VAASAN AMMATTIKORKEAKOULU
UNIVERSITY OF APPLIED SCIENCES

Riku Nurminen

RISK MANAGEMENT AND WIND POWER PROJECT IN GHANA

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VAASAN AMMATTIKORKEAKOULU
Ympäristö- ja energiatekniikka

TIIVISTELMÄ

Tekijä	Riku Nurminen
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Tässä opinnäytetyössä tutkitaan Ghanassa sijaitsevan Amedzofen alueen potentiaalia tuulivoimalan sijoituspaikkana teknillisistä ja taloudellisista näkökulmista, sekä tuulivoimalaprojektiin liittyvien riskien osalta. Tavoitteena on, että tutkimustulosten avulla voitaisiin tehdä päätös hankkeen jatkamisesta kalliimpiin suunnitteluvaiheisiin

Tutkimusmenetelminä tätä opinnäytetyötä tehdessä käytettiin kirjallisuustutkimusta, jossa keskityttiin projektihallintaan, tuulivoimalatekniikkaan ja riskienhallintaan liittyvä kirjallisuuteen sekä Ghanan energiakomissiolta ostettua tuulennopeus dataa, jota hyödynnettiin tuulivoimalan valitsemisessa sekä vuotuisen energiantuotannon arvioinnissa. Ghanan valtion yleisnäkymän pienimuotoissa selvityksessä käytettiin PESTLE-analyysia.

Tämän opinnäytetyön lopputulosta voidaan hyödyntää Ghanaan kohdistuvien energiahankkeiden suunnittelussa sekä opetusmateriaalina energialaitosten hankekehitykseen liittyvissä aiheissa.

Avainsanat riskienhallinta, hankekehitys ja tuulivoima

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ABSTRACT

Author	Riku Nurminen
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This thesis studies the potential of the area of Amedzofe located in Ghana for wind power projects from aspects of technical and financial viability, and the risks concerning such a project. The objective was to create a framework for a wind power plant project, which can be used to decide whether continuing the project towards more cost intensive project phases.

The research methods used in this thesis are literature research focusing on literature concerning project management, wind energy technology and risk management, and wind speed data purchased from the Energy Commission of Ghana, which was used to choose suitable wind turbine technology for the project and estimating annual energy production for Amedzofe.

The results of this thesis can be used as a framework for energy projects in Ghana and as an educational material for topics concerning the project development of energy facilities.

Keywords Risk management, project development and wind power

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1 INTRODUCTION

1.1 Objectives

The main objectives of this thesis are to study the financial viability of a wind power project placed to Amedzofe, Ghana and survey the risks concerning wind energy projects specifically in Ghana. With the results the author will develop a recommendation about the feasibility of the wind power project.

1.2 Research Questions

There are two main research questions for this thesis which are:

1. How viable is a utility scale wind farm in Amedzofe, Ghana from technical and financial aspect?
2. What are the risks in wind power projects?

1.3 Limitations

The focus of the case study of thesis is on risk management and preliminary phase of wind power project development, which focuses mainly on researching the energy production potential in Amedzofe with suitable wind turbine technology and financial feasibility of the project. Therefore, further planning and comparison between potential suppliers for each individual project phase in the construction and operational part of the wind turbine projects will not be included in the case study, anyhow those topics are explained briefly in the project development chapters.

Due to lacking proper information about the plot availability at the wind site, this thesis does not include the siting of the wind turbines, and that is why the estimation of annual energy production and financial viability of the project are based on one wind turbine only.

1.4 Structure of Thesis

1. Theoretical part of country overview, risk management and project development.
2. Case study.

   1. Overview of Amedzofe.
   2. Studying the wind regime on the site at Amedzofe.
   3. Choosing suitable wind turbine technology for the project based on the infrastructure of the site and wind regime.
   4. Estimate of annual energy production capacity for Amedzofe by using wind regime and chosen wind turbine technology.
   5. Cost analysis for the project based on the annual energy production calculations and estimation of investment costs for the project.
   6. Review the risks concerning wind power projects and Ghana as target country, possible impacts of the risks and how to manage them.
3. Analysis and discussion based on the research results
4. Conclusion about viability of the project

1.5 Research Method

This thesis relies heavily on annual wind speed data measured at Amedzofe and purchased from Energy Commission of Ghana by Dr. Adebayo Agbejule, and all the calculations concerning the case study of this thesis are based on that specific data.

Other research method of this thesis is desktop research, focusing on literature and online sources concerning project development in wind power projects, wind technology, risk management and country overview of Ghana.

The PESTLE analysis tool is used to study market environment of Ghana.

2 COUNTRY OVERVIEW OF GHANA

Ghana, formerly known as the Gold Coast, is a country located in the western coast of Africa. It is the first sub-Saharan country that gained independence after being colonized by the British Empire. Ghana's southern border ends to the Atlantic Ocean and Ghana is neighbouring country of Ivory Coast, Burkina Faso and Togo. Accra is the capital city of Ghana. /1/

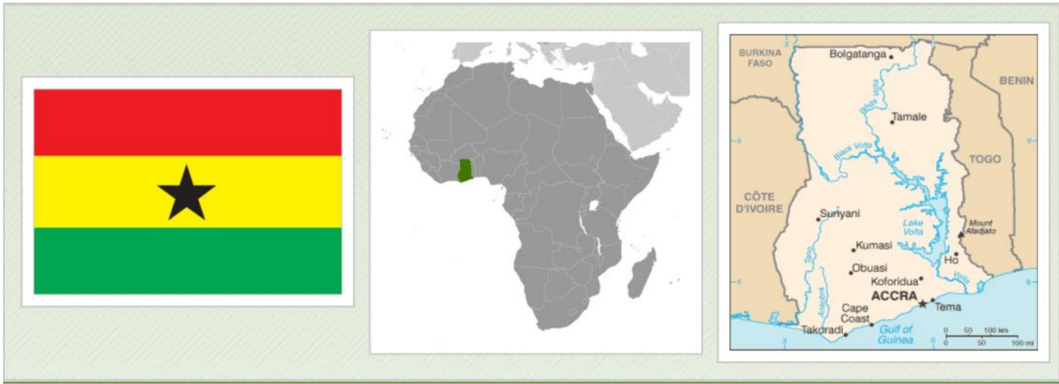

Figure 1. Flag of Ghana and Ghana on the map. /1/

2.1 PESTLE analysis of Ghana

The PESTLE analysis is used for a country analysis to understand better the business environment in Ghana.

The name PESTLE comes from the words political, economic, social, technological, legal and environmental, and the PESTLE analysis helps an organization to identify external forces that may impact their business. /2/

2.1.1 Political

- Ghana is among the most politically stable countries in the West Africa and outlook is predicted to continue being stable in the future. /3, 4/
- Ghana is a member of regional and international bodies such as the African Union, the United Nations and Economic Community of West African States (ECOWAS). /3/
- Ghana is a presidential representative democratic republic in which power is shared between the president, cabinet, legislature and judiciary. /3/

- The constitution determines the structure of the government, responsibilities of the elected officials and citizens, and the fundamental rights and freedoms of the people. The constitution attempts to decentralize executive power to reduce the chances of dictatorial regimes from developing. /3/
- The multi-party system allows parliamentary and presidential elections being held every four years. The Parliament has 275 members. Before adopting any laws, the president must approve the legislation made by the Parliament. Ghana has more than 20 registered political parties. /1, 3/

2.1.2 Economical

- Due to the political stability of Ghana, it is one of the most stable countries to do business in West Africa and is among the most competitive economies in West Africa. /1/
- In comparison with other countries in West Africa, Ghana has less policy barriers to trade and investments. /1/
- Ghana's economy has grown approximately by 4.3% per year over the past 4 years and is projected to grow approximately 6.1% annually over the next 5 years. /5/

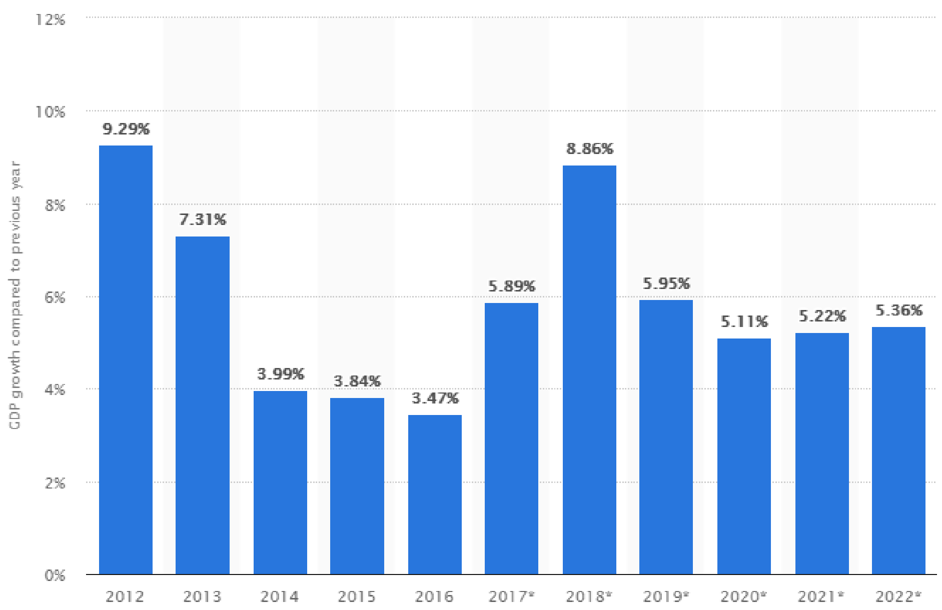

Figure 2. Ghana's growth rate of the real gross domestic product (GDP), compared to the previous years. /5/

- About 18.3% of Ghana's GDP comes from agriculture accounts such as cocoa, rice and cassava producers, which also employs almost half of the total workforce, 24.5% from industries such as mining, lumbering and petroleum and 57.2% from services. /1/
- Economic forecast for Ghana is good, but there are two main concerns to solve which are high debt of the government and lack of reliable electricity. Both problems have been recognized in Ghana and the government has been working on solving them by announcing energy policies to support new investments on the energy sector and establishing University of Energy and Natural Resources in 2011 to educate new professionals to improve Ghana's energy sector. Ghana also signed 920 million USD extended credit facility with IMF in April 2015 to help Ghana address its growing economic crisis. Ghana's government is committing to fiscal consolidation concerning the agreement with IMF. /3, 6/
- Recently found oil reserves boosted Ghana's economy, but after oil price started to fall in 2015 the benefits have been reduced. /1/
- Inflation in Ghana was 10.8% in January 2018 and has been decreasing and is now at the lowest since 2013. /8/
- In December 2017 wages varied from 588 to 1950 GHS (~102-353€) per month and living expenses for an individual were approximately 660 GHS (~120€) per month. /8/
    - Unemployment rate in Ghana was 5.77% in December 2016. /8/
    - Poverty in Ghana is present especially in the northern regions, but at the same time Ghana has one of the fastest poverty reduction rates in Africa. /19/
- The taxes are administered by the Domestic Tax Revenue Division (DTRD) of the Ghana Revenue Authority. /7/
    - In Ghana income taxes compromise:
        - Corporate tax paid by companies on their profits yearly, 25% tax rate. /7/ Companies that gain revenue through energy conservation, environmental protection, water-saving conservation and clean development mechanism are eligible for three-year corporate tax exemption and after that for another

three-year corporate tax reduction of 50%, starting from the year when the first revenue is generated. /10/

- Personal Income Tax paid by self-employed persons at graduated rates in four equal instalments. /7/
- Pay as You Earn (PAYE) tax paid by employers from the salaries of the employees to fulfil their income tax responsibilities, uses the same graduated rates as Personal Income Tax. /7/

- Other taxes are:
  - Capital Gain tax 15% paid from the realization or sales of chargeable assets where the gain exceeds 50GHS (~9€). The tax is imposed on assets including buildings, land, business assets including goodwill and shares of a resident company. /7/
  - Tax stamp collected from the small-scale self-employed persons on quarterly basis. The tax rate is adjusted based on the business type, class and size. /7/
  - Gift tax 5% is paid when the total value of taxable gifts received during period of one year exceeds 50 GHS (~9€). Assets concerning this tax are land, money (including foreign currencies), shares, bonds and securities, business and business assets. /7/
  - Rent tax 8% paid on the gross amount earned over the period of one year by the rent income earners. /7/
  - Mineral royalties 5% are paid by the persons who extract natural resources on or under the surface of the earth. /7/
  - Value Added Tax (VAT) 15% is broad-based tax included on the goods and services which consumers purchase. Businesses that are registered to charge the tax in the stages on the “value added” from manufacturing to retail level are collecting the tax. The tax is collected at the end of every month. All exports have zero (0) VAT. /7/

    - National Health Insurance Levy (NHIL) is imposed on all services and goods imported or supplied into the country, unless they are otherwise exempted. NHIL is charged at the rate of 2½ on the VAT and exclusive the selling price of goods or service rendered. The NHIL is collected in the same way as VAT by the registered businesses. /7/
    - VAT Flat Rate Scheme (VFRS) is a special method for accounting and collecting for NHIL/VAT. VFRS is designed for traders in the retail sector. Retailers registered under VFRS charge NHIL/VAT at a marginal rate of 3% on the value of each taxable item sold. /7/
  - Import Duty, Import VAT, Export Duty, Petroleum Tax and Import Excise are collected by The Custom Division, which is part of Ghana's security network. The Customs Division also attempts to prevent smuggling and ensure the protection of revenue by patrolling physically on the strategic points and borders, and examining goods, using search premises and viewing documentation of the goods. /9/
- Customs duties for renewable power generation systems and high-technology items have exemptions or reductions. Large-scale wind (>3MW) and some solar PV systems may be imported without tariff and VAT. /10/

2.1.3 Social

- English is the official language, but Ghana has a rich cultural background and there are many smaller ethnic group with less common languages. /1/
- The dominant religion is Christianity by 71.2% of the population and Muslims as the second largest religion by 17.6%.
- The population growth rate was 2.17% in 2017 and is projected to grow due improvements in quality of life especially in health care, nutrition and hygiene. /1/

- The educational system has been improved over the last centuries resulting in 2015 literacy rate reaching 76.6% among the population aged 15 years or older. /1/
- The population in Ghana is concentrated in the southern half of the country where urban areas are located. People living in the northern areas are often less educated and lack education, markets, suitable farming land and industrial centers. /1/
- Approximately 57% of the population are under age of 25, making Ghana's age structure young. The life expectancy at birth in 2017 was 62 years. /1/
- In December 2016 the population of Ghana was 28.21 million. /8/

2.1.4 Technological

- In 2014 21.7% of the population did not have access to electricity, but the rate is reducing rapidly as the country develops, therefore Ghana has high demand for new electricity production capacity now and in the future. /1/

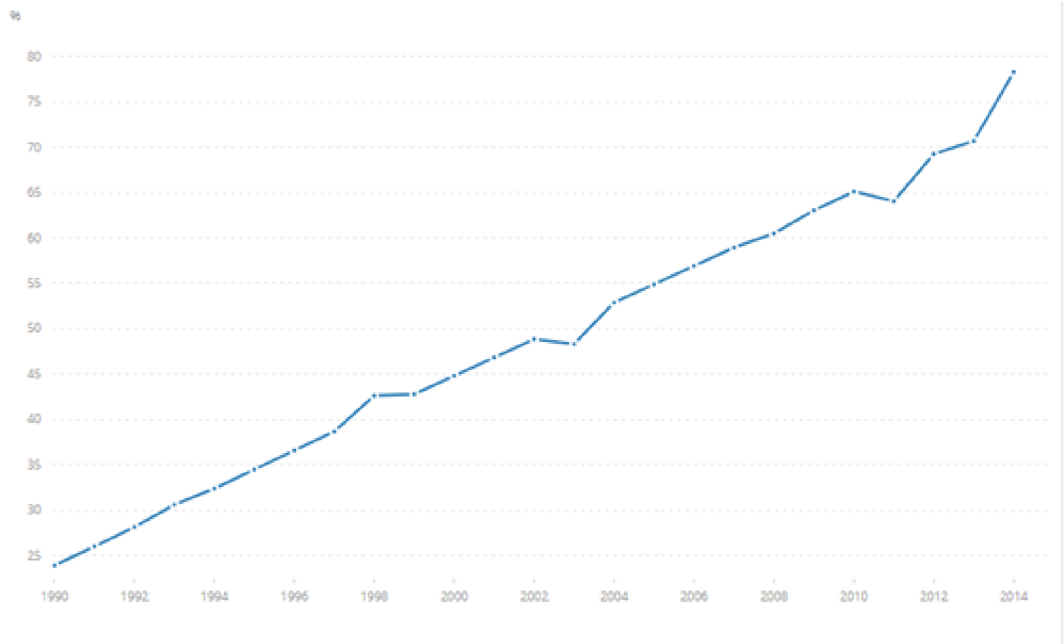

Figure 3. Access to electricity in Ghana (% of population). /15/

- In 2016 the total electricity generation capacity was 3774,5MW out of which 56% was using fossil fuels, 43% large scale hydropower plants and <1% other renewable sources, but in reality, the generation capacity of the large hydropower plants is lower due to the recent drought. The share of other renewable sources is going up within the next few years due to 155 MW solar plant constructed by Blue Energy and 225 MW wind power plant Ayitepa. /10, 11, 12/

PLANT	INSTALLED CAPACITY (MW)	DEPENDABLE CAPACITY (MW)
Hydro		
Akosombo	1,020	960
Bui	400	360
Kpong	160	148
Sub-Total	*1,580*	*1,468*
Thermal		
Takoradi Power Company (TAPCO)	330	300
Takoradi International Company (TICO)	340	320
Sunon Asogli Power (Ghana) Limited (SAPP) - IPP	200	180
Sunon Asogli Power (Ghana) Limited (SAPP2) - IPP	180	170
Cenit Energy Ltd (CEL) - IPP	126	100
Tema Thermal 1 Power Plant (TT1PP)	126	110
Tema Thermal 2 Power Plant (TT2PP)	50	45
Mines Reserve Plant (MRP)	80	70
Kpone Thermal Power Plant (KTPP)	220	200
Karpowership	235	220
Ameri Plant	250	240
Trojan*	25	22
Genser*	30	18
Sub-Total	*2,192.0*	*1,995*
Renewables		
Safisana Biogas*	*0.1*	*0.1*
VRA Solar*	2.5	2
BXC Solar*	20	16
Sub-Total	*22.6*	*18.1*
Total	3,794.6	3,481.1

Figure 4. Installed Electricity Generation Capacity operational in December 2016. /10/

- The electricity generation in 2016 was 12978 GWh and is projected to grow up to 20443 GWh in 2017 due to increased thermal power plant capacity. /10/
- In 2006 Energy Commission of Ghana set a goal of 10% renewable energy contribution in the electricity generation excluding already existing hydro-electric generation and 30% penetration of rural area electrification by the year 2020, but as mentioned before the amount of installed renewable energy production capacity is still low and the goal have not been reached yet. /10/
- In 2015 Ghana experienced 159 days of blackout because of unstable and too little electricity production and grid faults. /13/

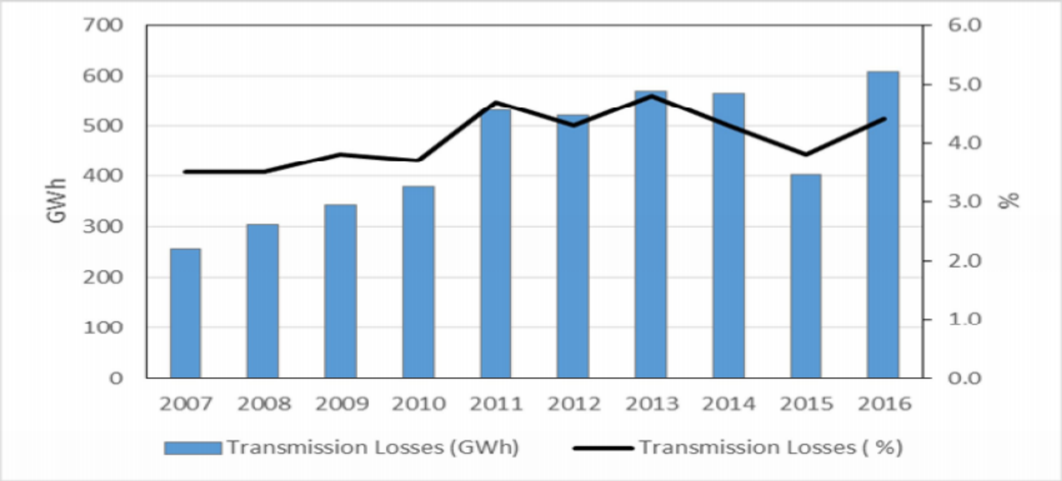

Figure 5. Yearly electricity transmission losses. /10/

- The power grid of Ghana is divided into one transmission company Ghana Grid Company (GRIDCo) and two state owned distribution companies Northern Electricity Distribution Company NEDCo and Electricity Company of Ghana ECG. NEDCo supplies electricity to the northern areas of Ghana and covers two-thirds of the landmass of Ghana, while ECG operates in the southern parts of Ghana. /14/

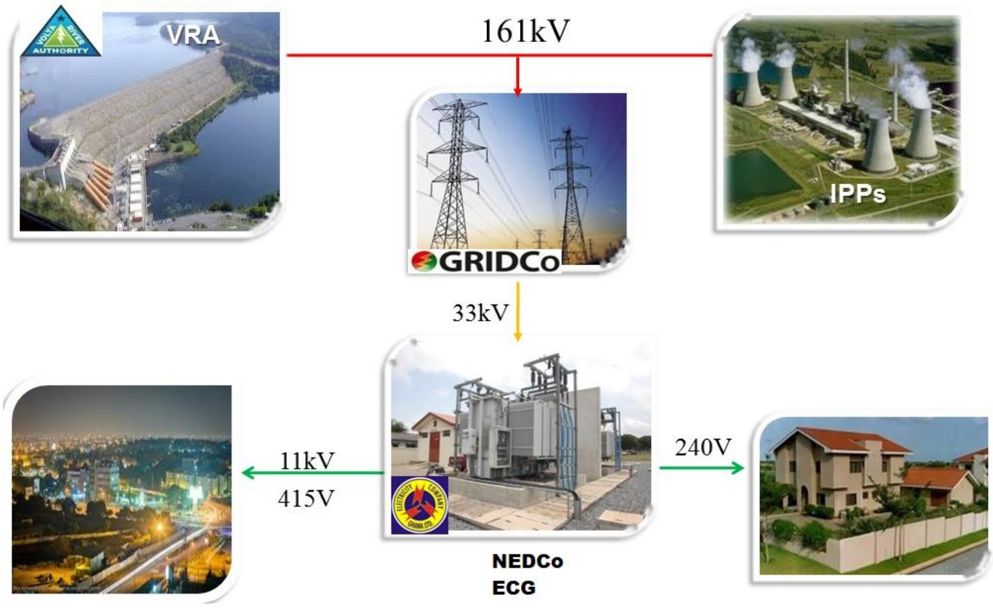

Figure 6. Electricity supply chain map of Ghana /16/

- The National Interconnected Transmission System (NITS) consisted approximately 5208 km of high voltage transmission lines. The transmission lines consist 364 km of 330 kV line, 4637 km of 161 kV and 133 km of 69 kV lines. There is also two 161 kV tie-lines that interconnect Ghana to Togo's grid and 225 kV tie line which connects Ghana's grid to Ivory coasts' grid. Ghana also has one single circuit tie line of 225 kV connecting Ghana's network with Ivory Coast. /10/

2.1.5 Legal

- The judiciary is arm within the government and independent from legislature and the executive. The legal system of Ghana is formed from the framework of the 1992 constitution, the traditional law and the British common law. Ghana has four courts of appeal, which are traditional courts, magistrate courts, the high courts and the highest of all the Supreme Court. The head of the Supreme Court is the Chief Justice. The judges and other members of the judiciary are appointed by the president through recommendations of the Judicial Council. /3/
- Corruption is a problem in Ghana, but is relatively low compared to the other countries in the region. Ghana's government has a strong anti-corruption legal framework, but the country faces problems with execution of it. /4/
- Bribery is present across public services and in the judicial system. It is common that bribes are exchanged in return for faster and favourable decision. Some large cases are prosecuted, but time consuming and convictions slow. In 2015 thirty-four judges and other judicial officials were implicated for extorting bribers and twenty-five of them were released dismissed after the revelations. /4/
- Despite the actions and measures taken against corruption and bribery, allegations of corruption have been expressed concerning tendering processes. The government has set aside international tender awards for the benefit of national interest. /4/
- The Government of Ghana is progressing to amend laws on public financial administration and public procurement to improve accountability,

transparency, value for money and efficiency in the use of public resources. The present president's administration has sworn to combat corruption and follow specific steps to promote better accountability and transparency. /4/

- The Ministry of Employment and Labour has set a wide labour act in 2003 (ACT 651) to consolidate and amend the laws relating to employers, trade unions, labour and industrial relations. /17/

2.1.6 Environmental

- The climate in Ghana is tropical and the terrain is mostly low plains. /1/
- The south coast is dry and warm, the northern parts of the country are hot and dry, and the south-western areas are hot and humid. The average temperature for the year is around 30ºc. /1/
- About 69.1% of the land is agricultural land, 21.2% forest and 9.7% others. /1/
- Especially the northern parts of Ghana suffer from floods and drought that have negative impact on farming. /1/
- The infrastructure of Ghana is on moderate to good level, but in rural areas it is partly on insufficient level, which may cause problems with transportation. /1/
- The mean elevation of the country is 190m above the sea level, the highest point is 885 m at Mount Afadjato and the highest settlement is Amedzofe at approximately 600 m /3, 18/
- Ghana has great circumstances for renewable energy production including hydro, solar and wind from of which especially hydro has been exploited for energy production for centuries. /6/
- Ghana does have incentives for environmental friendly energy generation such as tax reduction for wind and solar technology components and feed-in-tariff for electricity generated from renewable energy sources. /20/
- The Ministry of Environment, Science, Technology and Innovation (MESTI) has launched environmental policies such as National Environmental Policy (NAP), the National Climate Change Policy (NCCP) and in

addition developed a Climate Change Strategy to operationalize the implementation of NCCP. /21/

3 PROJECT DEVELOPMENT IN WIND POWER PROJECTS

The project development of a wind farm project consists of four phases which are in order from the first to the last: preliminary, planning, realization and operation. Each of these phases may be divided into three aspects which are technical aspect, aspect of permission regulations and economic aspect. Wind power projects take usually three to four years from the beginning of preliminary investigation to the operational state of the wind power plant. /22/

Figure 7. Project development process in wind power projects. /22, 33, 38/

3.1 Preliminary Phase

Before taking any formal or cost intensive steps, it is recommended to complete the preliminary investigation, which consists of technical analysis of the site, technological feasibility and review of local laws and regulations, and their impact on the project. Preliminary investigation results decide if the project is continued or put on hold or cancelled. /22/

The analysis of the site concerns estimation of the wind regime on the site, this can be done by using general meteorological data and the geography at the site such as the terrain structure, the surface roughness and the terrain boundaries. If the general meteorological data is not available or the quality of the data is not good enough, it is possible to install a wind measuring station on the site for more specific wind data. Apart from the wind data, it is important to register single obstacles such as rows of trees or other wind turbines due their impact on the behaviour of the wind. It is very important to get the wind speed estimation at the site as accurate as possible, because if the mean wind speed is 10% lower than estimated, the energy yield may decrease by 30% or more. /22/

Other site-specific conditions regarding technical and economic aspects to be investigated are the lease or purchase contract of the plot and local infrastructure due to the requirements for safe transportation of wind turbine parts and machines to the construction site, which have an impact on service availability and operation and maintenance costs (O&M), and whether the power grid extension is required. Also, regarding the stability of wind turbine, each individual turbine needs geotechnical investigation to determine the capacity that the soil beneath the foundation can bear. If the soil is solid, flat foundation will do, but when soil is soft, more expensive pile foundation may be required. /22/

Apart from the area of the site, is it crucial to investigate the availability of the grid connection to determine the number and rated power of turbines to be installed. It is recommended to contact the local grid owner during the early stage of the planning and request information about the possible grid connection capacity, voltage level of the grid connection and the distance to the closest possible feed-in point. If the power grid extension is required, it may require a separate environmental impact assessment. For larger wind power plants (>20MW) it may be necessary to build a separated sub-station. /22/

With the available area of the site and grid capacity it is possible to estimate the number and power curve of the wind turbine and therefore estimate the energy yield. The energy yield is predicted by using wind frequency distribution and the power curve of the chosen wind turbines and it is done for each wind direction, which is necessary to optimize the wind turbine placing to gain the maximum energy yield from the site. /22/

Local laws may have further restrictions that need to be taken in consideration while planning the turbine siting e.g. environmental protection policies and distraction concerns affecting the nearby living areas, airport or roads. Local laws vary between countries and sometimes even between provinces of a country, e.g. in Germany wind power projects have strict requirements concerning the distances to the local settlements and noise levels of the wind turbines, while in less developed countries the need for new energy due to regional development is huge and therefore the opinion of nearby locals does not have the same impact on the project as in Germany. /22/

3.2 Planning Phase

After the preliminary investigation that proves technical feasibility for the project, it is time to start the planning phase. The planning phase consists of financing, planning of construction, grid connection and application for building including environmental impact assessment (EIA). A well planned project reduces delays during the realization phase and increases cost efficiency of the project. /22/

A first economic viability check should be performed during the planning stage to clarify whether the project will be economically sustainable. In case the result is negative, the project should be put on halt to avoid any further costs. The wind regime and estimation of investment costs are determinative parameters when investigating this assessment. The investment costs vary slightly between the projects, but literature provides the basis for making a rough estimation of costs. /22/

Table 1. Typical Investment cost structure for a project with a single wind turbine in Germany (onshore). /22/

Wind turbine incl. Transport and erection	77.1 %
Foundation	5.0 %
Transformer substation	4.1 %
Grid connection (1000 m)	4.1 %
Access lane (400 m)	1.6 %
Planning and construction survey	2.1 %
Administration / legal and tax advise	3.0 %
Miscellaneous	3,0 %

The biggest expense of the investment is the wind turbine itself, because the price usually includes the transportation and on-site erection costs due to the bundles offered by the wind turbine manufacturer. The expenses vary a lot depending on the wind turbine technology, size and the local conditions concerning the transportation of the wind turbine parts to the site. The costs of wind turbine investment also include the design and development costs, the profit and in addition costs concerning warranty and erection. /22/

The second largest investment costs are usually the costs for the grid connection or for the foundation. These costs depend a lot on the local conditions such as the number of wind turbines, the distance to the grid feed-in point and specifically the type of soil in the area due the requirements of foundation platforms. If it is necessary to use piling foundation instead of flat foundation, the foundation costs go up significantly. Because of this kind of site specific conditions, it is difficult to compare economically same sized wind farm projects, because there is always dispersion in the actual project costs. /22/

The costs of the access lanes and roads vary once again depending on the conditions at the site and on the layout of the wind farm. Regarding the wind turbine size, it is necessary to take the bearing capacity in notification due to the weight of components and machinery such as the crane used on the area during construction phase. /22/

Planning, permission and indemnification measure costs form so called "soft costs" for the organization of the operating company and financing costs. The costs vary usually from 3 to 6% of the total investment cost for the wind farm. /22/

To compare different wind farm projects there are two indexes available which can be calculated by using the information regarding the total investment costs, installed capacity and annual energy yield. /22/

The first measure is power specific investment cost index (SIK_L):

$$SIK_L = \text{Total investment costs} / \text{installed capacity} \quad (1)$$

However, power specific investment cost index does not give any information regarding the potential of the site e.g. the annual energy yield or production. So, there is another measure called yield-specific investment costs index (SIK_E):

$$SIK_E = \text{Total investment costs} / \text{annual energy yield} \quad (2)$$

Each country has their own typical values for these indexes, but for example in Germany the power-specific investment costs in index are around SIK_L = 1100 €/kW and for the yield-specific investment costs index the value of SIK_E = 0.50…0.75 €/kWh_a. /22/

The financing plan has an important role when adjusting the economic efficiency of a wind farm project. The financial plan varies based on the site quality and the financial standing of the investors(s), but usually approximately 70% of the investment costs are covered with a loan from banks and 30% by equity from investors. /22/

When calculating annual proceeds and expenditures by using the estimation of annual energy yield and possible feed-in-tariff, it is advised to use a safety margin of 10-15% on the predicted proceeds. This should cover the uncertainty of wind regime and the fluctuation of annual wind regimes on the site. /22/

The financial analysis should also include estimation of annual operating costs. Especially the partition of maintenance, repair and replacement costs should be checked carefully. It is estimated that approximately 2.5% of the wind turbine investment costs are paid yearly during the first operational decade for maintaining the wind turbine and that the costs rise to about 4% of the wind turbine investment cost per year during the second operational decade due to changing worn components. Also, the depreciation of the wind turbine should be included into operational expenses. /22/

To lower the technical risk for the operator, it is possible to purchase a full-service contract from the manufacturer of the wind turbines, but the contract increases running costs. Some insurance companies reduce insurance costs for the operators if full-service contracts are used. /22/

Table 2. Typical operating cost structure for a wind farm project in Germany, onshore and without capital service. /22/

Insurance	13 %
Electricity consumption	5 %
Lease of land	18 %
Management and taxes	21 %
Miscellaneous	17 %
Maintenance and repair	26 %

During the planning phase the operator signs the feed-in contract with the grid owner and power purchasing agreement (PPA) with the customer, so the chance for a project failure during the construction phase is neutralized and also, once the wind turbine starts to produce electricity, the operator can start gaining revenue as soon as possible. /22/

3.3 Realization Phase

The construction and erection phases are the next things to start after the planning phase has been accomplished and all the permits or at least preliminary ones, have been received. The construction of access lines and cabling are the first tasks to do during the erection phase, after those the foundation will be built. Depending on the purchase contract, but most often, the wind turbine manufacturer will transport the wind turbine components to the site and erect them. /22/

In Germany the erection phase typically takes three to six months, but remote places of the world have much bigger challenges regarding the transportation and erection for example size of the cranes available, capacity or steepness of the roads may be limiting factors. Therefore, it is important to consider these matters already during the technical and financial planning phase. /22/

Once the road and foundation works have been finished and positions for the cranes have been prepared, the components of wind turbines can be delivered. The transportation of the components is done on the road by heavy trucks and long vehicles. Tower sections, nacelle and rotor blades are usually delivered one after the other since they usually come from different suppliers and factories and because for the assembly they are needed in the right order. There may be country-specific transportation permits and regulations regarding the use of these transportation methods which may cause special preparations for the transportation such as the transportation is not allowed to be done during the day due traffic interruptions. Also, when planning the route for the transportation it is important to pay attention on the overhead heights below the bridges, the radii of the curves and other bottlenecks on the way to make sure that the transportation can be done safely and without unnecessary stops. /22/

The rotor blades of the MW class turbines are a critical issue for the transportation due to their length. Especially passing through villages or curvy roads in the mountains pose a problem. A specially designed long vehicle can carry up to three rotor blades of <2.5MW turbines, longer rotor blades must be carried one by one because of their blade depth is the second limiting factor besides the length. /22/

Weight is the critical factor when it comes to transporting the nacelle. The dimension of the nacelle varies between manufacturers and the size of the wind turbine, but for example 2 MW Nordex N-80 Wind turbine has a nacelle with dimensions 10 x 3 x 3 m (length, width, height). Even larger turbines such as 5 MW class turbines may have nacelle sized of a single-family house. /22/

The erection process of wind turbine is an expensive process due to the price of hiring the mobile crane, therefore the time spending may cause problems. The timing of the erection depends heavily on the weather conditions on the site. Low wind speeds are desirable during the erection period to avoid causing collisions and damaging of the components, also if the weather is too windy it increases the risk of toppling the crane. Apart from the wind, there may occur fluid dynamic problems that may cause intense time pressure on certain assembly steps when the requirements for accurate positioning of components may be in the range of millimetres. The risks are even greater for offshore wind turbine installation due to waves. /22/

The assembly process starts with the erection of the tower, after which the nacelle is mounted on the tower. Assembling the nacelle differs between the wind turbine manufacturers, some are assembled component by component, while others mount the whole nacelle as one piece on the tower. The last part is to lift the complete rotor and mount it to the rotor shaft, another way to install the rotor is to mount the hub and rotor shaft and lift them with the nacelle and install the rotor blades one by one afterwards. /22/

After the shell construction has been erected the construction will continue with the electrical installations inside the shell. /22/

3.4 Operational Phase

After several weeks of testing the wind turbine should have got rid of the common problems such as rotor unbalance. The operator or an independent expert will inspect the wind turbine. The purpose of the inspection is to make sure that the wind turbine is operating faultlessly, and all the terms agreed on the construction contracts and other permits has been fulfilled. Once the inspection has been passed, the wind turbine is ready for commissioning and the operator can take-over the wind turbine. After the commissioning the wind turbine should be able to produce electricity for the next 20 years. /22/

Usually the first two years of the operational time are liability period, during which the wind turbine manufacturer takes care of the maintenance and repairing at his own expense. After the liability period the operator takes the full responsibility for it, unless there is a full-service contract made. /22/

The wind turbine should be inspected, maintained and repaired throughout its operational lifetime. Based on the local laws, the wind turbine is inspected usually every 2 to 4 years to minimize risks concerning the machine itself, environment and humans. /22/

All the necessary maintenance and inspection works are documented. These works include lubrication of the bearings and maintaining mechanical, electrical and control components. All the repairs should be done without delay if possible to lower the risk of small problems turning into something bigger and more expensive to repair as well. /22/

During the operational time the operator must acquire an insurance for the wind turbines. The most common questions from insurance companies are regarding what types of risks are there and who is responsible for them. It is advised to have an insurance against external risks, such as lightning, fire and so on, but also for machine breaking. Also, the financing bank of the wind turbine project usually requests an insurance for the downtime periods to make sure that the loan can be repaid even while there is no production. It is also advised to get an insurance that covers events in which someone or something is damaged caused by the wind turbine, such as falling ice from the rotor blades or fire beneath below the wind turbine caused by the nacelle. /22/

Once the wind turbine is at the end of its operating period, the wind turbine must be decommissioned or more economically repowered. The old wind turbines, usually many small ones, are replaced by fewer bigger wind turbines, but in order to do this, the local conditions must be checked already during the planning phase. The reason why the new wind turbines are bigger are that they are quiet compared to small ones, more efficient and have higher availability allowing higher yield at the same site. Bigger wind turbines also have lower service costs than small ones and less visual impact on the landscape. /22/

4 RISK MANAGEMENT

4.1 Definition of Risk

A risk can be defined as a type of uncertainty which has a positive or negative impact on the objectives of individual, group or organization if realized, for example, gaining or losing something valuable. All uncertainties are not risks, but all the risks are uncertain. Therefore, a risk is uncertainty which will affect achievements of the objectives, if it occurs. /23/

4.2 What is Risk Management

Risk management is about managing risky and uncertain world effectively. The future is uncertain and every one of us operate daily in a world of uncertainty. /24/

Usually risk refers to negative events in this context, but as explained in the previous chapter, the risk can be also positive. This is why risk management is not only about eliminating or lowering the chances of negative risk events, but also about considering positive outcomes. Risk management aims to seek better outcomes, therefore it is important to identify risk events and understand what causes them and what the consequences are. /24/

Risk management is proactive process and the objective is to act before the risk event. To achieve this objective the work must be done in advance to find out what are the risks and their consequences, instead of waiting for risks to realize and try to manage them through the consequences. Only this way it is possible to increase the chance of positive risk event to occur and reduce the probability of the negative risk event and to deal with the consequence efficiently, in case it occurs. /24/

It is important to the understand that consequences of risk event may cause another risk event which has its own consequences. In risk management this phenomenon is called a causal chain, network of linked events. When understanding the causal chain, is it easier to consider the probability of different risk events and the consequences and cost that the specific risk causes. After exploring different causal chains, it is possible to choose the one with the highest chance of positive events occurring and try to optimize the benefits if this event ever occurs. /24/

Managing risks is not always possible, for example when a factor affecting the objective changes, but it is out of the reach of project management such as regulation changes made by government or exchange rates. This kind of risks are called external risks. On the other hand, there are internal risks, which are possible to be controlled at least on some level, such as supplier or employee availability. The same difference appears between consequences too, for example it is possible to install sprinkler system for a fire to limit negative consequences, but in some other case there may be limitations to taking actions and purchasing an insurance against the fire is the only option. /24/

4.3 Risk Management in Projects

In projects the link between reward and risk is always present, meaning that projects with high risk have higher rewards than projects with low risk. To gain the rewards there must be successful projects, and the projects that have properly managed risks are the ones that succeed. /23/

There is a range of factors that introduce risk to projects, which are uniqueness, complexity, assumptions and constraints, people, stakeholders and change. /23/

- Projects are always unique, there is always some elements in the project that are being done for the first time, which increases the risk.
- Projects are complex combination of many tasks regarding different kind of areas such as technical, relational or commercial, which all have their own risks.
- Making assumptions and constraints involve guessing about the future, when a guess goes wrong, it is potentially turning into a risk.
- There are people involved in the project with different roles, and they are not completely predictable and therefore cause a risk. Particularly stakeholders, who have requirements, objectives and expectations for the project, sometimes their requirements may cause overlapping or conflicting and therefore pose a risk to the project.
- Projects also tend to change over time and each change may cause uncertainty.

Because of these reasons, each project must be analyzed from the perspective of risk management case by case. /23/

4.4 Risk Management Process

The risk management process includes identifying, assessing, prioritizing and taking appropriate actions to avoid or lower negative impact of negative risk event and on the other hand improve chances of positive risk event to occur before the risk event. /24/

Risk management usually starts by creating a risk management plan in the beginning of the project, which explains precisely what kind of methods, processes and tools are being used through the process to identify and manage risks. Benefits for creating well documented risk management plan are for example higher probability to identifying major risks, clear explanation about responsibility sharing and things such as how risks will be reported and reviewed. /24/

The risk management plan should also name the objectives which are at risk, this helps to identify risks that matter. It is also important to clarify how much risk key stakeholders are prepared to take in the project. These are the first things to solve in any risk process, to make sure that the objectives and scope are understood and determined. /23/

4.4.1 Identifying and Assessing Risks

There are many risk identification techniques and each of them has their own strengths and weaknesses, so it is recommended to use a few of them instead of only one to identify as many risks as possible. The goal is to go through all the known risks and causes of them, and document them, recognize that some of the risks are naturally unknown and understand that some of the risks only appear later in the project, this is why risk identification is a continuous process throughout lifespan of the project. /23/

The most common risk identifying techniques are /23/:

- Brainstorming
- Checklists and prompt lists to learn from previous risk assessments

- Interviews with stakeholders of the project to gain their aspect on possible risks affecting the project
- Checking other similar projects to identify common risks and effective actions to those risks.
- Precise analysis of project constraints and assumptions to find the ones that are most risky

When identifying risks and making a list of them, it is important to answer questions such as how possible it is for these risk events to occur, what the options to control these risk events are in order to reduce or avoid them and if there is something that may disturb the possibility to control these risk events.

To support risk identifying techniques there are tools such as risk breakdown structure (RBS) and risk register. Both tools are helpful when creating a framework for risks of the project. /24/

In the Risk Breakdown Structure, risks can be divided into several different aspects such as technical, management, commercial and external risks, and these aspects can be processed into more specific categories. Once the risks have been categorized, they can be allocated to risks owners, who will be responsible for making sure that the risk is being managed effectively. /23/

Table 3. Example of hierarchical Risk Breakdown Structure. /23/

RBS level 0	RBS level 1	RBS level 2
All Risks	Technical risk	Performance
		Reliability & maintainability
		Security
	Management risk	Resourcing
		Project management
		Health, safety & environmental
	Commercial risk	Subcontracts
		Supplier & vendors
		Customer stability
	External risk	Legislation
		Political
		Environmental/weather

The risk register is more precise about individual risks. In the risk register it is common to have information such as risk ID number, likelihood, impact, severity, owner, mitigating action, contingent action, progress on actions and status of the specific risk. /24/

Table 4. Example of risk register

ID & Identification Date	Risk	Likelihood	Impact	Severity	Owner	Mitigating action	Contingent action	Progress on actions	Status
1. 20.3.2018	There is a risk of thievery at the construction site	Low	High	Critical	J. Rahkala - Health, Security and Environment department	The construction site will be surrounded with mesh fence. Purchase Insurance.	Contract will be made with a local security company.	Update 25.3.2018 Mitigation actions implemented	Open

4.4.2 Prioritizing Risks

Once recognizing risks, some of them are less important than others, so it is necessary to prioritize and filter them to find the best opportunities and the worst threats for the project. Various characteristics can be used when prioritizing risks, such as what are the consequences, how probably they occur and when they can happen. /23/

The scope and seriousness of the risk defines the significance of the risk, but also the expected objective outcomes of the risk-taker affect it. Different instances may assess the same risk completely differently, and because of this, risks are once again reviewed case by case. /23/

The risk can be reviewed mathematically by using the probability theory, when knowing the probability of a specific risk and the impact of the risk on the wanted outcome. Note that in this method two very different risks may have the same risk exposure, but which should be managed completely differently /23/:

$$\text{Risk exposure} = \text{impact of the risk} \times \text{probability of the risk} \qquad (3)$$

In this formula the input data can be measured on scale from 1 to 5. /23/ The following tables are examples to calculate risk exposure for project investment costs. The figures in the tables could vary depending on the case based on the economic standing of the project financers.

Table 5. Estimation of risk probability factor. /23/

Probability of occurrence	**Probability factor**	**Probability of the risk**
1-20%	1	Very Low
21-40%	2	Low
41-60%	3	Medium
61-80%	4	High
81-100%	5	Very high

Table 6. Estimation of the risk impact factor for an investment costs of a project. /23/

Impact of the risk on total investment costs of the project	**Impact factor**	**Seriousness of the risk**
<2%	1	Insignificant
2-5%	2	Minor
5-15%	3	Moderate

15-50%	4	Significant
>50%	5	Unbearable

The outcome of the risk exposure can be put on a probability impact grid (PIG), sometimes referred as risk matrix or heat map, which aims to rank risks to identify the main risks of the case and help prioritizing them to optimize the focus of risk management to most important risks. /23/

Table 7. Probability impact grid. Numeral/colour indicator explains the seriousness of the risk. /23/

		Probability factor				
Impact factor		1	2	3	4	5
	1	1	2	3	4	5
	2	2	4	6	8	10
	3	3	3	9	12	15
	4	4	8	12	16	20
	5	5	10	15	20	25

4.4.3 Managing Risks

Once knowing what the existing risks are and which are the most important ones of them, and understanding what their consequences are, it is easier to start making decisions about how to control them. /24/

There are several ways to manage risks which are typically reducing or avoiding, transferring and sometimes even accepting the risk as it is. /23/

Reducing the risk can be done by minimizing the negative impact or lowering the possibility of occurrence of the unwanted outcome. This method is a must when the risk is very likely to occur, and the consequences are critical. /23/

Avoiding the risk can be done by choosing alternative options for the needs that may not have the same risk exposures, but this can also affect the opportunities in business. For example, when noticing that certain kind of plastic part of a machine is on the edge melting in hot operation environment, it needs to be replaced with other raw material that certainly tolerates this hot operational environment. /23/

Transferring risk usually means purchasing an insurance that covers the negative impact of realized risk event to the purchaser or making a contract with another company that transfers the responsibility of managing the risk to other party. For example in transportation matters there are several so-called Inco-terms set by International Chamber of Commerce (ICC), which describe who is responsible of the transported goods and at what point of the logistics chain. /24, 25/

If the risk is very likely to happen, but it has low impact on the project objectives or if the risk is worth taking even it cannot be controlled or controlling it successfully is less profitable than allowing it freely to realize, it may be left without any kind of controlling. /23/

5 CASE STUDY

5.1 Amedzofe

Amedzofe is located in the Ho Municipal district which is one of the 25 districts in the Volta Region, approximately 180km from Accra, the capital city of Ghana and 36km from Ho, the capital city of the Ho Municipal District. Amedzofe is the largest town in Avatime Hills with approximately 12000 inhabitants within 7 km radius and the town lies at an altitude of more than 600 meters which makes it the highest settlement in Ghana. /18/

Figure 8. Satellite picture of Amedzofe. /30/

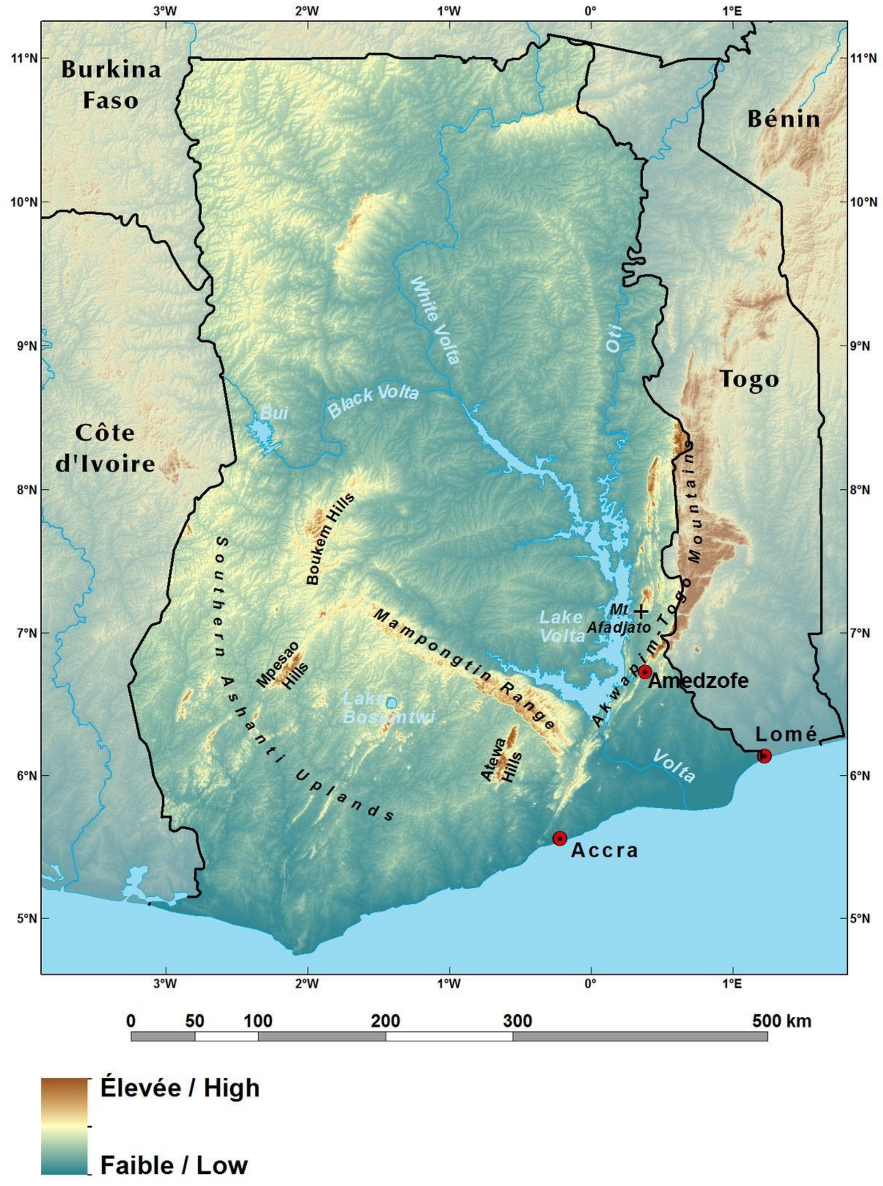

Figure 9. Topography of Ghana. /31/

The road connection from Accra to the nearby towns surrounding Amedzofe has asphalt and is in a moderate condition, but the last few kilometers of road to the settlement of Amedzofe are mostly narrow dirt roads and if there is asphal, it is party badly damaged. Also the road that takes to the settlement of Amedzofe has a few sharp turns, which may be bottlenecks for long transportations. /30/

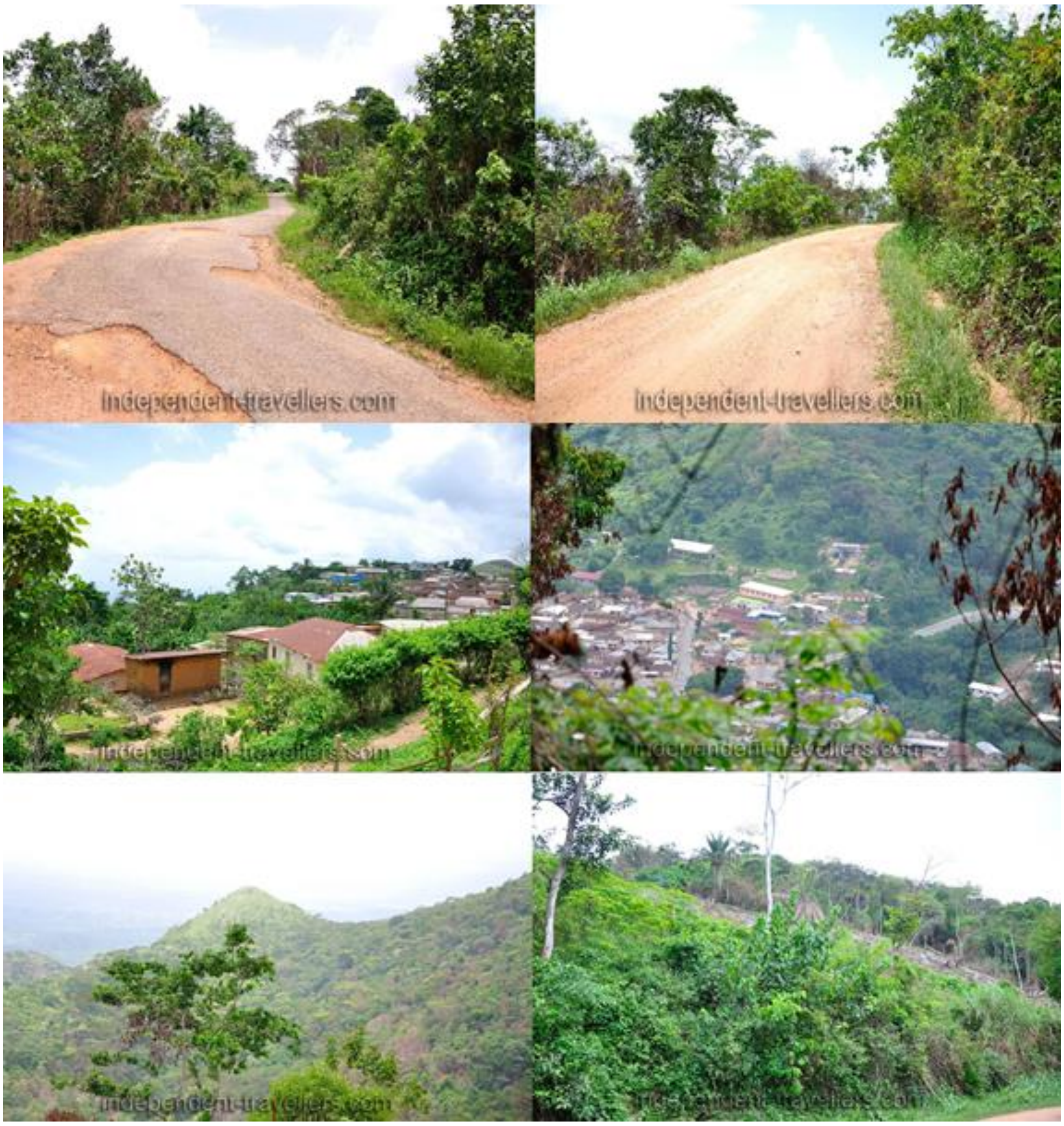

Figure 10. Roads, settlement and nature of the mountainous area of Amedzofe. /26/

Figure 11. Existing transmission power lines of Ghana. /16/

As can be seen in Figure 11, there are two substations with 161kV and 69kV power grid within 40km from Amedzofe for the grid connection.

5.2 Estimation of Annual Energy Production

Estimating annual energy production consists of three parts.

1. Studying wind regime of Amedzofe
2. Choosing wind turbine technology by using information gathered from wind regime study and overview of Amedzofe's infrastructure

3. Calculating annual energy production by using power curve of the chosen wind turbine technology and results of wind regime study

5.2.1 Wind Regime of Amedzofe

The original wind speed data is measured once per hour over one-year period at 20 m height. Because wind turbines used for 20 meters height are not a suitable option for a utility scale wind turbine project, the measurements are converted to estimate wind speeds at other heights which are more typical heights for larger wind turbines. This helps choosing suitable wind turbine technology for the site-specific wind regime and allows making more precise estimations regarding annual energy production.

It is possible to estimate wind speeds at targeted heights by using wind profile power law /27/:

$$V = (h / h_0)^{\alpha} V_0 \tag{4}$$

Where:
V = wind speed at targeted height, h = target height, h0 = height of the known wind speed, α = wind shear exponent, V0 = measured wind speed

The wind shear exponent is a factor which explains, how much the surrounding terrain affect the wind speed. /27/ For Amedzofe, the wind shear exponent of 0.25 was used due mountains, hills and vegetation around the area.

Table 8. Wind shear exponents /27/

Terrain	Wind shear exponent (α)
Open sea/lake	0.1
Plain, flat area	0.15
Farm land, crops	0.2
Short vegetation, a few trees	0.2
Forest	0.25
Many buildings	0.25
Mountainous area, hills	0.25

In the following table the measured wind speeds are spread on intervals of 1 m/s and frequency explaining how many hours a certain wind speed is available at each height per year.

Table 9. Annual wind speed distribution of Amedzore at different heights

	Frequency (hours/a)				
Bins m/s	50m	75m	100m	125m	150m
0	0	0	0	0	0
1	347	238	205	188	169
2	1272	1119	969	865	798
3	1102	1059	1044	1029	991
4	922	875	837	780	783
5	965	852	763	752	728
6	954	872	829	757	706
7	952	877	836	813	730
8	761	827	772	747	735
9	602	665	702	721	721
10	456	515	580	590	628
11	241	402	454	490	532
12	105	242	372	414	411
13	46	119	199	288	350
14	19	55	100	163	214
15	7	16	54	77	136
16	2	13	17	45	63
17	6	5	12	14	30
18	1	4	6	12	14
19	1	4	2	6	7
20	0	1	5	0	5
21	0	1	2	7	0
22	0	0	0	2	7
23	0	0	1	0	2
24	0	0	0	1	0
25	0	0	0	0	1

Table 10. Average annual wind speed of Amedzofe at different heights

Height (m)	Average annual wind speed (m/s)
20	3.9
50	5.0
75	5.5
100	5.95
125	6.29
150	6.59

5.2.2 Selection of the Wind Turbine

According to IEC 61400 standard, wind regime of Amedzofe is considered a low wind class in all examined heights. This information is used to select a suitable wind turbine designed specifically for sites with low wind speed.

The road infrastructure of Ghana, especially closer to Amedzofe play a big part in selecting the turbine as well. The transportation of large wind turbine parts and heavy crane machines required for erecting them may be difficult and even dangerous, because as mentioned in Chapter 5.1, the roads to Amedzofe are not suitable for transporting challenging large wind turbine parts.

Therefore, choosing an ETW model DW54-250kW wind turbine designed to operate at low-medium wind speeds and weak power grids with a 50m tower height and about 25-meter-long blades is justified. /28/ The blades must be transported as whole, but the tower can be transported in three pieces.

As can be seen in the following table, EWT DW54-250KW starts to operate at as low as 2.5 m/s wind speed, which makes it suitable for Amedzofe due to several hours of wind available at 2-3 m/s annually as explained in the previous chapter.

Table 11. EWT DW54-250KW specifications and power curve /28/

EWT DW54-250KW Specifications	
Rotor diameter	54m
Rotor speed variable	12 - 22 rpm
Nominal power output	250kW
Hub heights	35, 40 and 50 m
Cut-in wind speed	2.5 m/s
Rated wind speed	7.5 m/s
Cut-out wind speed	25 m/s
Generator	Synchronous multi-pole
Power output control	Pitch con-trolled
Power converter	IGBT-Con-trolled

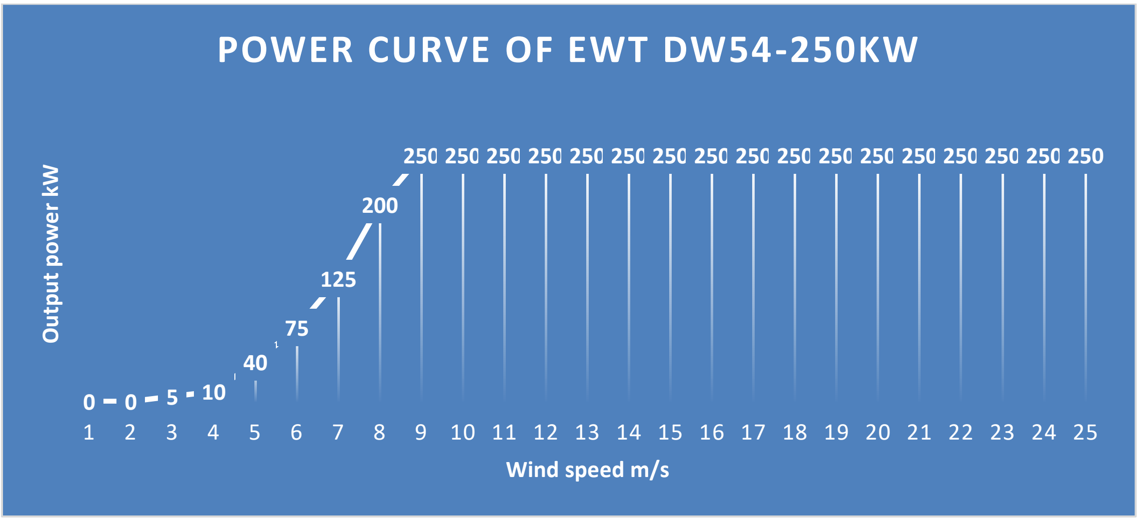

Figure 12. Power curve of EWT DW-2550kW. /28/

In order to support the decision to choose an ETW model DW54-250kW it is possible to calculate site specific Capacity Factor (CF) for it. The capacity factor explains the ratio of its output power to its theoretical maximum output at full capacity over specific period of time, in this case over one-year period. CF can be calculated with the following formula /27/:

$$\text{Net CF} = \text{Net AEP} / (365 \text{ days} * 24 \text{ hours} * \text{Turbine capacity}) \qquad (5)$$

Model DW54-250kW wind turbine reaches the gross capacity factor (CF) of 46% and the net CF of 30% in Amedzofe, which is considered good or average compared to wind turbines around the USA for example. /29/

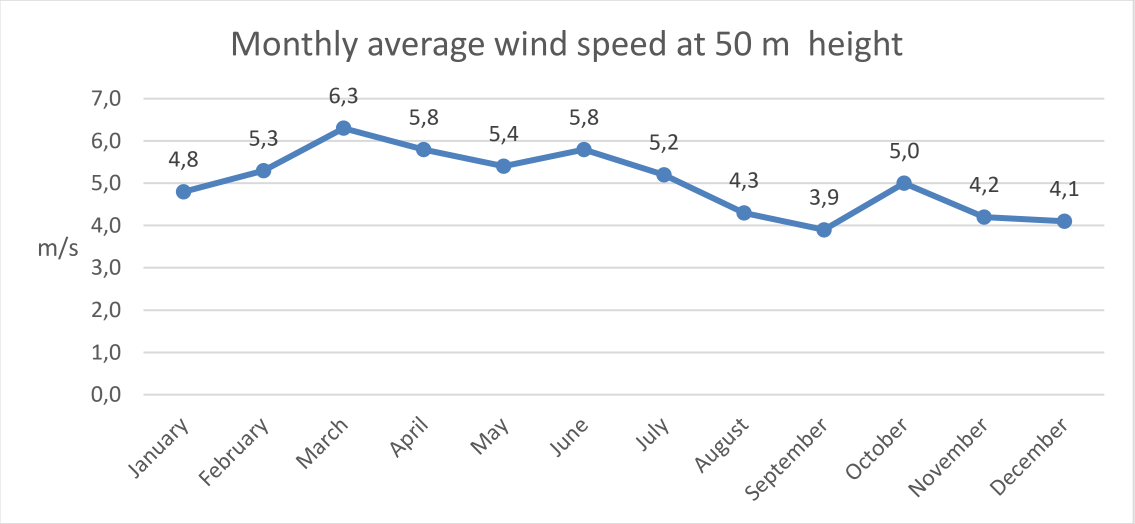

Figure 13. Monthly average wind speed of Amedzofe at 50 meters height.

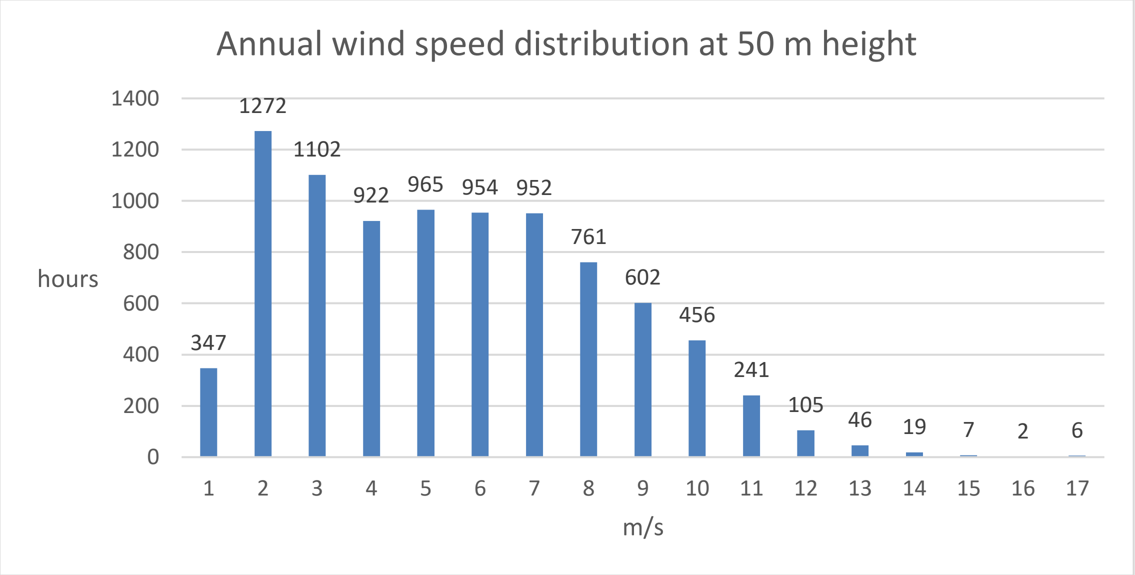

Figure 14. Wind speed distribution of Amedzofe at 50 m height.

5.2.3 Energy Production

By multiplying the power curve output value of the wind turbine at each wind speed with wind speed frequency values at 50 m height from the previous chapter, it is possible to estimate annual energy production (AEP) of the wind turbine per each available wind speed, it is important to take losses and uncertainties into account to lower the risk of ending up with too positive AEP results. /27/:

$$\text{Gross AEP} = \text{Wind speed frequency} * \text{Turbine output} \quad (6)$$

To get a realistic estimation of AEP and at the same time lower financial risks, losses need to be taken into consideration. Therefore, exceedance probabilities should be calculated to get a realistic net annual yield (P50) value. The P50 value states AEP value that will exceed with a probability of 50%. /37/

$$P50 = \text{Gross AEP} - \text{Gross AEP} * \text{Losses (\%)} \quad (7)$$

It is also recommended to take uncertainties into account and calculate the P84 value with the probability of 84%, to get even more realistic AEP value. /37/

$$P84 = P50 - P50 * \text{Uncertainties (\%)} \quad (8)$$

And finally calculate the P90 value with the probability of 90%. /37/

$$P90 = P50 - P50 * \text{Uncertainties (\%)} * 1.28 \quad (9)$$

Table 12. Assumption of the losses and uncertainties for the project. /37/

Losses	%
Wake losses	6
Turbine down time	3
Grid unavailability	0.6
Electrical losses in the wind farm	2
Electrical losses from the wind farm to the TSO grid measure-ment point	2.4
Environmental issues	4.5
Curtailment	2

Uncertainties	%
Wind measurement	3
Long term correction	2.5
Climate variation	2.5
Wind model: vertical ex-trapolation	2.3
Wind model horizontal ex-trapolation	1.2
other wind model	1.5
power curve	2

Total loss	**20.5**

estimating losses	1
total uncertainties	**16**

Table 13. Annual energy production for one EWT DW54-250KW wind turbine in Amedzofe at 50m height.

m/s	Hourly wind speed frequency at 50m	Turbine output (kW)	Annual pro-duc-tion (MWh)
0	0	0	0
1	347	0	0
2	1272	5	6.3
3	1102	10	11.0
4	922	40	36.9
5	965	75	72.4
6	954	125	119.2
7	952	200	190.5
8	761	250	190.3
9	602	250	150.5
10	456	250	114
11	241	250	60.3
12	105	250	26.3
13	46	250	11.5
14	19	250	4.8
15	7	250	1.5
16	2	250	0.5
17	6	250	1.5
18	1	250	0.3
19	1	250	0.3
20	0	250	0
21	0	250	0
22	0	250	0
23	0	250	0
24	0	250	0
25	0	250	0
		Gross:	**998**
		P50 (50% probability)	**793**
		P86 (86% probability)	**666**
		Net P90 (90% probability)	**657**

5.3 Cost Analysis

Because this thesis only examines the potential of one wind turbine, the cost analysis is done for one ETW model DW54-250kW wind turbine.

5.3.1 Incentives Affecting Cost Analysis

Ghana has the feed-in tariff of 0.118€/kWh of electricity produced with wind technology. /10/

As explained in the PESTLE analysis of Ghana, Ghana offers several environmental friendly businesses, including wind power, a complete tax redemption on profits for the first three years of operation and 50% reduction for the next three years after that. Normally Ghana's corporate tax is 25%. /10/

Ghana also offers reductions and redemptions on customs duties for wind power, but only for >3MW wind turbines, therefore it does not affect this project because the turbine used for the project is 250kW. /9/

5.3.2 Estimating Total Investment Cost

To find out if the project is financially viable, the investment costs for the project must be estimated. In this thesis the estimation of investment costs has been made based on statistics for cost of installed wind energy project globally created by International Renewable Energy Agency (IRENA).

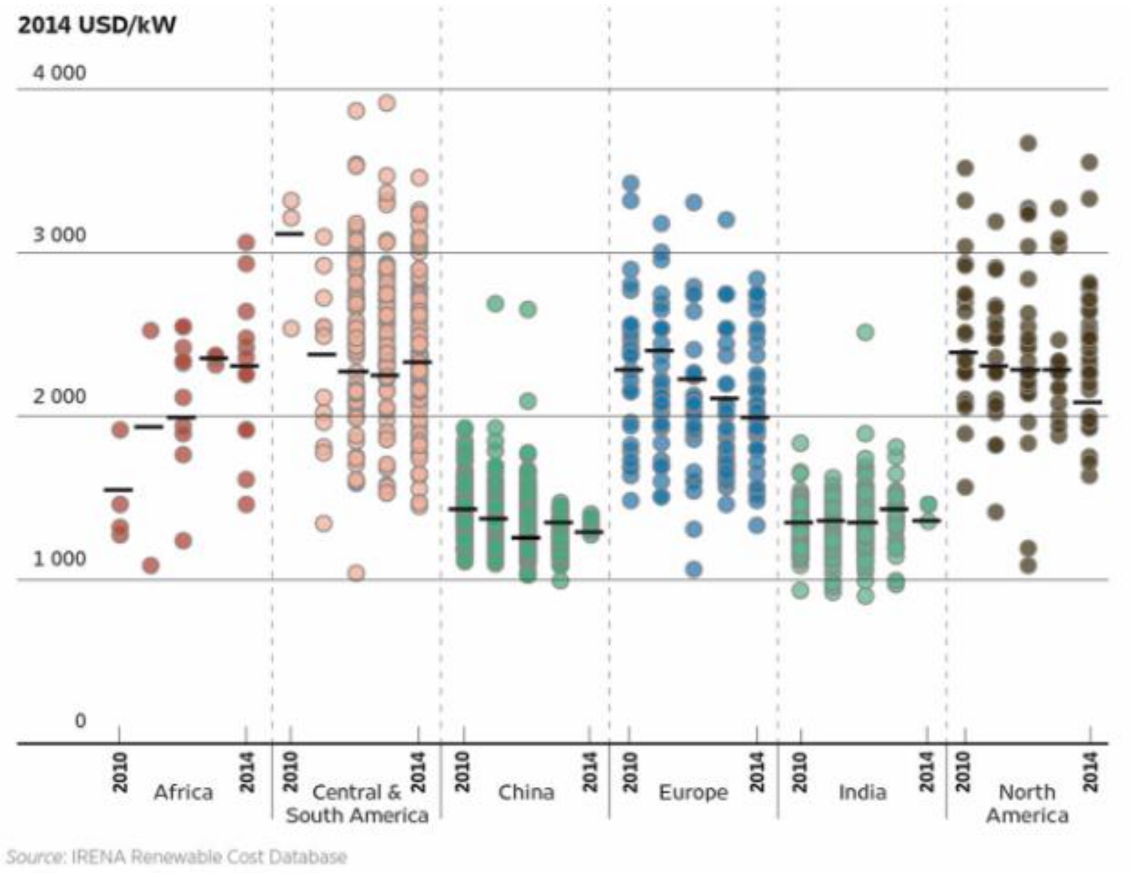

Figure 15. Evolution of total installed cost and weighted averages of commissioned and proposed large wind farms by region in 2014. /31/

As can be seen in the previous figure, the average cost per one kW of installed wind power capacity in Africa is around 2300 USD, which is around 1867 €, when 1 USD = 0,81 €. Therefore, by multiplying wind turbine capacity of 250kW with 1867 €, the estimation of the investment cost for the project is 466785€.

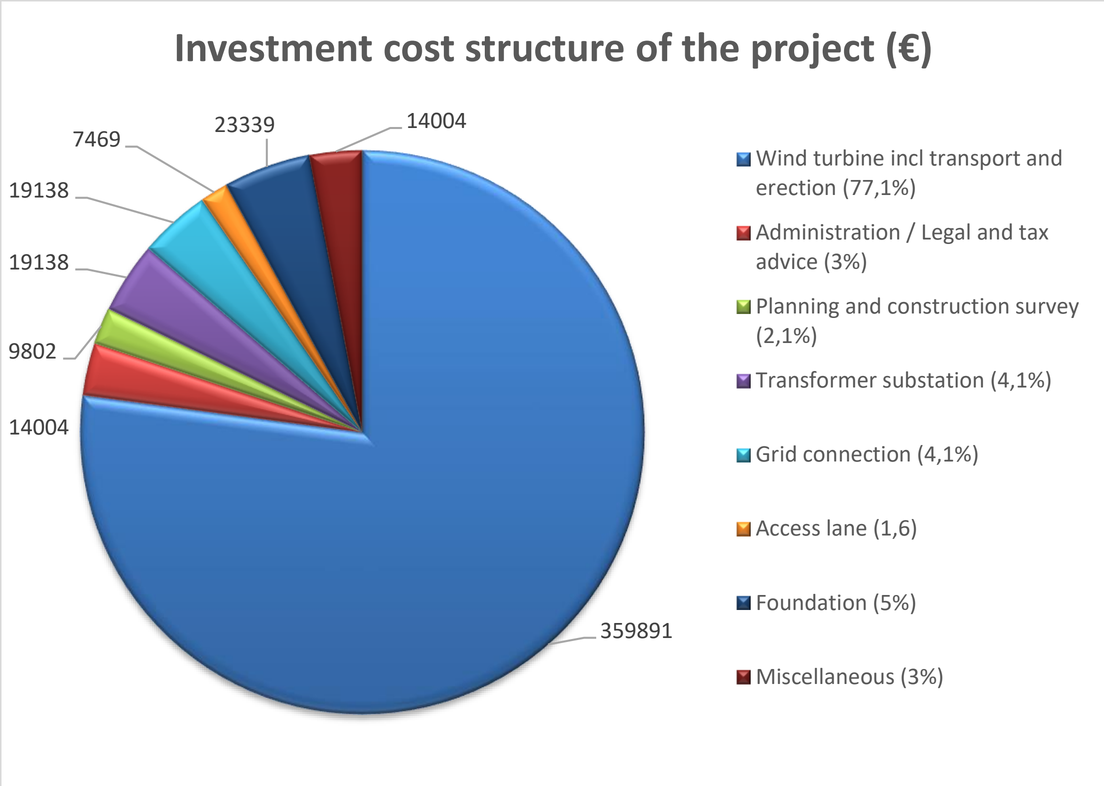

Figure 16. Investment cost structure of the project

5.3.3 Calculating Revenue

The revenue is calculated through the following formula:

$$\text{Revenue} = \text{net AEP} * \text{feed-in tariff} \tag{10}$$

The net AEP(P90) in this project is 657MWh and the feed-in tariff for wind power is 0,118€/kWh, therefore the revenue throughout the project life time is 77526€ per year.

5.3.4 Estimating Annual Operation Expenses and Depreciation

As explained in Chapter 3.2, the annual operation expenses can be estimated from the total investment cost of the project and it usually varies from 2.5% during the first decade to 4% per year for the rest of the operational time of the turbine. In this thesis the annual expenses were calculated by using 3.25% as an average over the operational lifetime of the wind turbine, which is 20 years.

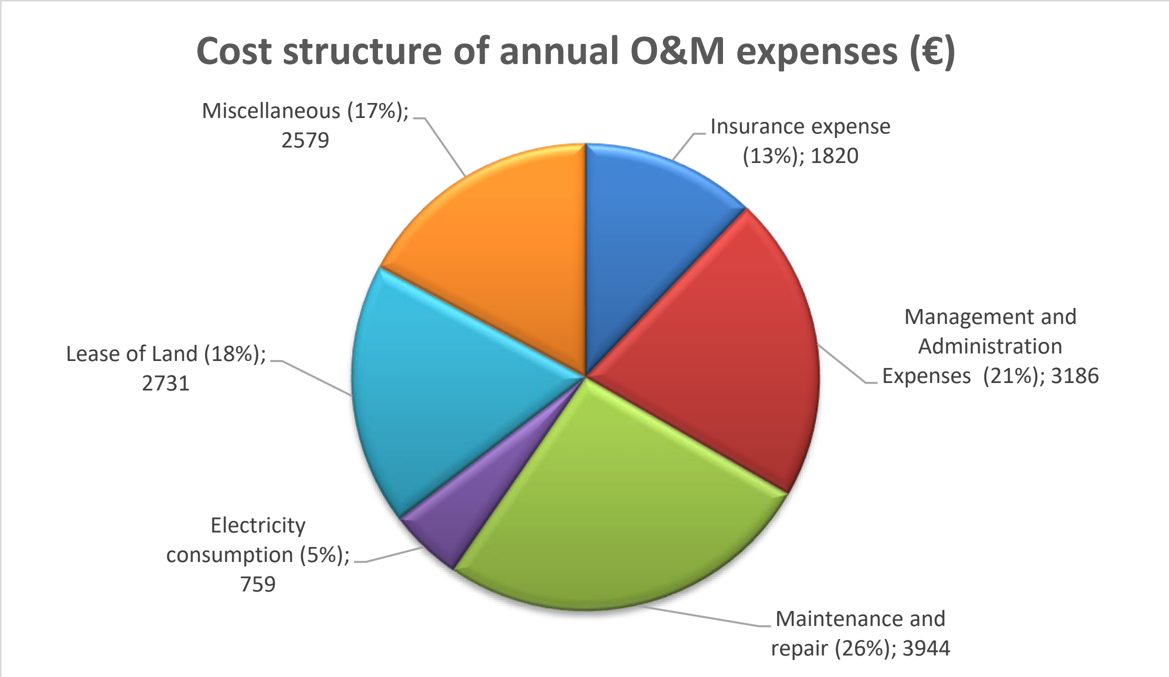

Figure 17. Cost structure of annual O&M expenses in euros.

Depreciation, which explains decrease in value of assets, in this case the wind turbine, is also included into the annual operation expenses. In this thesis depreciation is calculated by using straight line depreciation, which means that the depreciation expense is the same each year over the lifetime of the project. Depreciation can be calculated with the following formula. /22/

Annual depreciation expense = Total investment cost of the turbine / Life cycle of wind turbine (11)

Therefore, the straight-line depreciation for this project is 23339 € per year and when summed up with the operation and maintenance expenses, the total annual operating expenses are 38358€ per year overall.

5.3.5 Financing Plan

When deciding about the financing of the project, a decision must be made about the ratio between debt (loan) and equity (shares/stocks), as explained in Chapter 3.2. For this thesis, the ratio of 70% debt and 30% equity is used due its generality in wind power projects. /22/

Table 14. Amount of debt and equity financing in euros.

Equity Financing (EUR) (30%)	140035
Dept Financing (EUR) (70%)	326749

The payback schedule for the loan is 20 years, because of the operational life cycle of the wind turbine and interest of the loan is set to 8%, since Ghana is still a development country and it is riskier place to do business than for example Finland, where the interest could be as low as 5%. This is because the issuer of the loan e.g. banks want better return on their investment to give you loan in trade off for taking a risk to do so. /22/

The dept service plan of the following figure is calculated by using factors:

The annual payment is a figure that explains how much money should be paid annually to cover the loan that is still unpaid /34/:

$$\text{Annual payment} = \text{Unpaid balance} / \text{Present value factor} \qquad (12)$$

Principal payment is the payment that is left to be paid after deducting interest expense from annual payment and is calculated with the following formula /34/:

$$\text{Principal payment} = \text{Annual payment} - \text{Interest} \qquad (13)$$

Interest is a figure that goes to the issuer of the loan as a reward for making the loan available and can be calculated with the following formula /34/:

$$\text{Interest} = \text{Unpaid balance} * \text{Interest rate} \qquad (14)$$

Unpaid balance is a figure that explains how much loan is left to pay after each year until the end of the loan period and can be calculated with the following formula /34/:

$$\text{Unpaid balance} = \text{Existing unpaid balance} - \text{Principal payment} \qquad (15)$$

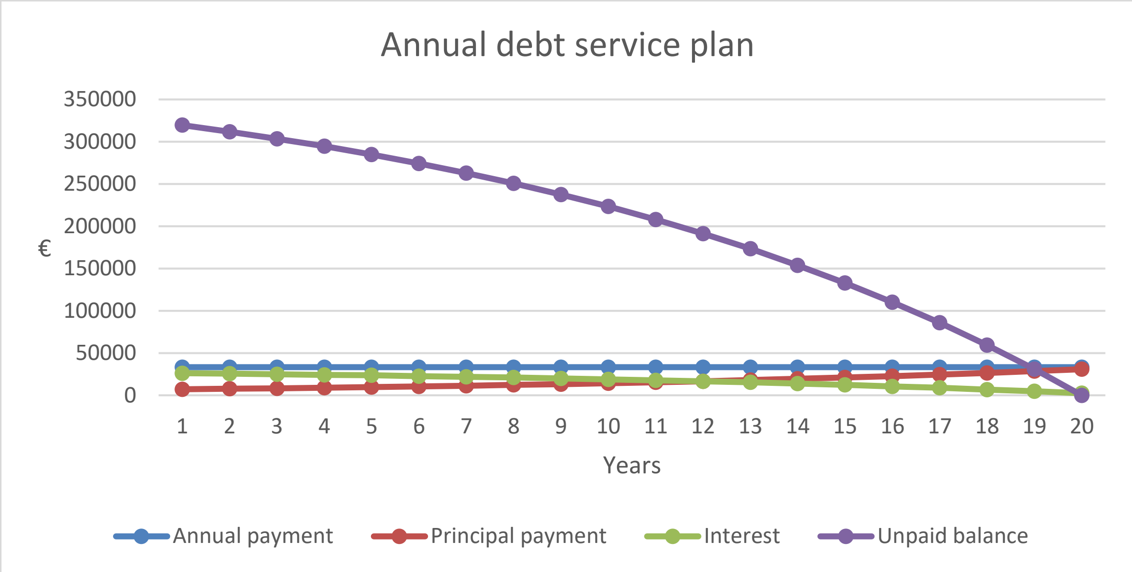

Figure 18. Debt service plan for the project.

5.3.6 Operating Income and Earnings Before Taxes

To calculate earnings before interest and taxes (EBIT) or concisely operating income, the following figures are required: /34/

1. Annual revenue. 77526€ (calculated in Chapter 5.3.3)
2. Total annual expenses, 23339€ (calculated in Chapter 5.3.4)

EBIT = Annual revenue – total annual expenses (16)

Therefore, annual EBIT for the project is 39168€.

Once the EBIT is calculated it is possible to calculate earnings before taxes (EBT), for which interest expenses are required. Interest expenses are calculated in Chapter 5.3.5. /34/

EBT = EBIT – Interest expenses (17)

Because interest expenses vary from year to year, EBT varies as well as can be seen in the following figure.

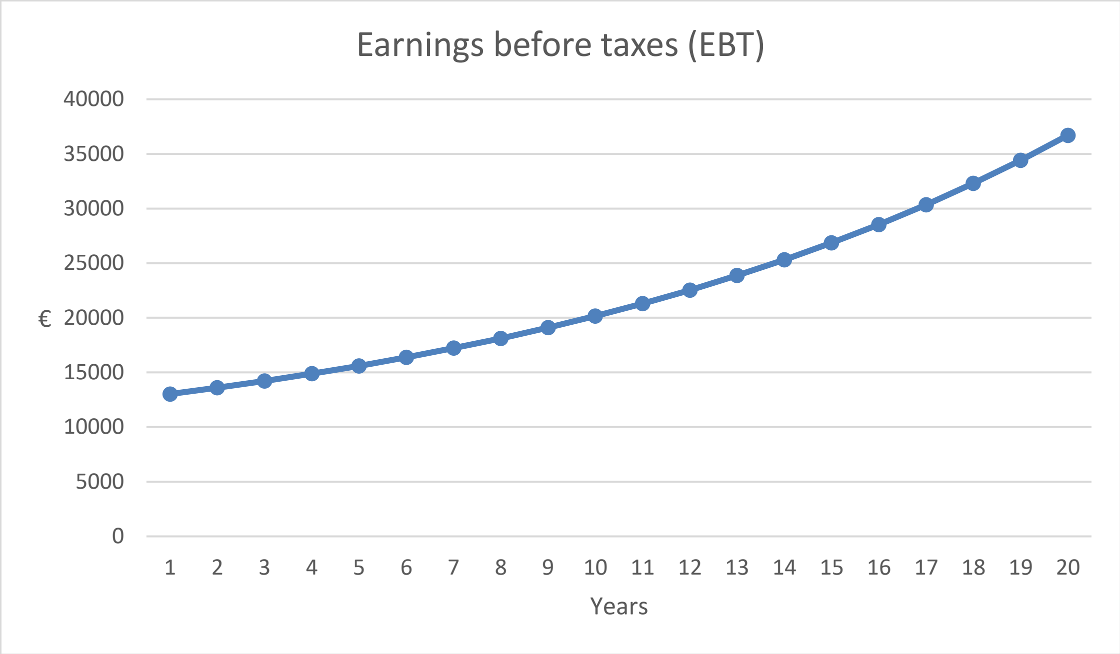

Figure 19. Annual earnings before taxes (EBT).

5.3.7 Net Income

Net income is calculated with the following formula /34/:

$$\text{Net income} = \text{EBT} - \text{Taxes} \tag{18}$$

Taxes are calculated with the following formula /34/:

$$\text{Taxes} = \text{EBT} * \text{corporate tax rate of Ghana} \tag{19}$$

The annual taxes for the project vary from year to year due Ghana's tax redemption and reduction during the first six years of operation and after because of EBT, which varies from year to year as well as can be seen in Chapter 5.3.6.

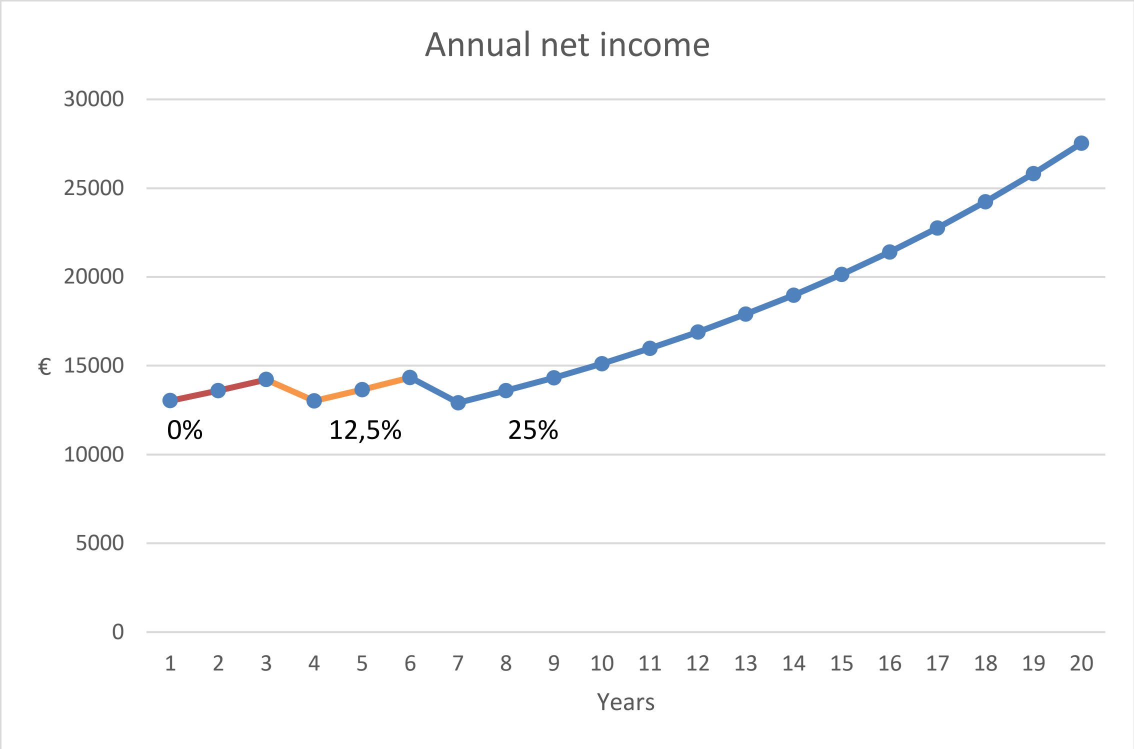

Figure 20. Annual net income

5.3.8 Cash Flow Available for Debt Service and Dept Service Covering Ratio

The cash flow available for debt service (CFADS) explains how much money is available to pay debt expenses, which in this case are interest expenses and principal payments, mentioned in chapter 5.3.5. /34/

CFADS is calculated with the following formula:

$$CFADS = EBIT + Depreciation - Taxes \quad (20)$$

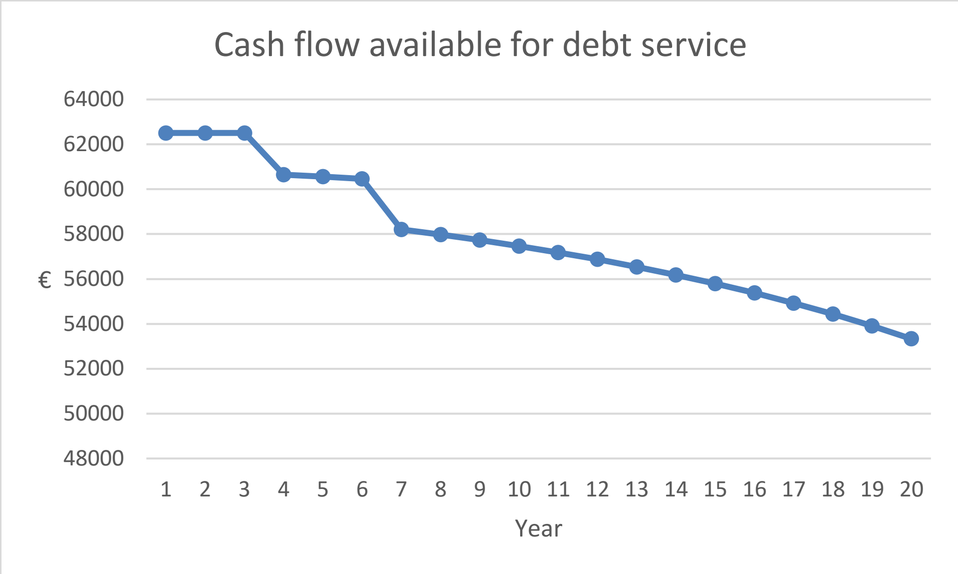

Figure 21. Cash flow available for debt service over the project lifetime.

Debt service covering ratio (DSCR) is a figure which tells the ratio between CFADS and debt expenses. It is used to measure the ability of the project or corporation to produce enough money to cover its debt. When above 1,3 over the project lifetime, the project is estimated to be financially viable enough for loan issuers to grant loans. /34/

DSCR is calculated with the following formula:

$$DSCR = CFADS / (\text{Principal payments} + \text{Interest expenses}) \qquad (21)$$

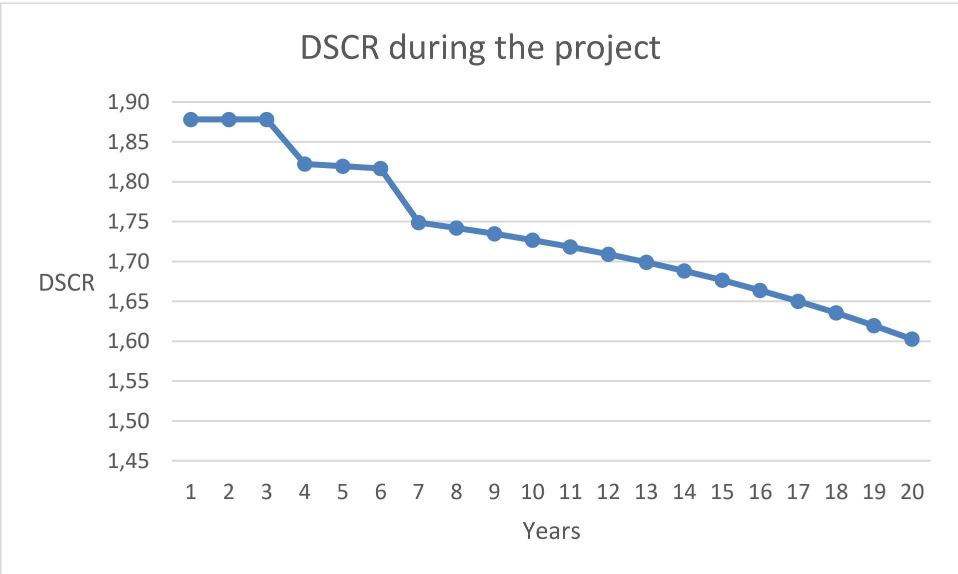

Figure 22. Debt service covering ratio over the project lifetime.

5.3.9 Free Cash Flow of Equity

Free cash flow of equity (FCFE) is a figure that tells how much money can be paid to the equity holders i.e. shareholders and is calculated with the following formula: /34/

$$FCFE = CFADS – Interest\ expenses – principal\ payments \quad (22)$$

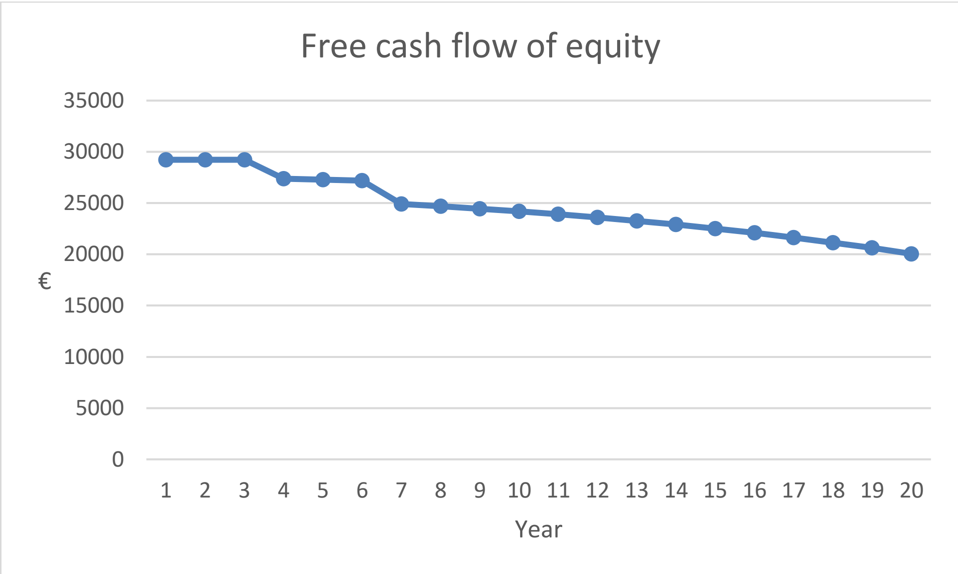

Figure 23. Free cash flow of equity over the project lifetime.

5.3.10 Present Value, Net-present Value and Internal Rate of Return

Present value (PV) tells how much a sum future of money is worth today given as a classified rate of return. PV is an important financial figure based on the concept that money received today is worth more than the equal sum of money received in the future. /34/

Present value can be calculated with the following formula:

$$PV = C / (1 + i)^n \quad (23)$$

C = future amount of money that must be discounted, FCFE in this project.

n = number of periods between the present date and where the sum is worth C

i = is the interest rate for one period, in this project 10%

So, when FCFE over the operational lifetime of the project is 489488€ in the future, the value of that amount of sum is 220958€ in today's money. The total equity financing of the project is 140035€, the assumption is that 140035€ grants the equity investors total return of 220958€ over the duration of 20 years. This alone tells that there is profits available in the investment.

To benefit from the result of PV, it is possible to calculate the Net-present value (NPV), which is used to find out the profitability of the project for the equity investors. /34/

NPV tells the difference between the present value of cash inflows and the present value of cash outflows. If the NPV is positive, the project can expect to be profitable and worth executing.

The NPV can be calculated with the following formula:

$$NPV = PV - \text{Total amount of equity financing} \quad (24)$$

$$NPV = 220958€ - 140035€ = 80922€$$

The internal rate of return (IRR) is a figure used in budgeting to estimate the profitability of investments. /34/

IRR cannot be calculated analytically and therefore it must be calculated by hit-and-error method, which is time consuming and inexact or by using software, such as Excel, like in this thesis. The function for calculating IRR in Excel is =IRR.

IRR for the project is 19%

5.4 Risk Management

Risks identified, evaluated and mitigated in this chapter are a combination of common risks presented within wind energy projects and projects overall in developing countries.

Reference for the information Chapters 5.4.1, 5.4.2 and 5.4.3 has been gathered from sources /35/ and /36/, along with personal brainstorming.

5.4.1 Risk Identification

The list of identified risks in the project can be seen in Table 15.

Table 15. List of risks identified

			When does the risk cause concern?			
ID	Category*	Risk	Preliminary	Planning	Construction	Operation
1	P	Cancellation or reduction of the feed-in tariff for new projects or before commissioning	x		x	
2	P	Opportunity: €/kWh or duration increase in feed-in tariff before commissioning	x		x	
3	P	Decrease or cancellation of taxation reduction and redemption	x			
4	P	Establishment of new regulations to be taken in consideration	x		x	
5	P	Delays due permitting			x	
6	P	Opportunity: Adjusting permitting processes to speed up the process			x	
7	P	Corruption, especially during permitting processes			x	
8	P	Safety issues (terrorism, thievery, sabotage)			x	x
9	P	Regional instability in some rural areas and close by countries (Burkina Faso, Nigeria, Mali)				x
10	E	Cancellation of PPA (power purchase agreement)		x		
11	E	Damage to components during the transportation, construction or commissioning			x	

12	E	Increase of interest rate of loan(s)				x
13	E	Uncertainty on interest rates due financial problems of the issuer of the loan				x
14	E	Increases or decreases in electricity price				x
15	E	Better or worse wind conditions during load hours than expected				x
16	E	Engineering, procurement and construction (EPC) contractor unable to keep on schedule			x	
17	E	Unexpected critical failure during the operation				x
18	E	Financial problems of planned equity partner(s)	x			
19	E	Currency risk due inflation		x		x
20	S	Delay due lack of skilled labour		x	x	
21	S	Delay due possible compulsory purchase process of property	x			
22	S	Delay due local rebellion against the project	x		x	
23	S	Damage to the nature during construction or operation (e.g. oil spillage of the gear box)			x	x
24	T	Lower yield than estimated				x
25	T	Opportunity: higher yield than estimated				x
26	T	Higher need for maintenance and repairs than expected				x
27	T	Existing infrastructure may be partly in bad condition and require upgrades		x	x	
28	T	Price uncertainty of the wind turbine technology		x		
29	T	Delays due bad weather conditions during construction phase, may increase CAPEX			x	

* P=political, E=Economical, S=Social, T=Technical

5.4.2 Risk Evaluation

The evaluation of risks can be seen in Table 16.

Table 16. Risk register

ID	Risk	Affects	Probability (1-5)	Impact (1-5)
1	Cancellation or reduction of the feed-in tariff for new projects or before commissioning	Revenue	4	3
2	Opportunity: €/kWh or duration increase in feed-in tariff before commissioning	Revenue	1	3
3	Decrease or cancellation of taxation reduction and redemption	Taxation	4	3

4	Establishment of new regulations to be taken in consideration	Capex and schedule	1	2
5	Delays due permitting	Schedule	5	2
6	Opportunity: Adjusting permitting processes to speed up the process	Schedule	1	1
7	Corruption, especially during permitting processes	Capex and schedule	3	2
8	Safety issues (terrorism, thievery, sabotage)	Revenue	2	5
9	Regional instability in some rural areas and close by countries (Burkina Faso, Nigeria, Mali)	Revenue	2	2
10	Cancellation of PPA (power purchase agreement)	Revenue and schedule	1	5
11	Damage to components during the transportation, construction or commissioning	CAPEX	3	4
12	Increase of interest rate of loan(s)	Interest	2	3
13	Uncertainty on interest rates due financial problems of the issuer of the loan	Interest	2	3
14	Increases or decreases in electricity price	Revenue	5	3
15	Better or worse wind conditions during load hours than expected	Revenue	4	3
16	Engineering, procurement and construction (EPC) contractor unable to keep on schedule	Schedule	3	3
17	Unexpected critical failure during the operation (higher OPEX)	OPEX	1	4
18	Financial problems of planned equity partner(s)	Interest	1	1
19	Currency risk due inflation	Revenue	2	3
20	Delay due lack of skilled labour	Schedule	3	1
21	Delay due possible compulsory purchase process of property	Schedule	3	1
22	Delay due local rebellion against the project	Schedule	1	1
23	Damage to the nature during construction or operation (e.g. oil spillage of the gear box)	OPEX	1	3
24	Lower yield than estimated	Revenue	4	2
25	Opportunity: higher yield than estimated	Revenue	2	2
26	Higher need for maintenance and repairs than expected	OPEX	3	1
27	Existing infrastructure may be partly in bad condition and require upgrades	CAPEX	4	1
28	Price uncertainty of the wind turbine technology	CAPEX	5	5
29	Delays due bad weather conditions during construction phase	CAPEX	3	3

After evaluating the risks, each risk can be placed in the Risk Matrix.

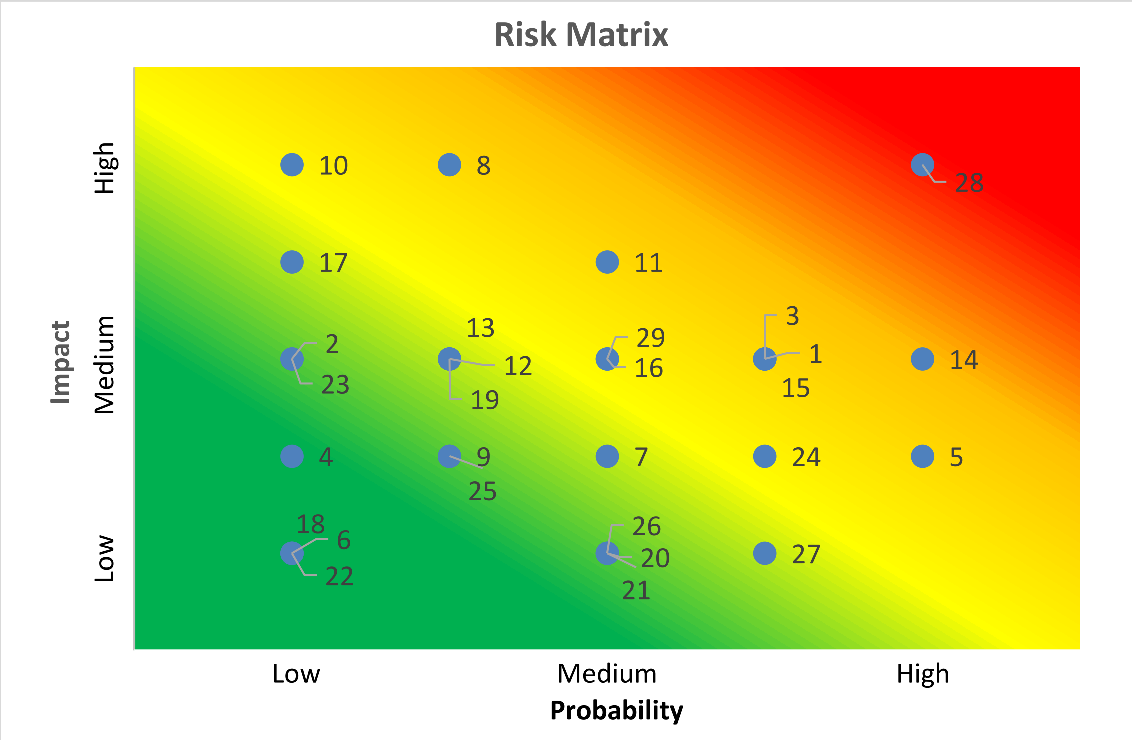

Figure 24. Risk matrix of the identified risks.

5.4.3 Risk Mitigation

Mitigation plans for each risk can be seen in table 17.

Table 17. Risk mitigation plan

ID	Risk	Mitigation plan
1	Cancellation or reduction of the feed-in tariff for new projects or before commissioning	Improve forecasting techniques
2	Opportunity: €/kWh or duration increase in feed-in tariff before commissioning	
3	Decrease or cancellation of taxation reduction and redemption	
4	Establishment of new regulations to be taken in consideration	
5	Delays due permitting	Effective project management
6	Opportunity: Adjusting permitting processes to speed up the process	
7	Corruption, especially during permitting processes	No specific strategy
8	Safety issues (terrorism, thievery, sabotage)	Insurance

9	Regional instability in some rural areas and close by countries (Burkina Faso, Nigeria, Mali)	No specific strategy
10	Cancellation of PPA (power purchase agreement)	Avoid corruption when applying for PPA
11	Damage to components during the transportation, construction or commissioning	Insurance, 3rd party contracts
12	Increase of interest rate of loan(s)	Fixed contracts
13	Uncertainty on interest rates due financial problems of the issuer of the loan	Creating secondary plans for "what if" scenario
14	Increases or decreases in electricity price	Insurance to cover sufficient price level
15	Better or worse wind conditions during load hours than expected	Insurance to cover sufficient price level
16	Engineering, procurement and construction (EPC) contractor unable to keep on schedule	Supply-or-pay contract (in case of failing to supply, EPC has to pay compensation fines)
17	Unexpected critical failure during the operation (higher OPEX)	Full service contract, Insurance, Manufacturer warranties, Rely on proven technologies
18	Financial problems of planned equity partner(s)	Improve forecasting techniques
19	Currency risk	Payment in stable currency (e.g. € or USD), purchase spot contract against fluctuations
20	Delay due lack of skilled labour	3rd party contracts
21	Delay due possible compulsory purchase process of property	Educate local population about the benefits of the project
22	Delay due local rebellion against the project	
23	Damage to the nature during construction or operation (e.g. oil spillage of the gear box)	Insurance, full service contracts with 3rd party
24	Lower yield than estimated	Insurance to cover sufficient price level, rely on proven technologies, manufacturer warranties
25	Opportunity: higher yield than estimated	No specific strategy
26	Higher need for maintenance and repairs than expected	Insurance, full service contract with 3rd party, rely on proven technologies
27	Existing infrastructure may be partly in bad condition and require upgrades	Clear responsibilities, project management should deal with the owner of the particular part of the infrastructure
28	Price uncertainty of the wind turbine technology	Effective project management
29	Delays due bad weather conditions during construction phase	Insurance, monitor weather, effective project management

6 DISCUSSION AND CONCLUSIONS

The results of the case study regarding Amedzofe's potential as a placement location of a utility scale wind power plant are promising.

The Net-Present Value and Internal Rate of Return both are on profitable level and the Debt Service Covering ratio is on a sustainable level, meaning that the project is estimated to have a financial viability to be able to pay the loan and interest rates back in the planned schedule of 20 years and on top of that generate profit to the equity owners.

Risks concerning the project are common risks regarding wind power projects and projects with similar risks have been accomplished successfully. As mentioned, Ghana is a stable country compared to other countries in the region and lowers the risks regarding the project. The risk exposure of the identified risks is mostly on low to medium level when measured on the risk matrix, therefore the project is not considered to be too risky, especially when taking the estimation of the profits in account.

Because the case study is done for one wind turbine only, it is recommended to try to acquire more information regarding the actual site and create deeper examination of annual energy production for the project by siting turbines on the available plot area. Also, the wind regime study does not include any simulations done with a proper software, therefore it is recommended to use such software to get more precise and accurate estimations regarding annual energy production.

Lack of electricity in Ghana is backing up the need of adding new electricity production capacity, which will lead to a better quality of life for the citizens, more business opportunities and continuation of growth of GDP of Ghana.

The conclusion is that the project should be continued by proceeding into more detailed development and planning phases.

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