produce electricity. The total cost percentage of the pitch system in an onshore project is about 2.66%. (U.S. Department of Energy 2013; Layton 2013)

The rotor hub is manufactured from cast iron. It holds the blade in position and help in transferring the wind energy from the blades to the rotor shaft. The total cost percentage of the rotor in an onshore project is about 1% of the cost of the turbine. (U.S. Department of Energy 2013; Layton 2013)

Bearings support the free turning of parts like the shafts, hub, and generator and yaw drive. They withstand the varying forces and loads generated by the wind. The bearing cost is about 1.22% of the total cost of an onshore turbine project. (U.S. Department of Energy 2013; Layton 2013)

The nacelle housing is made from lightweight glass fibre and steels that site on top of the tower. A box like cover that contains the gear box, shaft, generator, breaks and other component of the turbine´s drive train. It supports the entire turbine drive train and cost about 4.15% of the total cost of an onshore turbine project. (U.S. Department of Energy 2013; Pacella 2010)

The brake system brings the entire turbine mechanism to a halt or a standstill when required .The total cost percentage of the rotor in an onshore project is about 1.32%. (U.S. Department of Energy 2013; Layton 2013; Pacella 2010)

The main shaft also known as a rotor shaft is connected to the center of the rotor and when the rotor spins, the shaft transfers rotational force of the rotor to the gearbox or the generator. The cost of the rotor shaft is about 1.91%. of the total cost of an onshore turbine project. (U.S. Department of Energy 2013; Layton 2013)

The **gearbox** increases the low rotational speed of the rotor shaft to a higher speed to about 1,000-1,800 rpm needed to drive most generators to produce electricity. The gearbox cost is about 12.91% of the total cost of an onshore wind turbine project. (U.S. Department of Energy 2013; Layton 2013; Pacella 2010)

The **generator** uses the properties of electromagnetic induction to convert the rotational force of the shaft into electrical voltage. A basic generator is made up of magnets and a conductor in a form of a coiled wire. The magnets surrounds the conductor and when the conductor starts to rotate relate to the magnet, it induce voltage in the conductor. The cost of the generator is about 8.45% of the total cost of an onshore turbine project. (U.S. Department of Energy 2013; Layton 2013; Pacella 2010)

The yaw system consists of a yaw drive and a yaw motor. The yaw drive rotates the turbine nacelle to face the wind when the directions of the wind change and the yaw motor provides the power needed by the yaw drive to work. The down-wind turbine system is not constructed with a yaw system because the wind changes the rotor direction naturally by blowing the turbine. The cost of the yaw system is about 1.25% of the total cost of an onshore turbine project. (U.S. Department of Energy 2013; Layton 2013; Pacella 2010)

The anemometer attached to the nacelle measures the speed of the wind and transmits the wind speed data to the controller center. (U.S. Department of Energy 2013; Layton 2013; Pacella 2010)

The wind vane determines the wind direction and communicates any changes of the wind direction to the yaw drive to reposition the turbine direction properly with respect to the wind direction. (U.S. Department of Energy 2013)

Screws are the items that hold the main components of the wind turbine in place. They are designed to withstand extreme loads. The screws cost is about 1.04% of the total cost of an onshore wind turbine project. (U.S. Department of Energy 2013; Layton 2013; Pacella 2010)

The cables link all the wind turbines in a wind farm to an electricity sub-station and to the grid. The cable cost is about 0.96% of the total cost of an onshore wind turbine project. (U.S. Department of Energy 2013; Layton 2013)

The transformer converts the electricity produced from the wind turbine to a higher voltage required by the grid. The transformer cost is about 3.59% of the total cost of an onshore wind turbine project. Figure 25 shows an example of an assembly of a wind turbine component. (U.S. Department of Energy 2013; Layton 2013; Pacella 2010)

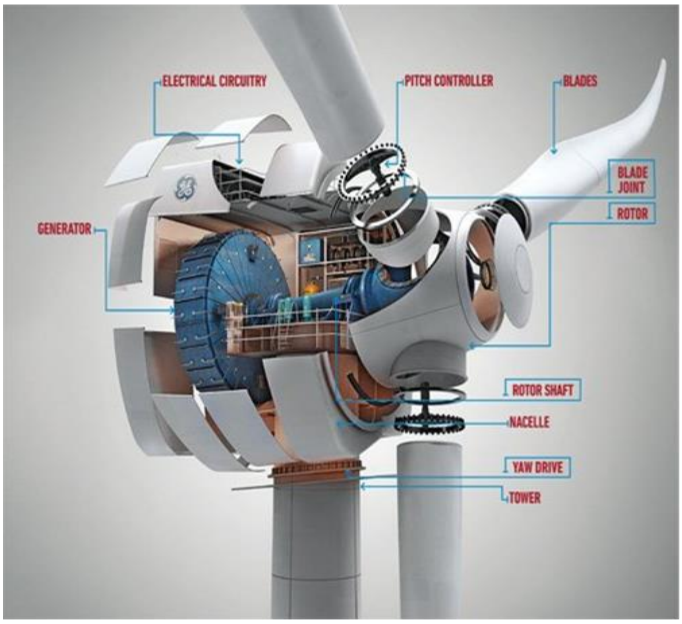


Figure 25. Wind Turbine Assembly (Pacella 2010)

4.3 Global Achievement of Wind Energy Generation

Global market data overview of the energy consumption in 2009 shown in Figure 26 indicates that the majority of the energy consumed was produced with fossil fuel about 81% of the total cumulative energy consumption for the year. Nuclear power had the lowest energy consumption of about 2.8%. The renewable energy mix consumption is the second, with about 16%. The renewable energy mix demonstrated traditional biomass as the highest form of energy consumed, (10% of the total energy consumption), followed by hydropower as the second highest renewable energy with about 3.4% of the total cumulative energy consumption for the year. 1.5% of the total energy consumed came from biomass, solar and geothermal for hot water or other heating. The consumption of energy from wind, solar, biomass and geothermal power generation was about 0.7% of the total energy consumed and biofuel as the least consumed energy of about 0.6%. Figure 27 shows the data analysis of the energy consumption for 2009. (Ren21 2011)

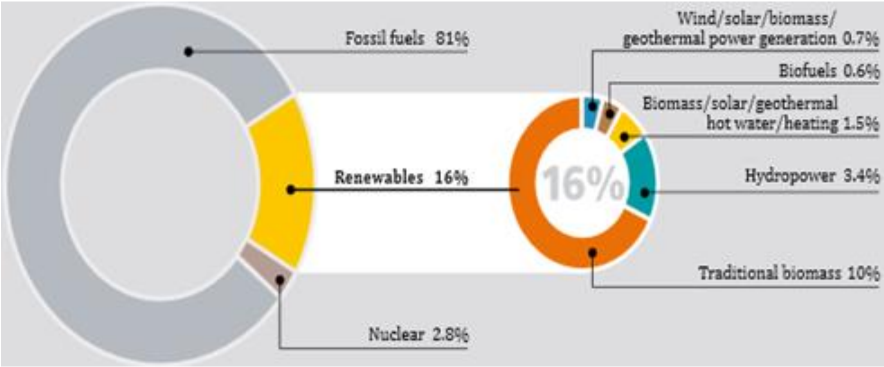


Figure 26. Global energy consumption in 2009 (Ren21 2011)

Figure 27 shows the global annual installation capacity of wind from 1996-2011. It illustrates that there has been an installations of wind turbine every year and also it shows that the installed capacity has an increase over the previous year. From the figure we can see that there was almost double installed capacity from 2000 to 2001 of about 3,760MW and 65000MW respectively. Figure 30 also shows a high increase in the installation capacity every year especially from 2008-2009, with a difference of about 11,595MW. The highest recorded installed capacity was in 2012, about 44,799MW. This shows there is a growing interest in the wind energy technology.

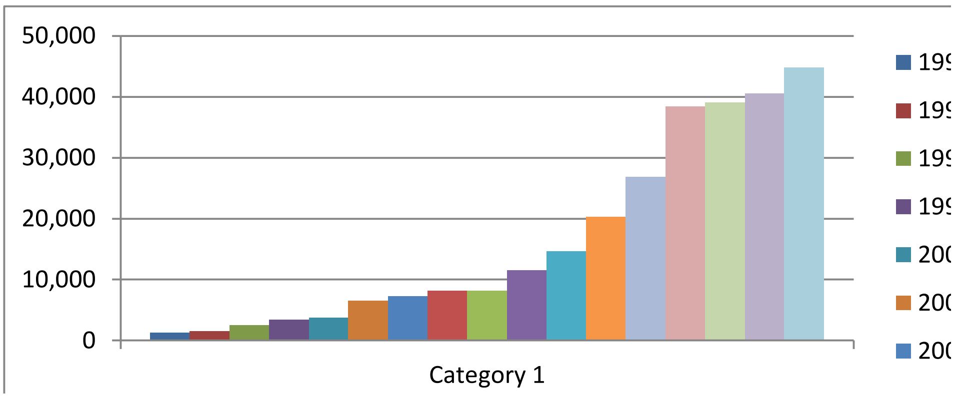


Figure 27. Global Annual installed capacity of wind Energy from 1996-2012 (Global Wind Energy Council 2012).

Table 2 shows an increase in the capacity of wind energy generation in some developed countries, in 2010 the United State of America added a capacity of 1,200 achieving the total capacity of 36,300MW and China had the highest added capacity of about 7,800 with the total available capacity of 33,800MW in the same year. India also had a high added capacity of about 1,200MW with the total of about 12,100MW. The data shown in Table 2 proves that interest in the wind energy technology was growing, so we continued the research to find out why.

Table 2. Evaluation of global cumulative installed capacity of Wind power in June 2010 (Merchant Brian Energy or Renewable Energy 2010)

Position	**country**	**Total capacity June 2010 (MW)**	**Added capacity June 2010 (MW)**	**Total capacity end 2009 (MW)**
1	USA	36,300	1,200	35,159
2	China	33,800	7,800	26,010
3	Germany	26,400	660	25,777
4	Spain	19,500	400	19,149
5	India	12,100	1,200	10,925
6	Italy	5,300	450	4,850
7	France	5,000	500	4,521
8	United Kingdom	4,600	500	4,092
9	Portugal	3,800	230	3,535
10	Denmark	3,700	190	3,497
Rest of the World		24,500	2,870	21,698
Total		175,000	16,000	159,213

4.4 Wind Turbine Manufacturers

The wind energy market demand is growing and as a result so is the wind turbine manufacturing companies. The wind turbine manufactures also have an effect on the wind technology because they make the product. They have been making constant modification and upgrade of the wind turbine technology therefore causing a growing interest in the wind energy technology. As a result the wind technology is becoming more effective and a reliable technology.

Table 2 shows an illustration of the top 10 wind turbine manufacturing companies showing their market share percentage. However according to the article by IHS

Emerging Energy Research Enercon overtook Vestas in Europe, as a market leader due to the boom in the German onshore market. But Denmark's Vestas was able to hold on to the position as the world's leading wind turbine manufacturer in 2011. (IHS Emerging Energy Research 2012)

Table 2. Top 10 wind energy turbine manufacturers in 2011 (IHS Emerging Energy Research 2012)

Country	**Name of Company**	**Market share**
Denmark	Vestas	12.9%
China	Goldwind	8.8%
Germany	Enercon	7.6%
India	Suzlon Group	7.6%
Germany	Siemens Wind Power	7.6%
United States	GE Energy	7.4%
China	Sinovel	7.2%
China	Guodian United Power	7.0%
Spain	Gamesa	6.4%
China	Ming Yang	2.9%

4.5 Area Suitable for Wind Energy Generation

As the name of the technology suggests, wind energy turbines need wind as a source of fuel to generate electricity for consumption. Generally the wind power potential is relative to the cubic area of the wind. So then, before wind turbines are built the wind flow of the area for the project should be measured with an anemometer or other kinds of instrument for measuring wind speed for at least two years to make it financially feasible before the project can take- off. An appropriate wind resource assessment is the most important and necessary data for a wind project. Figure 28 shows a general illustration of the global wind speed. The area indicated with blue on the land has an estimation of 3.0-4.5 m/s and the area indicated with green has a speed of about 4.5-6.0m/s. The area indicating yellow shows a speed of about 6.0-7.5m/s and the area with red has a speed of about 7.5-90m/s (LaMonica 2008).

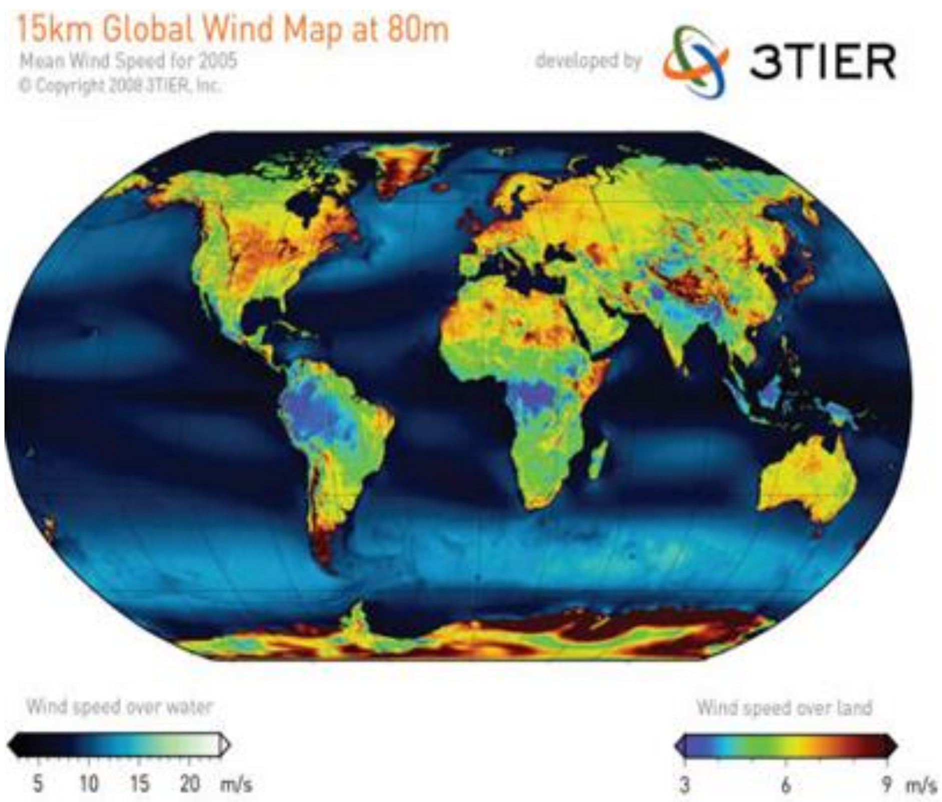


Figure 28. Global Wind speed Map (LaMonica. 2008).

There are two ways the wind forms around the world in a constant continuation, besides a random storm or a passing tornado. The two forms found were change in the temperature and rotation of the earth.

Change in temperature: The atmospheric wind flow formed is regulated by the difference in temperature over sea and land areas. The wind flow is from the sea to the land during the summer due to the fact that the warm air on the land areas evaporates and that allows cool air to move in that area. The same way during the winter the warm air on the sea ascends allowing air on the land to move in. Figure 29 illustrate the flow of the wind from a cool area to a warm area. (Garrison 1993)

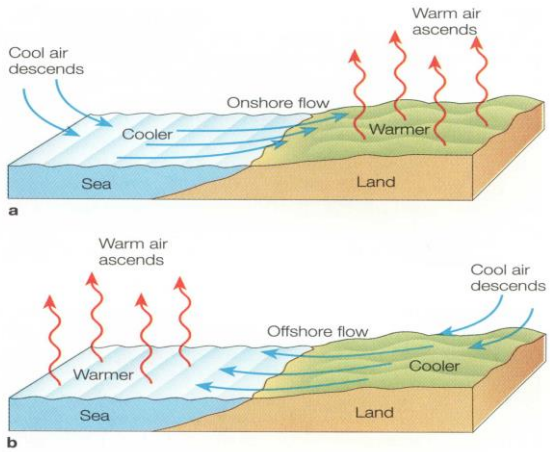


Figure 29. Illustration of the flow of the wind (Garrison 1993)

Rotation of the earth: The rotation of the earth also regulates the flow of the wind around the earth in two ways. First of all, as the air flow toward the equator, the earth rotation shifts the ocean and land eastward under it. The outcome is what we know as the polar easterly wind. The flow of high speed winds become unsteady forming eddies which restructure the air pressure circulation. Figure 30 illustrate the earth rotation regulating the atmospheric circulation of the wind. (Garrison 1993)

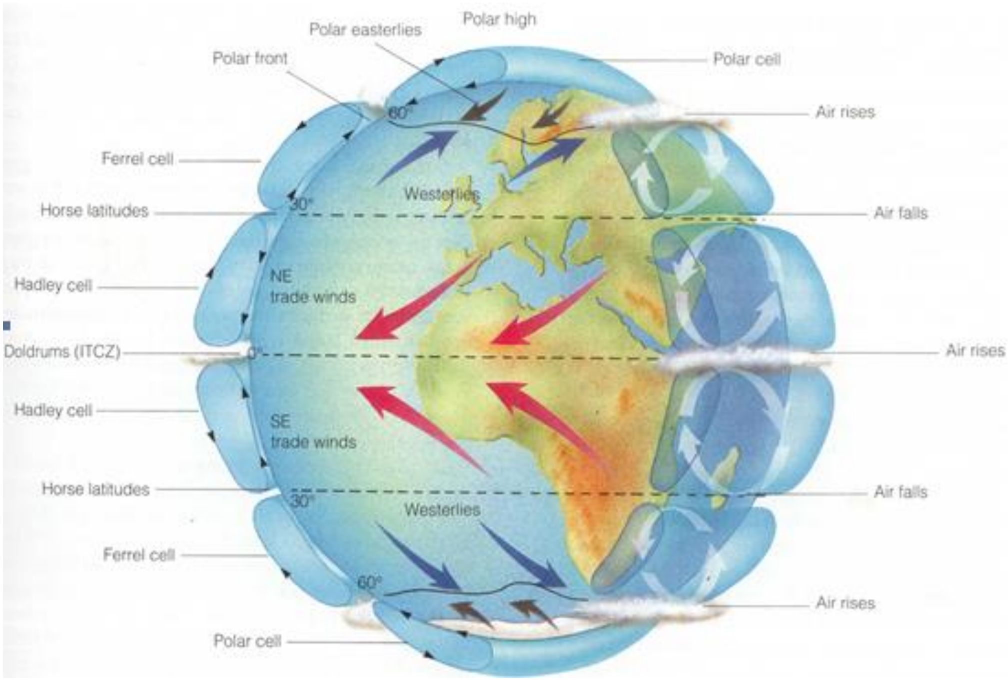


Figure 30. Wind formation around the earth (Garrison 1993)

4.6 Types of conventional wind energy constructions

There are several types of conventional wind energy turbine constructions. Such project can be classified based on where they are constructed, such as inland or mountain area wind turbine, onshore wind turbine, shallow water wind turbine, transitional depths and deep water wind turbine. Figure 31 illustrates the types of wind turbine constructions. (NREL 2013)

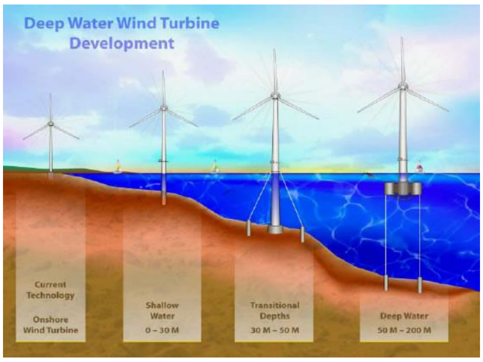


Figure 31. Illustration of the types of wind turbine projects (NREL 2013).

Generally, there are two main types of conventional wind energy turbine projects, the onshore and offshore wind energy projects

Onshore wind energy turbine projects are regular wind turbine projects that are constructed in land, on the ground. Attractive areas for onshore projects constructed with high energy production potential are normally located near coasts areas or on the edge of water bodies, inland areas with open terrain and mountain zone. (Feltes et al. 2012)

The offshore wind energy turbine projects are the wind turbine projects that have been constructed on water and have their foundations in the sea. The shallow water wind turbines are the wind turbines constructed near the shore but build in the water. Transitional depths wind turbines are the wind turbines built near the shore but deeper than the shallow water turbines. Deep water wind turbines are the wind turbine projects constructed deep in the water or sea far away from the land. (Feltes et al. 2012)

To construct a deep water wind turbine is difficult, the turbine has a short life span and is very expensive if the tower structure is mounted on the sea bed. Therefore, researchers have come up with a better solution known as the floating wind turbine. The floating wind turbine is mounted on a floating structure off-shore, far away from land, and a long tension leg cable made from steel is connected to the corners of the platform from a foundation made from a concrete block or another mooring system on the ocean bed. Figure 32 shows the offshore wind constructions, a floating mounted wind turbine both on and in the sea. (Stauffer 2006)

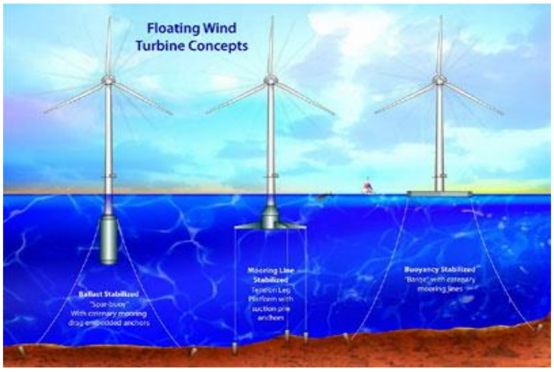
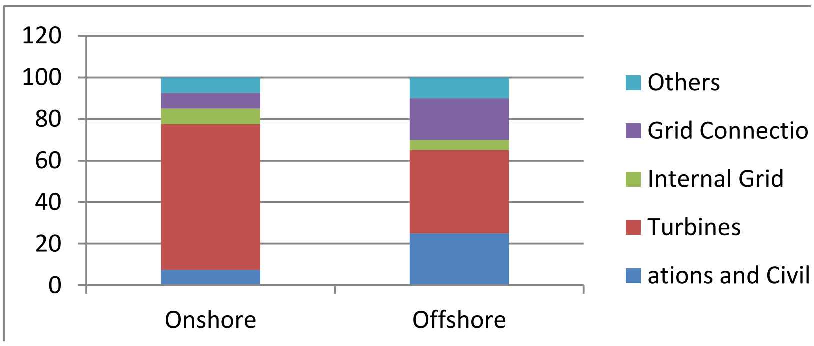


Figure 32. Floating mounted wind turbine concept (Stauffer 2006)

Table 3 shows the comparison of the cost of onshore and offshore. In an onshore conventional wind turbine project more than 50% of the entire cost goes to the cost of the turbines. Whereas in an offshore project the cost of grid connection and foundation cost increase making the wind turbine cost 50percent or less of the total cost of the wind project. (Feltes et al.2012)

Table 3. Comparative cost of onshore and offshore (Feltes et al.2012)



4.7 Wind Energy Application

The wind energy applications can also be categorized based on the end-usage of the technology. This chapter classifies the wind energy produced based on the grid connections used to transmit the energy.

On-grid: In an on-grid wind turbine application the electricity produced is feed directly into the electric grid which is connected to houses. There are two types of on-grid applications, isolated and central. (Csanyi 2013)

Off-grid: This type of wind energy application is where the electricity generated is not connected to a grid but mostly connected directly to houses. These wind energy application types are suitable for rural areas with high wind speed but located far from the national grid. This type of application often supplies small amount of power typically used for charging batteries that store the energy produced by the wind turbine to be used later for pumping water, providing electricity to electric lights and other electric appliances or for providing smaller amount of electricity to houses, an office or even industry back up batteries. (Csanyi 2013)

Isolated grid: This type is an electric network that is independent from the national grid which is often used in moderate scale applications for generating electricity capacity usually ranging from 10kW to 200kW. They are small wind turbine project that are generally constructed in isolated sites with good wind speed to help supply a portion of the electricity requirement. (Csanyi 2013)

The central-grid electricity generation has approximately 200kW or more power generation capacity. They involve large scale of wind energy turbines, clustered together to form a wind farm to provide multi megawatt range of electric power which are connected to the electric power transmission network. The area where the wind farm is development can be used for other purpose such as agriculture or forestry. (Csanyi 2013)

4.8 Arrangement of the Wind Farm

A wind farm consists of several number of wind energy turbines which are installed in rows perpendicular to the wind flow direction. When the passing wind sticks the turbine blades, there is a displacement in the winds direction and force which reduces the kinetic force of the wind on the next wind turbine. This phenomenon is known as a wake effect and it usually affects the energy production of the wind farm due to the disturbance in the flow of the wind. Figure 33 shows an illustration of a wake effect in a wind farm. (Longatt et al. 2012)

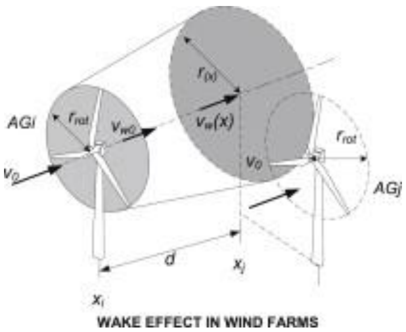


Figure 33. Wake effect in a wind farm (Longatt et al. 2012)

To better utilize the wind energy, the wind farm arrangement is very important for the energy production. Figure 34 shows an illustration of the arrangement of a wind farm adopted by a wind energy generation company.

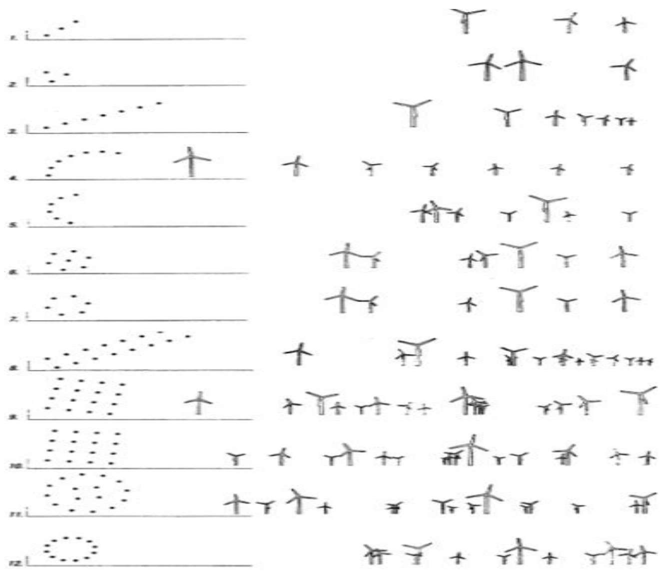


Figure 34. Wind farm arrangement (Longatt et al. 2012)

4.9 Environmental Effect

The environmental impact of an energy technology is one of the most significant aspects to check when selecting an energy generation technology. To best save and protect the environment from any form of environmental pollution for the future inheritance and their generations, it is very important that we check the environmental impacts associated with the technology so we can recognize and mitigate the effect before considering the construction of the project. The wind energy turbine is one of the top forms of green energy technologies since it does not produce any toxic waste or global warming emissions. The technology has a free, inexhaustible and abundant and is a possible continuous 24hours energy source and has one of the best ways of recycling. The wind energy technology itself does not occupy a large area but when constructing a wind farm the turbine needs spacing, approximately 5-10 rotor diameters apart. This makes them occupy a large area depending on the site. Wind turbines installed on flat sites occupy more land than those constructed on hilly site. The area or site can be also used for growing crops or other farm activities since the actual land surface is not in use. The conventional wind energy turbine technology is known to produce noises and visual impact. Most of the noise caused by the wind turbine comes from the movement of the turbine blades through the air and also by the movement of the turbine itself. Depending upon the turbine design and the wind speed the overall sound level can be reduced. Therefore the noise and visual impact of the wind turbine should be considered before erecting the turbine. The total wind turbine life-cycle stages including production, transportation, construction, operation and maintenance, decommissioning and dismantlement contribution to global warming emissions are between 0.02 to 0.04 pounds of carbon dioxide. The traditional energy generation sources pollute our environment, causing several health and environmental problems which also lead to global warming so switching to wind energy technology is a best way to reduce the pollution of in the Ghanaian environment and helps with reducing the Greenhouse Gas (GHG) Emission. (Union of Concerned Scientists 2013)

5 WIND ENERGY POTENTIALS IN GHANA

Ghana was chosen for this research because the energy demand of the country is higher than the energy production and there is a growing demand of the energy as described in Chapter 1.1. Also the government of Ghana aim at increasing the country's renewable energy production as observed in Chapter 1.1. Ghana has good feed-in tariffs that are fixed and applicable for 10 years but subjected to review every 2 years. The feed-in tariffs are as follows:

- wind 0.16 cent/kWh,
- solar 0.20 cent/kWh,
- hydro10MW or less 0.13, hydro10MW-100MW 0.11 cent/kWh,
- landfill gas 0.15 cent/kWh,
- sewage gas is 0.15 cent/kWh
- biomass 0.15 cent/kWh.

Wind energy technology was selected based on the reason that the feed-in tariff of the wind energy is higher than most of the other energy forms except for solar but there already exist so many well established solar companies in Ghana but there is no company for wind energy.

Also the wind technology has reached a maturity and eminence during the past 17years as a result of global commercial competition, mass manufacture and continuing technical improvement success in research and development as shown in Chapter 4. Even though the global installation capacity of wind power plants has reached about 282.5GW in 2012, a cumulative increase is almost 19% from installation recorded in 2011 as shown in chapter 4.3. However, the structural characteristics affecting the development of wind power plant project on the global scale has not have much impact on the African continent and this research aims to change that by addressing the potentials of wind energy in Ghana. The energy acquired from the wind is free, clean and inexhaustible. The kinetic force provided by the wind is a promising source of renewable energy with significant potential in many parts of the African continent. Wind energy is now being produced in a large scale all over the world, and is generating electricity at a price competitive with conventional power plants in the long term. (CIA 2013; ECOWREX 2011; Canadian Wind Energy Association 1996)

5.1 The Potential of Wind Energy Generation in West Africa

The results from a collected record propose that, wind energy generation in Africa remains small and that the energy contributions to the energy mix in the Africa continent may remain unchanged over a long period while we observe a rise in the number of wind energy project globally. Figure 35 shows some potential projects of wind energy in West Africa. The data shown in Figure 35 is the accumulation capacity of wind turbine potential in the various West African countries. Senegal and Ghana are objectively the best countries in West Africa for setting up a wind power plant farm. Senegal has the known highest potential generation capacity of approximately about 150MW and Ghana is the country with the second highest potential generation capacity, with about 100MW followed by Niger with about 30MW potential capacity. Cape Verde with about 27MW wind energy potential comes next, followed by Gambia with a potential of about 19MW and Togo and Nigeria with 20MW wind energy potential and Benin with 10MW. (Saho 2013)

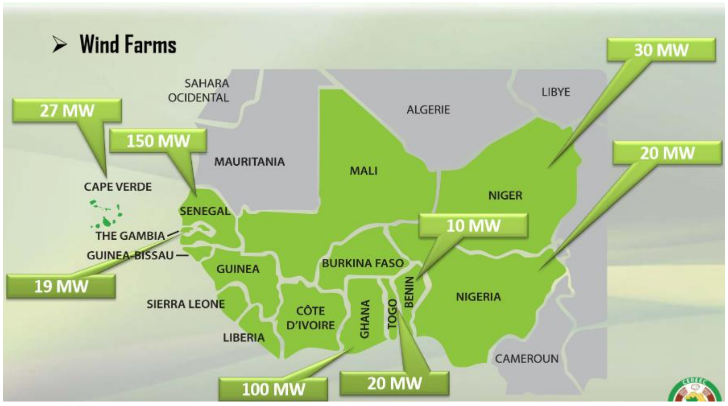


Figure 35. Potential wind project in West Africa (Saho 2013)

Ghana show some potential in wind energy generation, and so further analysis was made to identify the areas in Ghana where the potentials are highest and to develop how the potential can be used to benefit the Ghanaian community.

5.2 Production Process for Wind Energy in Ghana

In Ghana, the use of wind for producing electricity is being taken into consideration due to the energy demand of the country and the country's energy plans for exploitation of renewable source of energy. The development of a successful wind energy project in Ghana includes the availability of the wind resource in the location of the project, the acquisition of all permits for the project from several institutions, the design of the electrical, civil and mechanical infrastructure of the project, the outline of the wind turbines, the selection and purchasing of the wind turbine equipment, subcontracting, construction and the commissioning of the installation (see Figure 36). The construction includes the preparation of the site, grading of road to be used in transporting equipment for the project, the construction of the foundation for the turbine, installation of electrical lines and transformer, setting up the turbine and the erecting of the substation and other necessary buildings. (CIA 2013; ECOWREX 2011; Canadian Wind Energy Association 1996)

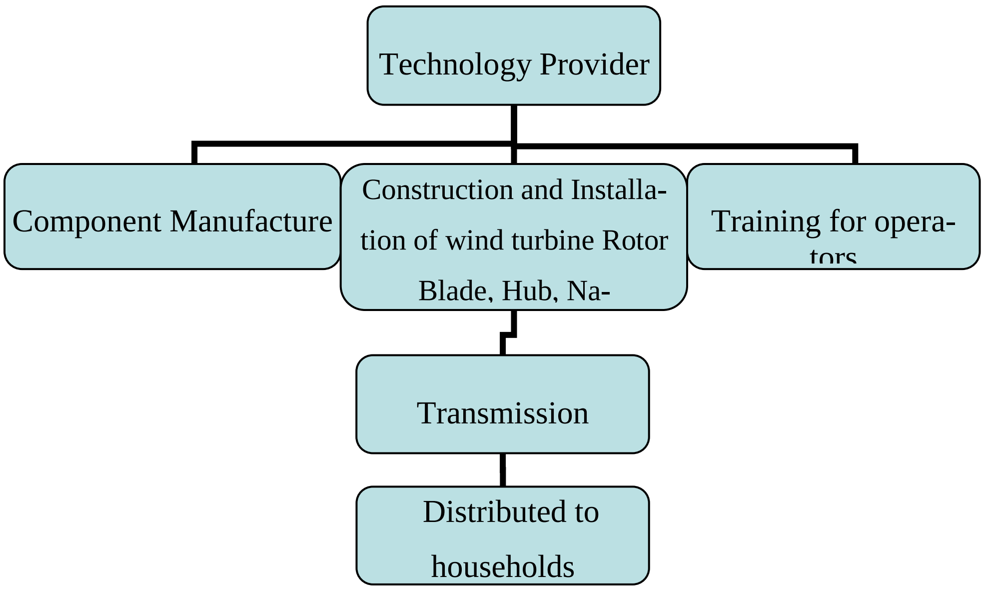


Figure 36. The supply chain of the wind project in Ghana

When the electricity is produced directly to a house hold that is if an isolated-grid or off-grid system is used, the actors involved are the technology providers and the household in concern. But if the selected project will be directly connected to the national grid, the actors involved in the transmission and distribution of the electricity generated will be GRIDCO and Electricity Company of Ghana (ECG) respectively. GRIDCO a transmission system operator in Ghana will supply the energy providers with a grid code to specify the requirements for interconnection to the transmission grid. The Electricity Company of Ghana will distribute the electricity to the households.

5.3 Procedure of Wind Energy Project to Ghana

As shown in Chapter 5.1 there is a potential of wind energy generation in Ghana. But for a further analysis to prove the potential of wind energy in Ghana, this section of the thesis uses a procedure of a wind energy project shown by Canada RETscreen International. In the analysis of the procedure of wind energy project several experts will be needed to contribute to the development, testing and validation of the wind energy project. The prototype procedure was adopted because it assisted in evaluating the amount of energy to be produced, the equipment needed for the project, investment and life-cycle costs, greenhouse gas emissions reduction, return on the investment and the risks involved in the project. Some experts needed for the prototype procedure for the wind energy project included the wind energy modelling experts, cost engineering professionals, greenhouse gas modelling specialists, financial analysis experts, and ground station and satellite weather database scientists. (Canada RETscreen® International 2004)

5.3.1 **Wind Energy Analysis for Ghana**

The wind resource assessment is the major activity in the wind energy project. This analysis will help in the selection of a location in Ghana. The wind turbines cannot generate electricity if there is no wind flowing through the area where the wind turbine has been constructed. The data of the wind speed is very critical for the electricity production, therefore it is recommended that the project developer collects at least a full year of wind measurements at the particular location where the wind project is going to be installed. (Canada RETscreen® International 2004)

Ghana wind speed data analysis

This section cumulates and evaluates the data of wind measurement located in Ghana. Before the wind energy project should begin, the flow of wind in the location of the wind project should be measured for at least 2 to 4years on a quality and quantity bases to ensure an accurate wind resource assessment. Most of the wind measurement used in this thesis was collected by Meteorological Service Department (MSD) of Ghana taken at the 22 synoptic stations they operate. The measurement was collected on monthly bases for a period of 1995 to 2002 above ground adjusted to 12m and 50m. The power production of the conventional wind turbine is proportional to the square area of the average wind speed. (NREL)

Table 4 shows the production of wind energy from one or more wind turbines producing at standard condition of atmospheric pressure and temperature. The parameters are based on the energy production curve of the selected wind turbine entered in the Equipment Data worksheet and the average wind speed at the proposed site. (NREL)

The hypothetical power, P of the wind is given as:

$$P = 0.5\rho(\pi/4)d^2x^3 \qquad (1)$$

Where ρ is the air density and is equals to 1.250 kg/m^3 at sea level and 20 °C, d is the air pocket diameter and x is the local wind speed. 41/ Where the total area in km^2 is 715, having a 0.3percent windy land area and having a wind speed of 6.976. (see table4)

$$P=0.5(1.25)(3.142/4)(71,500*0.3)(6.976)^3 = 3,574,510W$$

As shown in Table 3 the total capacity for a moderate wind resource scale with wind class 3 will have approximately 3575MW wind power generated.

Table 3. Wind scale of Ghana wind resource data (NREL)

Wind Resource Scale	**Wind Class**	**Wind Power at 50 m W/m^2**	**Wind Speed at 50 m m/s***	**Total Area km^2**	**Percent Windy Land**	**Total Capacity (MW)**
Moderate	3	300 – 400	6.4 – 7.0	715	0.3	3,575
Good	4	400 – 500	7.0 – 7.5	268	0.1	1,340
Very Good	5	500 – 600	7.5 – 8.0	82	<0.1	410
Excellent	6	600 – 800	8.0 – 8.8	63	<0.1	315
					Total	5,640

Using the wind class flow shown in Table 3, and the data collected by Meteorological Service Department (MSD) for Ghana wind flow the following result were obtained as shown in Table 4.

Table 4. Ghana wind resource data (NREL)

Region	**Class 3 (km^2)**	**Class 4 (km^2)**	**Class 5 (km^2)**	**Class 6 (km^2)**	**Good to Excellent Potential(MW)**	**Moderate to Excellent Potential(MW)**
Volta	181	161	66	61	1,440	2,345
Eastern	285	26	-	-	130	1,555
Northern	73	53	-	-	265	630
Brong-Ahafo	83	17	16	2	175	590
Ashanti	93	11	-	-	55	520
Greater Accra	-	-	-	-	-	-
Upper East	-	-	-	-	-	-
Upper West	-	-	-	-	-	-
Central	-	-	-	-	-	-
Western	-	-	-	-	-	-
				Total	2,065	5,640

Assumptions: Installed capacity per km^2 = 5MW

The total wind energy that can be generated in the Volta region by adding all the wind class flow from moderate to excellent as shown in Table 4 will be

(181 + 161 + 66 + 61) * 5MW = 2,345MW

The wind energy that can be generated with good to excellent potential or from wind class 4 to class 6 in the Volta region can be calculated as

(161 + 66 + 6) * 5MW = 1,440MW (see Table 4)

Table 5 shows some of the coastal areas in Ghana with wind speed usable for wind energy generation according to the Energy Commission of Ghana.

Table 5. Wind Measurement along the coast areas in Ghana (Energy Commission (EC), Ghana)

Site	**Position**		**Altitude (m)**	**Height (m)**	**Annual Mean Wind Speed at 12m(m/s)**	**Predicted Wind Speed at 50m(m/s)**
	Latitude (^oN)	**Longitude (^oE)**				
Adafoah	5.79	0.55	-	12	5.3	-
Aplaku	5.32	0.20	50	12	5.2	6.92
Asemkow	5.21	3.27	10	12	3.7	5.16
Kpone	5.68	0.07	96	12	4.9	7.18
Lolonya	5.79	0.44	40	12	5.4	7.15
Pute	5.79	0.52	3	12	5.5	7.37
Tema	5.62	0.07	50	12	5.0	6.66
Warabeba	5.22	0.35	50	12	3.9	5.38
Anloga	5.47	0.55	-7	20	5.4	6.80
Amedzofe	5.50	0.25	740	20	3.9	5.00
Kue	5.30	0.35	327	30	2.9	3.40
Nkwanta	5.15	0.30	295	30	3.5	4.00

The data collected in Table 4 and Table 5 shows that the Volta region is the area in Ghana with the highest wind speed. Data was also used from DATSAV2 global database acquired from the US National Climatic Data Center (NCDC), collected by first-order meteorological stations throughout the world. NREL examines several satellite-based scatter meter of wind data. Figure 37 shows the NREL analysis of the wind speed and location in Ghana.

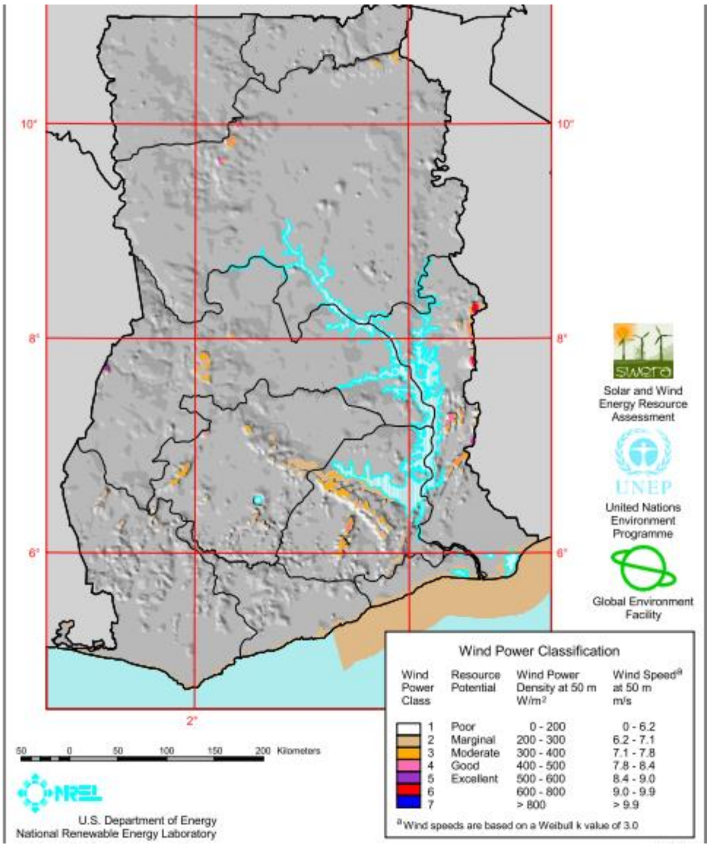


Figure 37. Map of Ghana showing Wind speed (NREL)

From the NREL analysis of wind speed and location in Ghana, the conclusion can be drawn that the specific area at the Volta region in Ghana with the most potential for wind energy generation is Nkwanta North District. By the analysis made by NREL the Nkwanta North District area has 9.0-9.9 m/s wind speed.

5.3.2 **Equipment Needed for the Project**

This section describes the various systems or information needed to actually start and complete the project after the wind speed data have been gathered. The systems or information needed for the project are information on Ghana's national grid, household energy consumption, location best for the wind turbine, the wind turbine system and all necessary contracts needed for the project.

The transmission network in Ghana is inter-connected with the grid connections with La Cote d'Ivoire, Togo and Benin. Burkina Faso is also connected to a 33kV line to Ghana. Figure 38 shows the Ghana national grid transmission lines, proposed grid lines, positions of existing hydro and thermal power plants and also potential power plant projects.

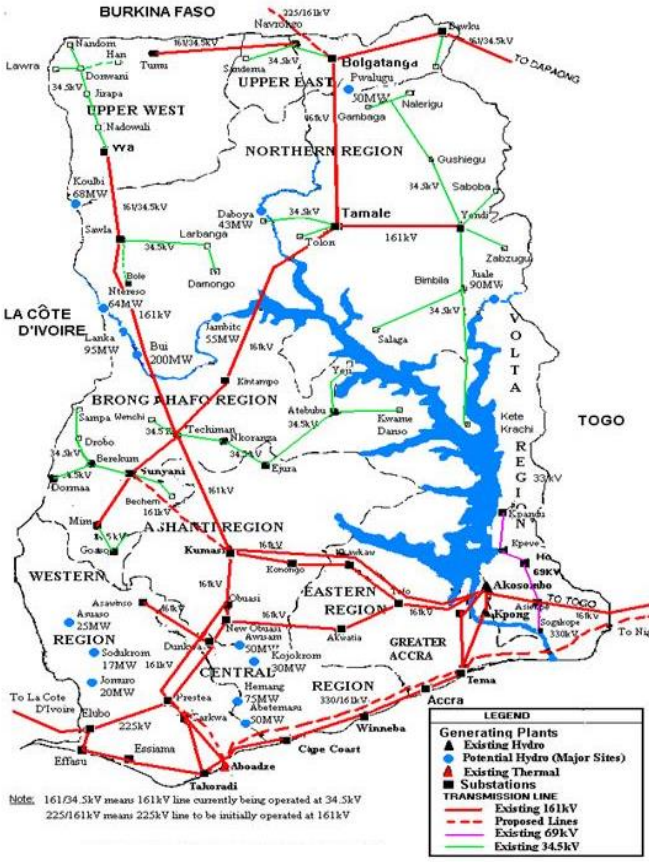


Figure 38. Map of Ghana showing Transmission Grid (Volta River Authority)

The Ghana's national grid is very important piece of information to have whether the system is an isolated-grid or off-grid, or if the energy produced is going to be fed directly into the grid. This is because an isolated-grid or off grid becomes competitors for the Electric Company of Ghana becomes and therefore that makes it very necessary to know where the grid lines are located to assist in market plans involving them and other future competitors. If the project aims at supplying the energy generated to the national grid then knowing how close the grid is to the site is very significant for the cost analysis of the project.

For an accurate market analysis especially for project located in area far from the national grid where off-grid or isolated application energy generation system is selected, the data for energy consumption is needed to determine the demand of energy by the population to help in generating sufficient wind energy.

Table 6. Annual kWh consumption surveyed for houses (Ghana Residential Energy Use and Appliance Ownership Survey 1999)

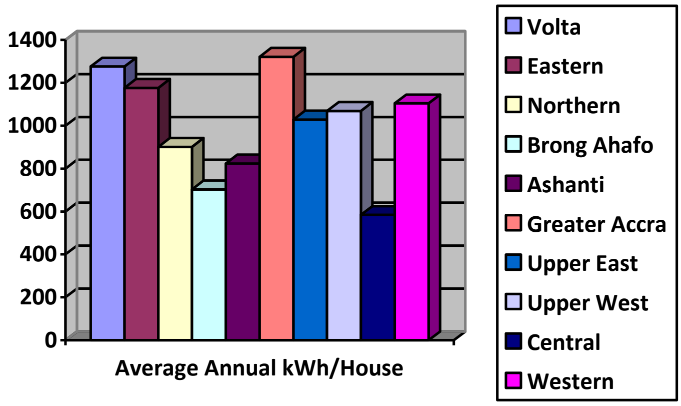


Table 6 shows a general average electricity consumption of a household in Ghana according to the regions. It shows Greater Accra as the region with the highest energy consumption per house followed by the Volta region with a consumption rate of more than 1200kWh. The region with the lowest energy consumption according to the article was Central and the second lowest was Brong Ahafo.

The reasons for choosing the location was based on the high wind speed data observe from Figure 37 and was compared with areas along the coast with wind measurement. The population in the area and their energy consumption in Table 6 were also taken into consideration. Since isolated-grids or off-grid applications were not used for the analysis but the closeness of the location to the national grid shown in Figure 38 was considered in the selection of a site for the construction of the wind turbine.

Nkwanta South District is one of the 25 districts in the Volta Region of Ghana located between latitudes 7°30’N and 8°45’N and longitude 0°10’W and 0°45’E. Nkwanta is the capital and administrative centre of Nkwanta South District.

Nkwanta had a population of about 153,276 in 2000 with a population growth rate of 3.0, higher than the whole Volta region which is 1.9 and that of the country 2. The district shares boundaries with Nanumba Municipal to the north, Republic of Togo in the east, Kadjebi District in the south and Krachi East District to the West. The Municipality has the largest land area in the Volta region about 4530km^2 representing 22.02% of the total land area of the Volta region which is about 20570km^2. Some of the other towns within the district include Kpassa, Nkwanta, Damaniko, Brewaniase, Sibi Hill Top, Nabu, Bonakye, Abunyanya, Keri, Tinjase, Sibi Central, Kecheibi, Nsuogya, Pusupu, New Agou, Kabre Akura, Nyambong, Nyambong, Odumase, Adele, Bontibor and Ofosu. The municipality is located at a very tactical position with potential for firm economic development. The district is accessed by a combination of small roadways, feeder roads, highways and water transport by the Volta Lake. The economic life of the people in the district is mostly commercial trading of farm products and fishes, partly processed farm products like cassava-dough, gari and local soap, and trading of manufactured products both imported and locally produced. The district lack electricity, therefore making their energy demand feasible for the project. Figure 39 shows the location of Nkwanta district on the Ghana map. (Nkwanta South District Assembly 2013)

Figure 39. Map of Ghana the location of the Nkwanta (google map)

Figure 40 shows the site selected for the wind project, an area located on a hill in Nkwanta. Since the project has been analysed for Nkwanta district, it is necessary to identify some of the roads in the area. Figure 41 shows an image of the roads in the Nkwanta district.

Figure 40. Location of the project (Flickr 2013)

Figure 41. Roads in Nkwanta District (Flickr 2013)

The distance from the Tema harbour where the turbine will arrive to Nkwanta is about 339km, which will take about 4hr and 27mins by car figure 42.

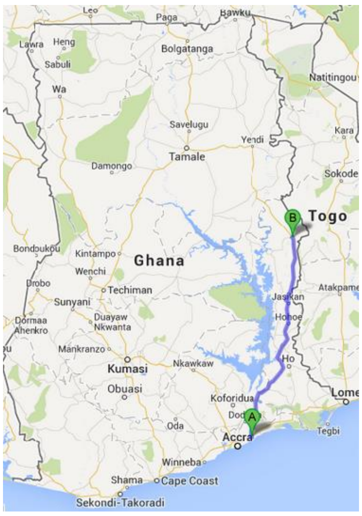


Figure 42. Direction from the Tema harbour to Nkwanta (google map)

The wind turbine system is the major equipment for a wind energy power plant project. The energy curve data of the turbine also referred to as the total amount of energy a wind turbine can produce over a range of annual average wind speed, can be used to help for the selection of the best turbine for a specific area based on the wind speed. There are three ways for specifying the energy curve data, they the Standard, Custom and User-defined. For the standard and custom circumstances the energy provider uses the wind turbine power curve data received from the turbine manufacturer and the Weibull probability function describe in equation 3 is used to calculate the energy curve data. (Hiester and Pennell 1981, Canada RETscreen® International 2004)

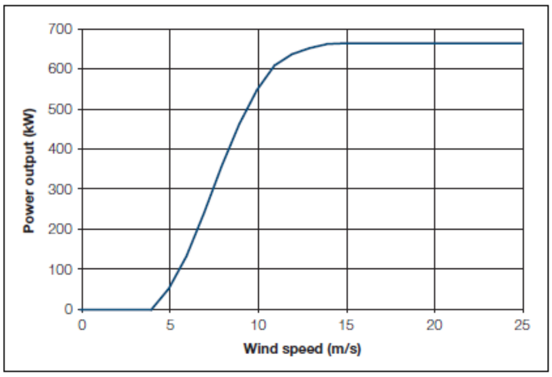


Figure 43. Power curve for Vestas V47-660kW wind turbine (Vestas)

Figure 43 shows an illustration of Vestas V47 with capacity 660kW wind turbine power curve. It shows how steadily the output of the turbine increases in respect to an increase in the wind speed but remains constant when the output of the wind turbine reaches about 670kW. Each point on the wind energy curve, Eẍ, is then calculated as:

$$E_{\ddot{x}} = 8760 \sum_{x=0}^{25} P_x \, p(x) \qquad (2)$$

Where ẍ is the mean wind speed considered (ẍ=0, 1,…,25m/s), P_x is the turbine power at wind speed x, and p(x) is the Weibull probability density function for wind speed x. Weibull expresses the probability *p(x)* as shown in equation 3 with a wind speed *x* during the year. (Hiester and Pennell 1981)

$p(x) = (k/C)(x/C)^{k-1} \exp[-(x/C)^k]$ (3)

Where k is the shape factor and is $k < 3$, $x \geq 0$, and $C > 0$. A low shape factor indicates a wide distribution of wind speed and a high shape factor point to a narrow distribution of wind speed around the average wind speed. C is the scale factor, derived from the equation. (Hiester and Pennell 1981)

$C = \ddot{x}/\Gamma(1+1/k)$ (4)

Where $\ddot{x}$ is the average wind speed value and taken as 7.5 from table 4 Wind Resource Scale. Γ is the gamma function.

$\Gamma(\ddot{x}) = (1x1) = 1$

Basing the wind speed distributions on Weibull k value, where the shape factor is equal to 2 since it fits in well with a number of sites long-term distribution of mean wind speeds. A wind speed of 7.0m/s based on Table 3 moderate wind speed and equation 2, equation 3 and equation 4. Each point on the wind energy curve

$C = 7.5/1(1+1/2) = 5$

$p(x) = (2/5)(7/5)^{2-1} \exp[-(7/5)^2] = 1.1$

$E_{\ddot{x}}$ = 578160, 5396160, 6359760, 6359760, 6359760

From the data collected on Ghana wind resource, the Volta region was known as having a high wind speed which is good for all the types of turbines (see Chapter 4.2). The best for utilizing the wind for generating of electricity is a horizontal axis wind turbine because the blade is positioned in a way to capture and generate a high torque for the generator. The Eastern region was also found to have a good speed but the areas with the high wind speed were found to have small volume. The paramount turbine to help increase the output of the turbine will have to be the shrouded wind turbine. This is because it can gather and direct the wind flows to the blades of the turbine. In the Northern and Brong-Ahafo region the wind speed and volume was identified to be average. Both shrouded and catching wind turbines will be ideal for the area in utilizing the wind resource. The Ashanti region has a low level of wind speed and the volume is also low. The best suitable turbine for the area will be the catching wind turbines. This can help to increase the energy generated. There was no data on the other regions wherefore identifying the best turbine for those areas will be a very challenging task so no suggestions were given for them. Figure 44 shows an illustration of the wind energy technology system schematic. It describes the structure of an installed wind turbine and the dimensional names for some important areas needed for the calculation of the output of the turbine.

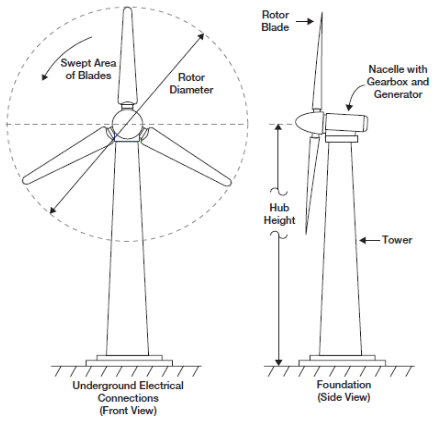


Figure 44. Wind Turbine Schematic (Canada RETscreen® International 2004)

The reasons for the selection of the above wind turbines for the locations in Ghana and the selection of 660kW wind turbine for Nkwanta was based on the fact that there is less fluctuation in the electricity output even if there is random wind speed. Secondly the closest local electric grid to Nkwanta as shown in Figure 37 when compared to Figure 38 is 34.5kV which may not be able to accommodate high capacity. Also the existing wind resource can be more efficiently used when the turbines selected for Nkwanta is a horizontal wind turbine. Furthermore the cost of building new roads, strong and wide enough to carry the turbine components may be very high. The stability of the wind turbine whenever the blade and other part of the turbine were struck by the wind was also consideration in the selection of the wind turbine.

Table 7. Turbine information needed for the project (Vestas)

System	Information
Number of Blads	3
Power density	0.03m²/kW
Rotor diameter	47m
Rotor Speed	28.5rpm
Cut-in speed	4m/s
Cut-out speed	25m/s
Swept area	1,735m²
Hub height	40m

Table 9 shows some basic information on the turbine that can be used to assist in the project developmental plans. Figure 44 shows the installation mechanism of the wind energy turbine. It shows some dimensions that are used in the installation process.

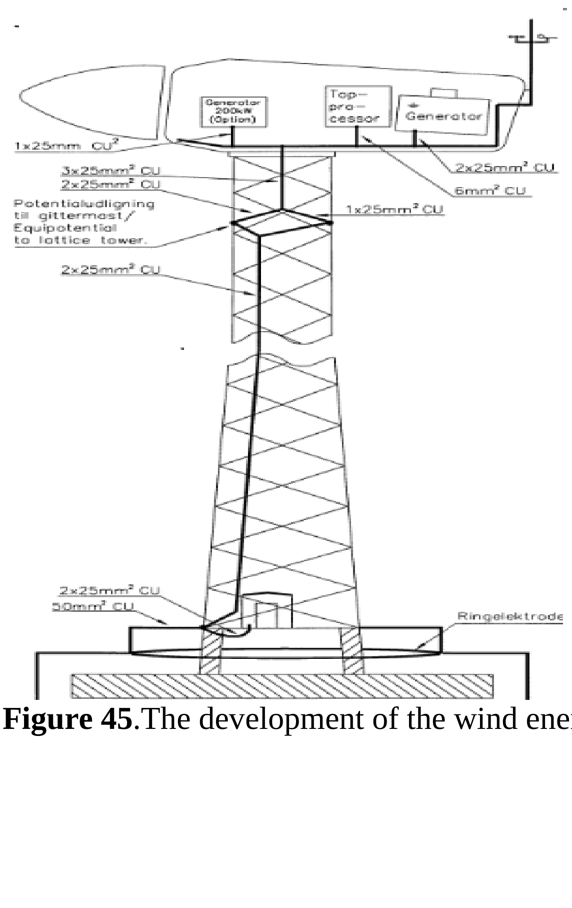


Figure 45.The development of the wind energy turbine (Vestas)

The installation and generation of the wind turbine in Ghana will require several contracts as explained in the article ‘Renewable Energy Contracts Library’. Some of these contracts include power purchase agreements, interconnection agreements, request for proposals, engineering and construction contracts, operation and maintenance contracts, renewable energy leases, green leases and miscellaneous .The following contracts mentioned in this section is the summary of the contract needed in the generation of wind energy and the construction of wind turbine in Ghana. (NREL 2013)

Contracts with Wind Turbine Manufacture: Wind Turbine Manufacture supplies the wind turbine to be installed for the generation of the wind energy.

Contracts with transportation: Available shipping company will be contracted for transportation of components and other necessary equipment for the construction

Contracts with landowner: Lease of land for about 20 or more years will be made with landowner in the area for the construction of the wind turbine.

Insurance contracts: Insurance including hedging and other insurances must be than before the project begins.

Training contract: Training for operators and maintenance technicians mush be than in time before the construction of the project takes off.

Operation and maintenance contract: Contract with employees must be taken into account when planning for the project.

Construction and installation contracts: Contracts for technicians, labourer, equipment, materials and subcontractors for the installation of the project must be taken into consideration if the project is not going to be constructed by the manufacturers of the turbine.

Loans, grants, subsidies and public equity contracts: For financial support the technology providers can go in for loans, grants, subsidies and public equity contract for the project.

Utility entities: If the energy generated is connected to the national grid the technology providers must get a contract with the utility service such as Energy commission (EC), Ghana, Ministry of Energy and Petroleum.

GridCo is the company responsible for energy transmission and transmission lines. A contract with GridCo will be made to use their transmission services.

Electricity Company of Ghana ECG takes care of the distributing of the energy to customers. (University of Ghana 2005)

Public Utilities Regulatory Commission (PURC) is an independent body set up to regulate and oversee energy and water services offered to the public. A contract with PURC will help identify the average rate of selling our power.

5.3.3 Cost analysis

The cost used in this area is an estimation of the original cost for the development of a wind energy project to help with the analysis of a wind energy turbine project. For an accurate analysis the update of the cost involved should be checked. The case selected for the analysis was for an on-grid system due to the extra cost in making grid connections in an isolated-grid or off-grid applications. The investment plan is the estimated cost which includes auxiliary and operation (O&M) cost of a Vestas V47-660kW wind turbine.

This cost involves the turbine, land, construction and other cost shown in Table 8. The wind project application type selected was an on-grid electricity generation. This application type was selected due to the adequate layout of the Ghanaian national grid and the grid expansion plans the government has in place for the transmission of electricity. Table 8 was adopted for making the auxiliary cost analysis in Table 9. If an off-grid procedure is selected then adding an additional cost after making estimation for the cost of the installation should be considered. If an isolated-grid system is selected then there will be an additional cost involved in the auxiliary cost for the construction of a grid connection in the area.

Table 8. Cost structure for a typical medium size wind turbine (850kW-1500kW). (Morthorst)

Auxiliary cost	**Share of Total Cost**	**Typical Share of other cost %**
Turbine	74-82	-
Foundation	1-6	20-25
Electric installation	1-9	10-15
Grid-connection	2-9	35-45
Consultancy	1-3	5-10
land	1-3	5-10
Financial costs	1-5	5-10
Road construction	1-5	5-10

Table 9. Capital cost (Cc)

Auxiliary cost	**Cost €**	**Share of cost %**
Turbine including tower	770000	77
Foundation	41000	4.0
Electric installation	21000	2
Grid-connection	31000	3
Consultancy	21000	2
land	31000	3
Financial costs	50000	5
Road construction and transportation	50000	5
Total	1015000	100%

In the auxiliary cost illustration, the connecting cable to the grid is assumed to be included in the construction cost.

The operation and maintenance cost according to Poul Erik Morthorst has an average share of about 20%-25% over the lifetime cost per kWh which may increase by 10%-15% to about 20%-35% at the end of it life. The total O&M cost in table 12 was derived by using 25% as the average. Figure 46 was adopted to assist in the procedure for the **O&M** cost in Table 10.

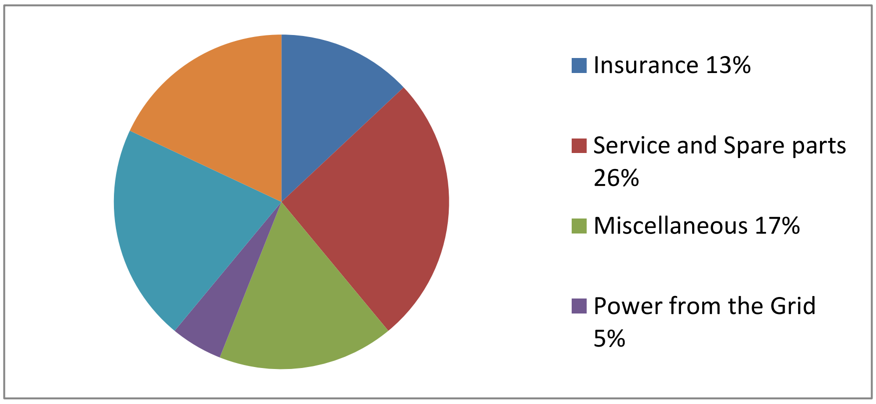


Figure 46. Average operational and maintenance cost (Morthorst)

Table 10. Operation and Maintenance cost **(O&M)**

O&M	**Cost €**	**Share of cost %**
Insurance	1950	13
service and spare parts	3900	26
Miscellaneous	2550	17
Power from the grid	750	5
Administration	3150	21
Land rent	2700	18
Total	24,283	100%

The calculations can be seen in the appendices section.

5.3.4 Greenhouse gas emission reduction analysis

The Greenhouse Gas (GHG) Emission Reduction analysis is optional but can provide an additional profit in the emission trading platform. The purpose of the GHG analysis worksheet is to provide estimations on the greenhouse gas (GHG) mitigation potential of the proposed project. On this worksheet the wind energy produced is analysed by a greenhouse gas emission reduction expect and the project can trade with a power plant that produces CO_2.

5.3.5 Financial summary

This section analyses the summary of the finances involved in setting up an energy wind turbine and the daily operation of the setup. The financial summary deals with the investment, the operation cost and the cash flow of the project. The financial summary in this thesis is an estimation of the original cash flow employed to provide an idea of the profitability of the wind energy project. To analyse if the project will be profitable, we will find the cash payback period using the Danish Wind Industry Association economics calculator to assist in the calculation and obtain the net present value. The result of the calculation is shown in Table 11. (Danish Wind Industry Association)

Table 11. Financial summary for the wind project to Ghana

Capacity of wind turbine **CWT**	660kW
Energy generated in a year **Ea**	1,734,480 kWh
Capital cost **Cc**	€1,015,000
Cash outflows **O&Mc**	€24,283
Feed in tariffs	0.16cent or €0.12/ kWh
Cash inflow for each year **CF**	€208,138
Profit or Net income per year **P**	€183,854.88
Cash payback period **Cp**	5.5year
Net present value **NPV**	€790,087

Assuming the plant capacity factor PCF is 30%, hours of operation in a year is 8,760hr, fixed rate is 8% and the project last for 20years. The taxes, depreciations and Inflation were not considered.

We identify the wind energy generated in year Ea,

$$Ea = CWT.\ h\ .PCF \qquad (5)$$

where CWT is the capacity of wind turbine and h is the hours in a year.

Ea = 660kW × 8,760hr × 0.30 = 1,734,480kWh (see table 14)

Referring to how the operation and maintenance was found in table 12 we use the cost of energy COE, the equation is

$$COE = [(Cc.FCR)+Co\&m]/Ea \qquad (6)$$

Where Cc is the capital or auxiliary cost, FCR is the fixed charge rate that reflects the interest one pays if the money were displaced from savings, Co&m is the annual operation and maintenance cost, and Ea is the annual energy generated. Assuming the fixed rate is 8%.

COE = [(€1,015,000*0.08)+ €15,000]1,734,480 kWh = €0.056/ kWh

Using 25% as the average cost from the analysis made by Poul Erik Morthorst

O&Mc = 25% × €0.056/ kWh × 1,734,480kWh = €24,282.7

$$CF = Ea\ .\ COE \qquad (7)$$

$$P = CF - O\&Mc \qquad (8)$$

$$Cp=Cc/P \qquad (9)$$

$$NPV = \sum_{i=1}^{n}[P / (1+r)^{t}] - Cc \qquad (10)$$

All result shown in Table 11 has been calculated in the appendices section by using equation 7, equation 8, equation 9 and equation 10 to derive the values.

5.3.6 Risk analysis

Several risks were observed for the wind energy project to Ghana. The risk analysis can help to increase the possibility of succeeding at the venture. The risk selected and evaluated for the analysis was acquired from some articles of other wind energy project in other countries, news in Ghana relevant to this theses topic and opinions of some Ghanaians concerning politics that are related in affecting wind energy generation in Ghana. Some of the most important risk chosen for the analysis is shown in Table12.

Table 12. Show some potential risk and how to mitigate it (Lyon et al. 2011)

Risk	Why	How to Mitigate?
Financial	Ghana has an unusable market, an inflation rate of 9.1% in 2012. Commercial bank interest rate of 25.1% in 2012 which could affect the investment value after some years.	Hedging against the fall in price of power. Adjusting the company's structure to ensure access to capital at a reasonable cost
Political /regulatory	Uncertainties in Ghana governmental control and risk of a change in policy. Whenever there is a change in government there are new regulations made by the current government which could have a negative effect on the investment	More frequent communications with policy makers and regulators, and seeking redress from governments for the impact of adverse policy decisions. Good relationship with all politicians.
Weather-related volume	Ghana wind flow is unstable and the direction keep changing	Hedging against weather adverse, weather conditions and improving analysis of weather data at location ahead of construction
Building and testing risks	There are common events in Ghana where properties get damage during building or testing	Using only proven technology in construction
Operational risk	Ghana has regular black outs due to plant damage or component failure.	Training of employees and regular maintenance of plant and equipment

5.4 The Barriers in Implementing Wind Power Plants in Ghana

By identifying the barriers of wind energy we hope to find an answer to why Ghana has not had any wind energy project. Several barriers in the implementation of a wind energy technology transfer to Ghana can be identified. These barriers were detected after careful analysis of some recent events in Ghana relevant for wind energy transfer to the country and comparing to some barriers mentioned by Beck and Martinot on other wind energy project in other countries.

Policies: Policies can be barriers for wind energy generation in Ghana because if policies for supporting wind energy generating transfer such as government subsidies for renewable energy companies and policies ensuring quick availability of land for renewable energy project do not exist, then wind energy transfer becomes very difficult.

Policies Information relay: Ghana has some good polices that supports wind energy transfer but the information on these policies in Ghana that can help attract wind energy investors to Ghana (such as free clearing of renewable energy goods at the harbour) is not easily available or known by the persons required to help with the implementation of this policies, such as the custom officer. Also information on energy policies that can attract wind energy technology transfer to Ghana, such as feed-in tariffs that was recently passed by the Government of Ghana has not been well publicized or advertised to spread among all renewable energy investors especially wind energy companies.

Environmental: The site for the project is within the mountain areas, far from the city and other resident near the location. But the issue of good drinking water and sanitation system is a problem in the area and this could cause some problems for the employees responsible for the construction and operation of the project. Generally Ghana lack good drinking water, contributing to 70% of the country disease problems. Some of the diseases include malaria, sleeping sickness, and guinea worm. That can affect the worker and the working condition of the project.

Technical expertise: Lack of technical knowhow. The technicians in Ghana do not have the skills, knowledge and experience to help speed up the technology transfer. To help provide good services and maintenance when needed it is crucial for the energy provider to train technicians before the construction of the project.

Subcontractors expertise: Lack of good subcontractors with the know how to help to improve the wind technology for Ghana in the constructing of the project and providing parts for future usage.

Transportation: Lack of good road from Nkwanta to Accra the capital of Ghana where the main harbour is located. The roads are seriously deteriorated especially during the rainy season as a result of serious erosion problem due to inadequate drainage system and lack of constant maintenance. The Lake transport in Nkwanta is also plagued with challenges, such as lack of adequate number of river crafts, also tree stumps presence in the lake and good landing sites for the river crafts.

Political: The lack of transparency in the governance of the country makes it difficult to acquire support from the Ghana government in promoting the wind energy project.

Financial: It is very difficult to get funding for wind energy project especially to Ghana or other African country. Banks and NGO have lot of requirements that the energy provider interested in the wind energy generation must meet before they are given funds in a form of grants, loans or partner investor to support the wind project. It is also difficult to acquire low interest rate on loans for renewable energy business

Technology Awareness: The Ghanaian locals do not have much knowledge or information about the wind energy technology. Even the literate have not heard much about the technology, this results them to believe the technology does not work and will be a waste of time and money if the government involves the country resource in to the wind energy technology transfer to Ghana.

6 CONCLUSIONS AND RECOMMENDATIONS

The data collected on the wind energy technology all over the world suggest that the interest and demand for wind energy is increasing and that has also caused the technology to advance rapidly to a point where better ways of building and applying the technology has been uncovered. The technology was found to be good for the environment especially Africa because it will provide enough energy to satisfy the people cutting down trees for fuel and also because it has the best recycling among the other renewables energy. Wind energy technology was found to be the best for the Ghanaian environment in helping to solve their energy crisis.

During the research about the wind energy technology transfer to Ghana the following conclusions were made:

- The data indicated that the expected total power that can be generated from the wind speed in Ghana is adequate for wind energy farm generation.

- The accumulation of wind flow, potential for power generation in Ghana is expected to generate about 5.64GW as shown in Table 4 for a conventional wind turbine, which is objectively adequate for a wind farm to generate energy for the country.

- The cash payback period for the wind setuo in Nkwanta was estimated to be about 5.5years, which is very good for wind energy generation.

- The research shows that Nkwanta district has the highest values of wind potentials adequate for a wind energy project. However further research should be made on the site before it should be considered for the wind project. It should be noted that data could not be collected for all areas in Ghana but the sites that were acquired shows that Eastern and Volta has the highest potential of wind power generation of about 1,555kW and

2,345kW respectively, as can be seen in Table 4and a power potential cumulating value is about 3,900 kW.

Based on these findings thesis, we can conclude that there is the potential of wind energy generation in Ghana and so we encourage investors in wind energy technology to invest in transferring the wind energy technology to Ghana.

The analysis made in Chapter 5.3 can be modified and used in different location in Africa. The barriers observed were found to be major obstacles for a wind project but could be mitigated to help reduce the risk of the project failure.

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APPENDICES

The calculation for the financial summary:

The capital cost was observed in Table 9, and the operation and maintenance cost can be seen in Table 10. The data on the feed-in tariffs in Ghana was gathered from Institute of Developing Economies and shown in Chapter 1.1.

The total cash flow for each year CF,

$$CF = Ea \cdot COE$$

Where Ea is the annual energy generated and the cost of energy is COE. Assuming the project is connected to the national grid with feed in tariffs estimated to be 0.16cent/kWh or €0.12/kWh in Ghana. Total cash flow for each year

CF = 1734480 kWh × €0.12/ kWh = €208,137.6

Total profit or net income per year *P*

P = CF - O&Mc

P = €208137.6 – €24,282.72 = €183,854.9

For the cash payback Cp,

Cp=Cc/*P*

Cp= €1015000/€183,854.88= 5.5year

The Net present value was found by using

$$NPV = \sum_{t=1}^{n} [P / (1+r)^t] - Cc$$

Where *P* is the profit or net income per year, r is the fix rate, life time duration of the project t and Cc is the capital cost or initial investment. Using the present value interest factor for an annuity of one dollar $P_n=[1-1/(1+r)^n]/r$. for a period of 20years with 8% discount rate the table shows 9.818

NPV = (€183,854.88× 9.818) - €1,015,000 = €790,087.2

The project according to the calculations will take approximately 5.5years to pay back the capital cost. The net present value for the project for 20 years at a discount rate of 8% is about €881,219 which is 86.8% of the capital cost for the project shown to be €1,015,000.