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SUPPLY CHAIN DESIGN FOR A WIND POWER PLANT IN GHANA

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TIIVISTELMÄ

Tekijä	Jonne Rahkala
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Tämän opinnäytetyön tarkoitus on toimitusketjun suunnittelu tuulivoimalaan, joka tulisi sijaitsemaan Nkwantassa, Ghanassa. Toimitusketjun suunnitteluvaiheessa tehtävät päätökset ja tutkimukset vaikuttavat toimitusketjun toimivuuteen ja samalla koko tuulivoimalan tuottavuuteen. Opinnäytetyön pohjana on paikan päällä mitatut tuulennopeuden arvot. Näiden pohjalta voidaan arvioida vuoden keskimääräinen tuulennopeus, sekä tuulennopeuksia eri korkeuksissa.

Opinnäytetyössä tarkastellaan aluksi Ghanaa käyttämällä PESTLE –analyysiamallia. Lisäksi työssä käsitellään toimitusketjun periaatteita yleisesti ja lopulta määritellään toimitusketjun varsinainen rooli tuulivoimaprojektissa. Lisäksi työssä määritellään, kuinka tuulivoimalahanke kehitetään ja mitä eri vaiheita siihen liittyy.

Olemassa olevien tuulennopeusarvojen perustella pyritään laskennallisesti valitsemaan sopiva tuuliturbiini kyseiselle alueelle. Toimitusketjua suunnitellessa tarkastellaan, millä tavalla tuuliturbiinit tulisi kuljettaa tuulivoimala-alueelle sekä mistä kyseiset tuuliturbiinit tuodaan. Työssä tarkastellaan myös paikallista sähkönjakelun toteutusta, verkoston sijaintia ja kuljetuksiin liittyviä esteitä.

Työssä vertaillaan kolmea eri turbiinimallia ja laskelmien perusteella sopivin turbiini kyseiselle alueelle on DW54250 –malli. Kyseinen turbiini olisi kustannustehokkain malli kyseiselle alueelle, sillä se on erityisesti suunniteltu toimimaan alhaisilla tuulennopeuksilla. Lisäksi kyseisen turbiinin kuljettaminen ja pystyttäminen ei pitäisi aiheuttaa suurempia teknisiä vaikeuksia. Opinnäytetyössä laskennalliset osuudet on tehty Microsoft Excel –ohjelmalla. Tutkimusmateriaalina on käytetty useiden internet-lähteiden lisäksi alan kirjallisuutta ja artikkeleita.

Avainsanat toimitusketju, tuulivoima, projektin kehitys, ghana

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ABSTRACT

Author	Jonne Rahkala
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The purpose of this thesis work is to design a supply chain for a wind power plant in Nkwanta, Ghana. The decisions made regarding to the supply chain affects the performance of the supply chain, and also to the profitability of the entire wind power plant project. This thesis work is based on previously measured wind speed values from the specific town. Based on measured wind speed values it is possible to calculate the average wind speed, and wind speeds at various heights.

In the beginning of the thesis work the PESTLE –analysis tool is utilized to create a country overview of Ghana. The term supply chain is also explained and the supply chain regarding to a wind power plant is described. Additionally the actual development of a wind power plant project is described.

With the help of previously measured wind speed values the most suitable turbine for the area can be selected. During the supply chain design the transportation routes for the wind turbine transportation is designed. Additionally the turbine manufacturer is chosen. Local infrastructural barriers and the situation of the local electricity network are also considered.

The thesis work includes a comparison of three different wind turbine models of which the most suitable for the wind power plant project is DW54250 –model. The DW54250 –model was chosen based on the fact it operates in low wind speeds with acceptable rate. Additionally, the erection and transportation of the DW54250 –model should not present technical difficulties. The calculations in the thesis work were made with Microsoft Excel. The research material gathered for the thesis work was gained from different websites, and also from literature and articles relating to energy sector.

Keywords Supply chain, wind power, project development and Ghana

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

1 INTRODUCTION

One of the targets in this thesis is to provide basic information about Ghana with the help of the PESTLE –analysis tool. Additionally the thesis aims to not only define the term supply chain on a general level, but also to describe what is included in the supply chain in wind energy. This thesis also targets to define how a wind farm project is developed and what aspects should be taken into account in each stage of the wind farm development.

The primary target in this thesis work is to provide basic information to anyone who wants to establish a wind farm in Ghana. The decisions made in the supply chain design affects the outcome of the project greatly-, and more importantly the overall profitability. The supply chain design for a wind power plant starts by defining the term supply chain in wind energy, after which all individual links in the supply chain can be defined.

2 LITERATURE

2.1 Country Overview of Ghana

2.1.1 Geological

The Republic of Ghana is a country in West-African region facing south to the Gulf of Guinea. As can be seen from Figure 1 Ghana shares a land boundary with Togo (east), Burkina Faso (north) and Cote d'lvoire (west). The total area of the country is 238 533 square kilometers. The capital city of Ghana is Accra, which is located at the southern part of Ghana near the coast. /1/

Figure 1. Map of Ghana. /1/

2.1.2 Political

After its transition to multi-party democracy, Ghana is considered one of the more stable countries in West Africa. /2/ In the past 20 years there have been five fair elections and two peaceful transfers of power. Because Ghana is one of the best governed and stable states in the Sub-Saharan region, it attracts investors to do business in the state. /3/

In 2016 the World Press Freedom Index has ranked Ghana as 26th globally and 2nd in Africa. The World Press Freedom Index measures pluralism, media independence, legislative framework quality and safety of journalists. /3/

The ECOWAS Renewable Energy Policy was adopted with a goal that renewable energy sources should cover up to 19% of installed capacity and 12% of total energy generation in the region by 2030, without taking into account large hydro power production. Additionally the government of Ghana has expressed that it wants to reach 10% renewable energy in the power generation mix by 2020. /4/

When it comes to the electricity access in Ghana, the flagship project is The National Electrification Scheme (NES) whose target is to achieve universal access to electricity by 2020. When the project started in 1989, only 15-20% of the population of had access to electricity whereas 82.5% of the population had electricity access in 2016. At the moment, it seems Ghana will miss its electricity access target unless the process is stimulated. /5, p.2/

It seems the power sector of Ghana is suffering of unstable power supply, which could cause difficulties regarding the universal electricity access target. Ghana has endured serious power rationing/load shedding in the years 2003, 2006-2007 and 2011. /6, p.8/

In 2007 the Ghana Energy Development and Access Project was started and the main goal was to improve the efficiency of electricity distribution system and extend the population’s electricity access. This is achieved with adding renewable energy sources, improving the capacity the managers of the distribution system and with reducing losses in the distribution network. Apparently, the project is funded by the World Bank. /6, p.8/

Table 1. Feed-in tariffs. /7/

Electricity production method	**(1-10 years) Guaranteed FIT US cents/kWh**	**20 years indicative FIT US cents/kWh**	**10 years FIT €/kWh**	**20 years FIT €/kWh**	**Maximum Capacity (MW)**
Wind	16,6	14,50	0,14	0,12	300 MW
Solar PV	15,1	13,00	0,12	0,11	
Hydro ≤ 10MW	13,4	11,60	0,11	0,10	150 MW
Hydro 10MW > ≤ 100MW	14,3	12,30	0,12	0,10	
Tidal wave	13,4	11,60	0,11	0,10	No limit
Run off River	13,4	11,60	0,11	0,10	No limit
Biomass	17,5	15,10	0,14	0,12	No limit
Biomass (Enhanced Technology)	18,5	15,90	0,15	0,13	No limit
Biomass (plantations as feedstock)	19,8	17,00	0,16	0,14	No limit
	1 $	=	4,463	GHS	
	1 €	=	1,221	$	

As can be seen from Table 1, the Public Utilities Regulatory Commission of Ghana has set the technology specific feed-in tariffs regarding the renewable energy sources. The duration of the feed-in tariff is from 10 to 20 years. /7/

In addition, The Renewable Energy Act 2011 has put in place a Renewable Energy Purchase Obligation (REPO) in order to encourage private sector investors. Due to that, the electricity distribution companies are obliged to buy a certain amount of the required electricity from renewable energy sources. /7/

The government of Ghana has also set in place other important provisions, such as net metering, Renewable Energy Authority, and Environmental Protection Agency. The Renewable Energy Authority is allowed to own, utilize and manage renewable energy resources on behalf of the country. The Environmental Protection Agency aids private sector investors with environmental regulation and permitting /7/. Net metering enables the residents to feed excess electricity to the national grid. /8/

Other policies that are set in order to attract private sector investors are mandatory connection policy and renewable energy fund. The mandatory connection policy obliges transmission and distribution companies to contribute connection service in order to connect renewable energy sources. The renewable energy fund offers financial aid, for instance financial incentives, capital subsidies, equity participation and production –based subsidies. The financial help mentioned before can be gained for matters such as advertising, development and utilization of renewable energy. /9/

When it comes to the taxes the Corporate Income Tax Law states, “ Corporate revenues earned by energy conservation and water-saving conservation projects, environmental protection and clean development mechanism projects are eligible for a three-year corporate income tax exemption, followed by another three –year 50% reduction of the corporate income tax rate” . The normal taxation rate of 25% is implemented from the sixth year onwards. /10/

2.1.3 Economic

The economy of Ghana is market-based with only a few policy barriers towards trade and investment when comparing to other countries in the region. Ghana also is rather well-endowed with natural resources. According to the Central Intelligence Agency, the economy of Ghana was strengthened by competitive business environment and comparatively sound management. However, in recent years Ghana’s economy has suffered from loose fiscal policy, high budget and account deficits, and depreciation of the currency. /1/

Nowadays agriculture corresponds 20% of the GDP and employs more than 50% of the workforce. The main exports are cocoa, gold and oil. The growing oil industry has boosted economic growth, but especially the fall in oil prices in 2015 reduced Ghana’s oil revenue by 50%. /1/

In 2017 the major concerns regarding economy were the lack of reliable electricity and high debt burden. Ghana has signed a $920 million dollar extended credit facility with the International Monetary Fund (IMF) as aid for the unfortunate economic situation. Nevertheless, the IMF requires Ghana to boost tax revenues, reinforce revenue administration and to cut subsidies. Rescheduling some of the Ghana’s debt, accelerating economic growth, inflation reduction and current stabilization are the most important tasks for the administration. /1/

When it comes to the GDP growth rate, it seems that the highest growth rate within the last ten years was in 2011, when the growth rate was 14.046%. After the peak the growth rate has been in decline and in 2016 the growth rate was 3.577%, which was relatively low compared to the peak growth. /11/

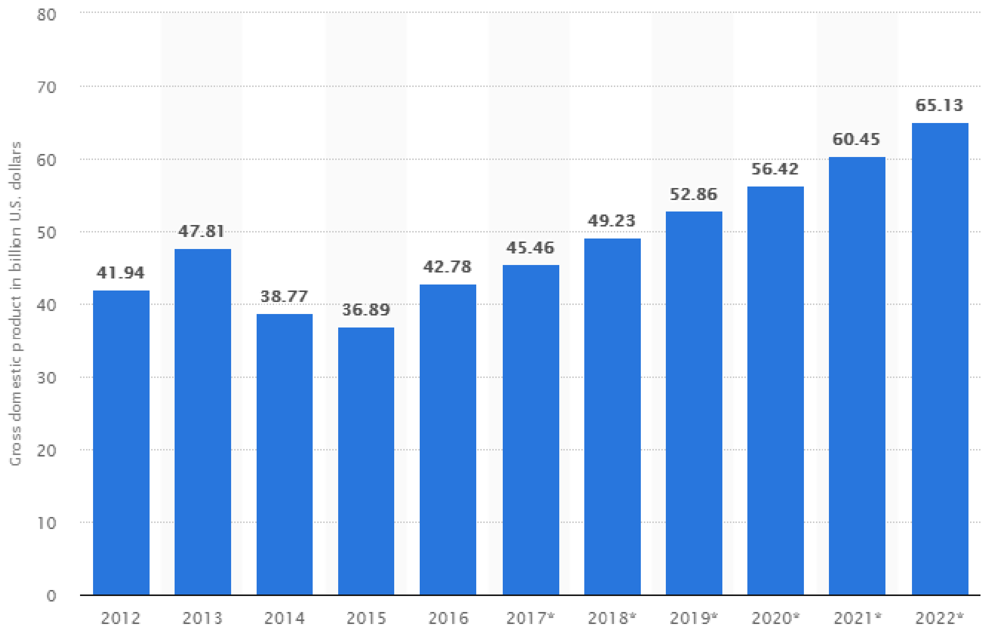

Figure 2. GDP in Ghana. /12/

Figure 2 illustrates the GDP in Ghana from in which it can be seen that the GDP (in U.S dollars) in Ghana was in decline after 2013 but started to improve in 2016. The GDP is estimated to be 49.23 billion U.S dollars in 2018. The GDP is predicted to be growing every year until 2022. /12/

The inflation rate was 12.37% in the year 2017 and it is predicted to drop down to 8.73% in 2018. Additionally the inflation rate has been predicted to be decreasing all the way to 8% in 2020. /13/

The monetary unit of Ghana is Cedi (GHS) and the subunit of cedi is pesewa. One cedi equals to one hundred pesewas. /14/

2.1.4 Social

Today the population of Ghana is estimated to be 29.46 million people. The population has been growing in the recent years since the population was 24.2 million in 2010. Nowadays 50.9% of the people of Ghana are males and 49.1% are females. The population growth-rate is estimated to be 2.18% in 2018. The population is focused on the southern part of the country and the highest concentration is near the Atlantic coast. In 2017 approximately 55.3% of total population lived in urban areas and the rate of urbanization is estimated to be 3.07%. /15/

Accra is the most populous city in the Republic of Ghana with 2.27 million inhabitants. The population of Accra is also predicted to grow to 3.26 million people in 2030. There are about 4 million residents in The Greater Accra Metropolitan Area (GAMA), which makes it the 11th largest metro area in Africa. English language is considered the official language in Ghana. /16/

2.1.5 Technological

The electricity consumption per capita has been increasing since 2010 when the electricity consumption was 280.51 kWh. The latest information states that the electricity consumption was 354.71 kWh in the year 2014. /17/

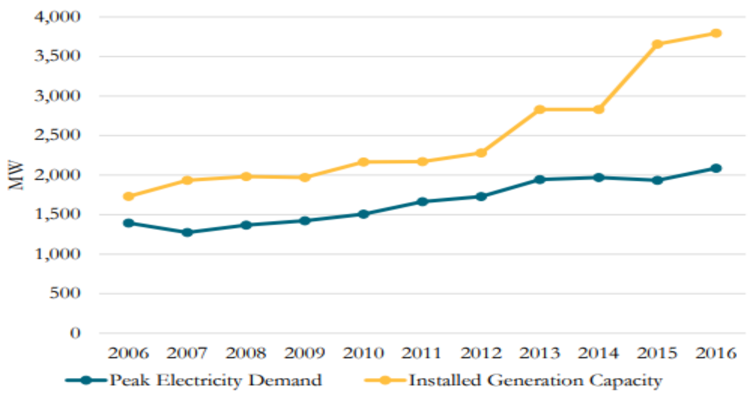

Figure 3. Peak Electricity Demand versus Installed Generation Capacity in Ghana. /5/

Figure 3 shows a graph of the peak electricity demand and also the installed generation capacity in Ghana. Within years 2006-2016 the peak load has increased from 1393MW to 2087MW. In the same time the generation capacity has increased from 1730MW to 3759MW, which means average annual increase of 8.60%. Notwithstanding the fact before Ghana still suffers from power supply shortage /5, p.9/. The generation capacity is currently estimated to be about 4200MW of which 1580MW is from hydro power, 2620MW is from thermal power and 22.5MW from renewable energy sources. /18/

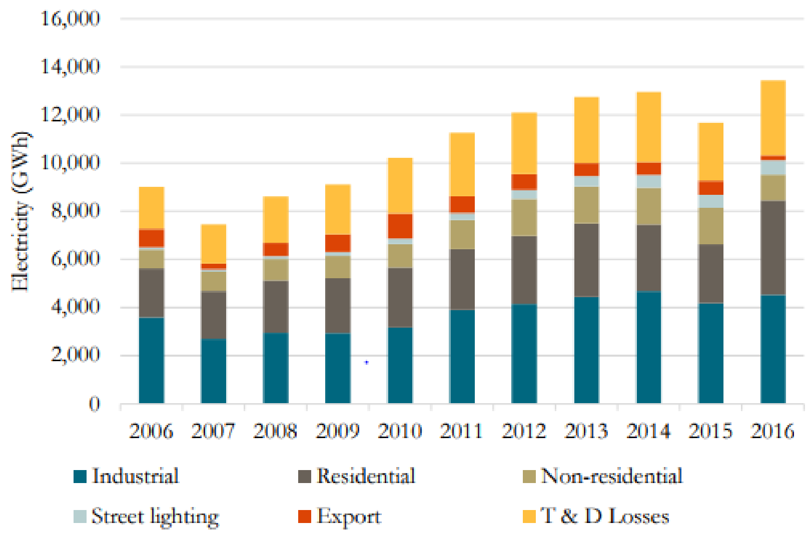

Figure 4. Electricity consumption in Ghana. /5/

As can be seen from Figure 4 the gross electricity consumption has increased from 2006 when the consumption was approximately 9000GWh. In 2016 the consumption was approximately 13800GWh.

The electricity consumers in Ghana are categorized into following groups; Industrial, Residential, Non-residential, Street lightning, Export and T & D Losses. According to the chart above the industrial, residential and T & D losses were the major electricity consumers in 2016, whereas export, street lightning and non-residential were minor consumers. In the past two decades, the biggest individual electricity consumer has been the Volta Aluminum Company (VALCO). /5, p.9/

It is also worth noting that the electricity losses in transmission and distribution were bigger than the electricity consumption in the non-residential sector. In addition the annual average distribution and transmission losses are 21.9% of the total electricity consumption. /5, p.9/

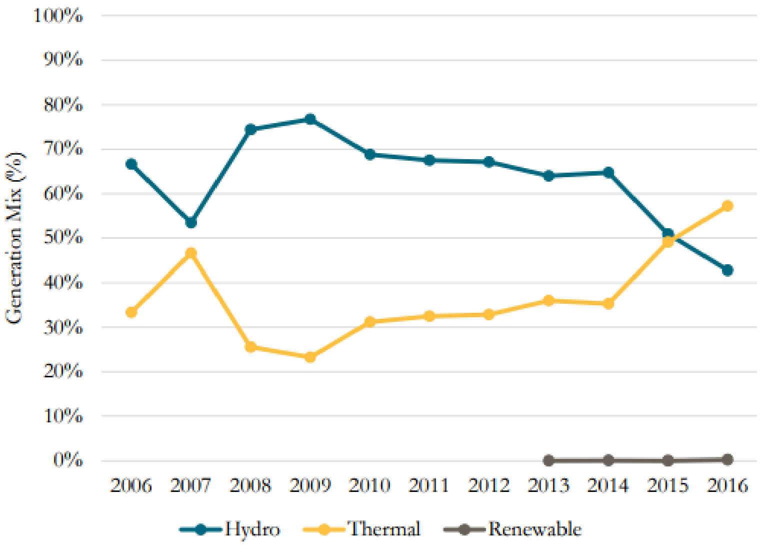

Figure 5. Electricity Generation Mix from 2006 to 2016. /5/

As can be seen in Figure 5 the electricity is mainly produced with hydro power and thermal power. At the end of 2016, approximately 57.21% of the electricity was produced with thermal source and 42.79% with hydro power. In the same year, renewable energy sources produced 0.2% of the total electricity. The previous was achieved with 2.5MW solar photovoltaic plant (owned by Volta River Authority) and with a 20MW solar plant owned by BXC Ghana. /5, p.11-12/

With the funding support of the Ministry of Finance and Economics planning (MOFEP) the Ministry of Energy is accountable for formulating, supervising and evaluating policies, programs and projects for the power sector in Ghana. In addition, the previously mentioned National Electrification Scheme is carried out by the MOFEP. /5, p.14/

The Energy Commission (EC) and the Public Utilities Regulatory Commission (PURC) are corresponding for the activity regulations of the power sector. The EC is accountable for technical regulation including the operators' licensing and the counseling of the Minister of Energy in energy policy and planning related matters. The PURC is accountable for economic regulation of the power sector, especially for approving the rates for electricity sold by distributors to the public. The PURC is also corresponding for monitoring the quality of electricity delivered to consumers. /5, p.14/

The three major groups responsible for power generation in Ghana are the Volta River Authority (VRA), Bui Power Authority (BPA) and Independent Power Producers (IPP). The state-owned company VRA is the largest electricity generator in Ghana with the total installed capacity of 2435MW (in 2015), which covered 66.1% of the Ghana's total installed capacity. /5, p.16/

The National Interconnected Transmission System (NITS) handles the transmission of the electricity from generators to the distributors. The NITS is owned by the Ghana Grid Company Ltd (GRIDCo), which is also state-owned company. /5, p.16/

The two state-owned companies the Electricity Company of Ghana (ECG) and the Northern Electricity Distribution Company (NEDCo) are responsible for the distribution of electricity to the final consumers. NEDCo distributes the electricity to northern sector and ECG to the southern sector. /5, p.16/

Table 2 shows the summary of the power sector of Ghana.

Table 2. Power Sector of Ghana. /5/

Agency	Responsibilities
Energy Commission (EC)	Technical regulator and advisor to Government on energy matters. Issues licenses for RE business in Ghana
Public Utility Regulatory Commission (PURC)	Sets rates for purchase of electricity from conventional and renewable energy sources
Environmental Protection Agency (EPA)	Aids investors with environmental regulation and permitting
Volta River Authority (VRA)	Power Generation
Bui Power Authority	Power Generation
Ghana Grid Company (GRIDCo)	Owns and operates the transmission network
Northern Electricity Distribution Company (NEDCo)	Distribution services within the Northern part of Ghana

The transportation by road is important for the Ghanaian economy, since 96% of passenger and freight traffic is handled with road transport. The road network is composed of 13 367km of main roads, 42 100km of feeder roads and 12 600km of urban roads. The traffic density is low in Ghana with the exception of cities like Accra or Kumasi where the density can be high at peak hours. The target is to set tolls for the existing highways and get private investors to participate in road construction and ownership. /19/

When it comes to the railways, they form a triangular shape and link three cities Kumasi, Takoradi and Accra-Tema. The purpose of the railway has been not only the hauling of minerals, cocoa and timber but also the handling of passenger traffic. The government is seeking to restore network, improve speed and load capacity and replace outwore railroad cars. /19/

Ghana is in central a role of international airline network which links the country to Africa and other parts of the world. The Kotoka International Airport (KIA) located in Accra receives regularly international carrier flights being the main airport in Ghana. In 1996 deployed rehabilitation programme has made it possible to upgrade and expand the international terminal building and domestic terminal. Therefore, these terminals have boosted traveller and cargo capacity. The airport's runway has also been lengthened to be able to organize any kind of aircraft flights. /19/

The "Ghana Corridor", the Volta Lake is an important link between north and south by contributing low cost alternative to railway and road transportation. Volta Lake Transport Company provides a fleet for transporting general cargo. /19/

2.1.6 Legal

Since the start of 2018, Ghana has got a competition law in force, which is supposed to stop anti-competitive business practices by organizations and needless government step in the marketplace. Anti-competitive business practices involve for instance cartels, abusive monopolies, complicity tendering. /20/

In Ghana corruption is low when compared to other African countries but still poses an obstacle for investing in Ghana. In principal judiciary do not face political interference but scarce resources and underpaid judges have led to bribery and extortion in the courts. The corruption risk is especially high within the police. Corruption is also present in land administration, since nearly four in every ten companies expect to give gifts and irregular payments to the officials in order to obtain a construction permit. /21/

2.1.7 Environmental

The climate of Ghana is tropical. The two seasons in Ghana can be divided into dry season in winter and wet season in summer. The rainy season in the central part of the country lasts from April to October and during winter the temperature is rather high since the usual daytime temperature is 35 C in December and January. In the central part monsoons appear in March and may cause thunderstorms. /22/

Figure 6 shows the wind resource map of Ghana which indicates that there is about 2000 MW of potential wind energy to be gathered. The data provided by the National Renewable Energy Laboratory of USA shows that the annual average wind speed along the Togo border can exceed 8 m/s. It is also estimated that over 300MW installed capacity of wind farm could be established to the coastal part to generate 500 GWh to the energy supply. /23, p.27/

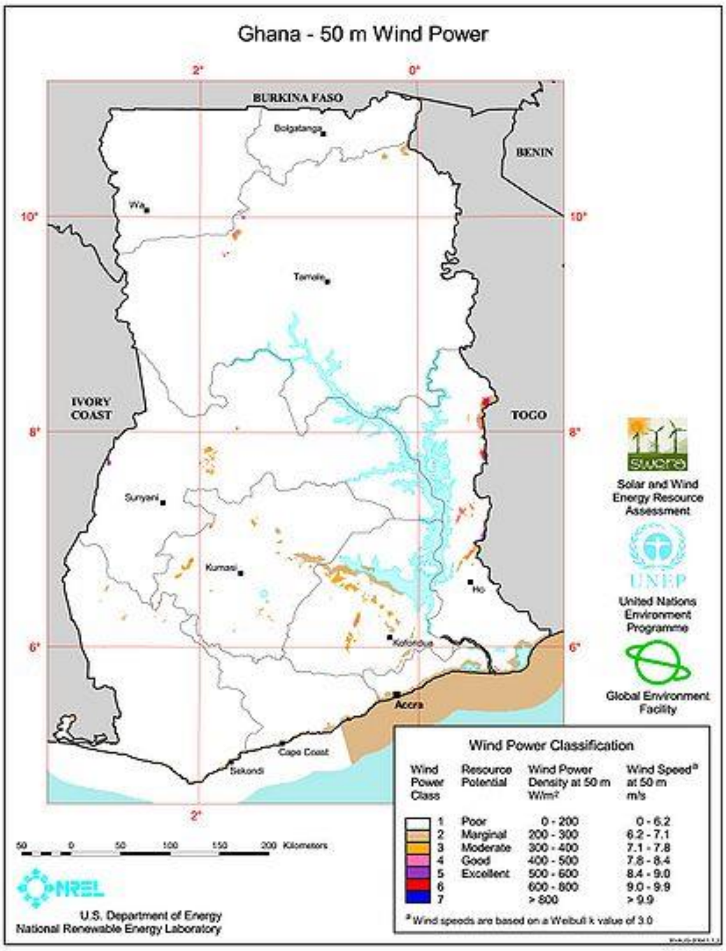

Figure 6. Ghana Wind Potential. /23/

2.2 Supply Chain Design

2.2.1 Definition of a Supply Chain

A supply chain is comprised of every entities involved either directly or indirectly to fulfill a customer request. The supply chain consists of the manufacturers and suppliers and also of transporters, retailers, warehouses and customers themselves. /24, p.13/

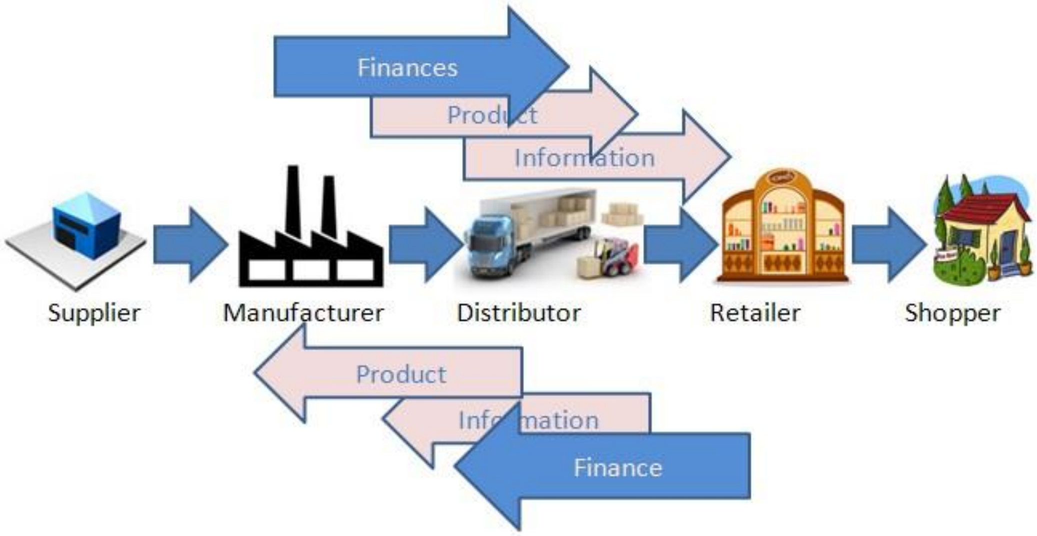

Figure 7. Supply Chain. /38/

As can be seen from Figure 7 the supply chain includes constant flows of product, information and funds between various stages. The customer has a crucial role because the primary aim of the supply chain is to meet the customer's needs and make profit for itself. The term supply chain can connote an image of product or supply moving from suppliers to manufacturers and through distributors and retailers to customers. However, it is important to recognize that information, product and funds flow along both directions of the chain. The term supply chain may also suggest that only one organization is included in each stage, but for example, manufacturers may get material from multiple suppliers and then supply for various distributors. Therefore, supply chains are actually supply webs or supply networks. /24, p.14/

The aim of a supply chain is to maximize the overall full-scale value generated. The value a supply chain generates can be defined as the difference between the value of the final product and the costs of supply chain when fulfilling the customer's request. Supply chain profitability is the difference between the revenue generated from the customer and the full-scale supply chain cost. The level of the supply chain profitability describes how successfully the supply chain has been developed. /24, p.15/

The successfulness of the supply chain ought not to be measured by the profits of every individual stage but in respect to the whole supply chain profitability. Focusing on the profitability of individual stages only can reduce the total supply chain profits. Every flow of product, funds or information creates costs in the supply chain and therefore proper management of the flows is the answer for successful supply chain. /24, p.16/

2.2.2 Decision Phases in a Supply Chain

A successful supply chain demands decisions regarding the flow of funds, production and information in order to increase the supply chain surplus. The decisions can be divided into three phases; Supply Chain Strategy or Design phase, Supply Chain Planning -phase, and Supply Chain Operation –phase. /24, p.18/

In the Supply Chain Strategy or Design phase an organization decides the configuration of the supply chain. Additionally, the organization decides how the resources will be divided between the stages and what processes each stage will carry out. Strategic decisions determine whether certain supply chain function is performed in-house or outsourced, and also the capacity and location of production. Moreover, it is necessary to decide the type of transportation and information systems. When making the prescribed decisions companies have to consider uncertainty in anticipated market conditions for the upcoming few years. /24, p.18-19/

In the Supply Chain Planning phase the aim is to maximize the supply chain surplus, which can be done by considering the constraints established during the strategy or design –phase. Organizations start the planning phase by forecasting the demand and other aspects such as prices and costs in various markets. In the planning -phase the companies make decisions relating to which markets will be supplied from which locations and the timing and size of marketing and price advertisement. Additionally, companies make decisions concerning the manufacturing subcontracts and the inventory policy. When a company is making the decisions, it is also necessary to take into account uncertainty in demand, exchange rates and competition. The planning phase results in the definition of operating policies to manage short-term operations. /24, p.19/

The Supply Chain Operation phase includes decision making relating to individual customer orders. At this point, the supply chain structure is regarded fixed and planning policies are defined. The aim of the operation –phase is to deal with incoming customer orders. Within this phase, companies make an order to specific shipping mode and shipment and set delivery schedules of trucks. Additionally, companies allocate inventory or production to individual orders. The aim of the operation phase is to optimize performance. /24, p.19/

The successfulness of the company depends on the decisions made in the supply chain design, planning and operation phases. In order to stay competitive a supply chain must be able to accommodate to changing technology and customer expectations /24, p.18/. The decisions made in the design phase restrain or enable good planning, which restrains or enables effective operation. /24, p.19/

2.2.3 Process View Methods and Macro Processes in Supply Chain

There are two methods for process viewing in supply chain; a cycle view and push/pull view. When it comes to the push/pull process viewing methods it classifies the processes of a supply chain depending on whether they are carried out to response the customer's request or as anticipation for the customer's order. The push/pull view is handy when observing strategic decisions regarding to the supply chain design. The aim is to recognize suitable push/pull limits so that the supply chain is able to match the demand and supply successfully. /24, p.20, 24/

Every supply chain processes mentioned in the two process viewing methods can be categorized into three macro processes; Customer Relationship Management (CRM), Internal Supply Chain Management (ISCM), and Supplier Relationship Management (SRM). The macro processes take care of information, production and funds flows in order to fulfill the customer's request. The CRM involves processes such as order management, call center, selling, pricing and marketing. The ISCM processes involve preparing of supply and demand plans and fulfilling of actual orders. The ISCM processes take care of the planning for the size and location of warehouses, which include the planning of inventory and picking, packaging and sending of the actual product. The SRM processes include negotiation of supply terms, selection and evaluation of a supplier, and communication with suppliers. /24, p.25/

2.2.4 Supply Chain Drivers

The main drivers in the supply chain are; facilities, inventory, transportation, information, sourcing, and pricing. These drivers decide the performance of the supply chain in relation to responsiveness and efficiency. Moreover the drivers affect the financial measures of the supply chain. The aim is to configure the drivers to reach a desired level of responsiveness at as low cost as possible, which increases the supply chain surplus. /24, p.53/

Facilities are the physical locations in the supply chain network in which product is fabricated, compound and stocked. The location, capacity and flexibility of facilities effect on the supply chain performance. The costs of a facility depend on whether the facility is owned by the company or rented /24, p.53/. The centralization, meaning that the goods are manufactured or stored in one place boosts efficiency but reduces responsiveness and vice versa. The decisions regarding the amount of facilities depends on the firm's supply chain strategy. Some of the facility-related metrics have an impact on the performance of the supply chain are: capacity (maximum amount the facility can produce), processing time, and processing cost. /24, p.57-58/

Inventory consists of work in process, raw materials, and finished products in a supply chain. If the inventory is owned by a company it is reported under assets. Large inventories guarantee high responsiveness but reduces efficiency therefore using large inventories can be dangerous in business where inventory value decreases fast. /24, p.53/

Transportation means to move inventory from one point to another in a supply chain. Transportation can be a combination of various transportation methods and routes of which each has its own performance aspects. The decisions made regarding transportation have great effects on the responsiveness and efficiency of the supply chain /24, p.53/. Faster transportation methods increase the responsiveness of the supply chain, whereas slower methods increase efficiency. /24, p.71/

Information includes data regarding facilities, transportation, inventory, prices, costs, and customers within the supply chain. Information have impacts on each supply chain driver and is therefore the biggest driver of performance and when information is managed properly, it makes the supply chain more efficient and responsive. /24, p.54/

Sourcing decides which entity carries out which activity in the supply chain. These activities are for instance production, transportation, storage, and information management. The decisions made by sourcing determine which activities are performed by the company itself and which activities are outsourced to other companies. The decisions of sourcing have impact on both efficiency and responsiveness of a supply chain /24, p.54/. Proper sourcing decisions lead to boost in the supply chain profits by delegating supply chain processes to the right party. /24, p.71/

Pricing decides the how much the company charges for the products and services that they make available in the supply chain. The behavior of the customer is influenced by the price of the products and services, which again affects the supply chain performance. Pricing contributes low cost to customers who do not value responsiveness and higher responsiveness at higher cost for customers who value it. /24, p.54/

2.2.5 The Network Design in a Supply Chain

The decisions regarding the supply chain network involves the determination of facility role; manufacturing location, transportation and storage –related facilities location, and market and capacity allocation. The decision concerning the facility location has a long-term influence on a supply chain performance; therefore proper location can aid the supply chain to be responsive with low costs. /24, p.120-121/

One of the factors affecting the design decisions of the supply chain network is a strategic factor, which is related to the company's competitive strategy. For instance, a company who values low costs may set up a facility in a location where the costs are lowest, even if the location chosen is far away from the actual markets. On the other hand, if a company values high responsiveness it may locate a factory closer to the markets, even though it would mean higher costs. /24, p.121-122/

Macroeconomic factors also have a notable impact on whether the supply chain is successful or not. Macroeconomic factors include tax incentives, exchange rates, shipping costs and customs. When it comes to the customs, they are being paid when products or equipment are transported over the boundaries of country, state or city. Tax incentives are basically tax reductions, which can be contributed by countries, cities and states. The tax incentives are provided in order to encourage companies to set up facilities in certain areas. When designing supply chain networks companies have to take into account possible fluctuations in exchange rates, fuel and freight costs, and demand. For instance, rapid increase in oil price may cause problems for the supply chain, even if the supply chain is flexible. /24, p.122-124/

Political and infrastructural factors are also worth noting when designing a supply chain network. Political stability is a matter of significance because firms are more likely to locate facilities in stable countries where rules regarding to commerce and ownership are well defined. However, political risk may be hard to identify but there are some indicators, such as the global political risk index, which companies use when investing in emerging markets. The availability of proper infrastructure is also a significant requirement when the location for a facility is chosen. The most important infrastructural matters to consider are; site availability, contiguity to airports, seaports, railways, transportation terminals, and highway. /24, p.124/

2.2.6 The Framework of Supply Chain Network Design Decisions

The purpose of designing the supply chain network is to maximize the company's profits while fulfilling the customer's needs regarding demand and responsiveness. In order to design a competent network the manager has to consider factors described in the previous chapter. /24, p.126/

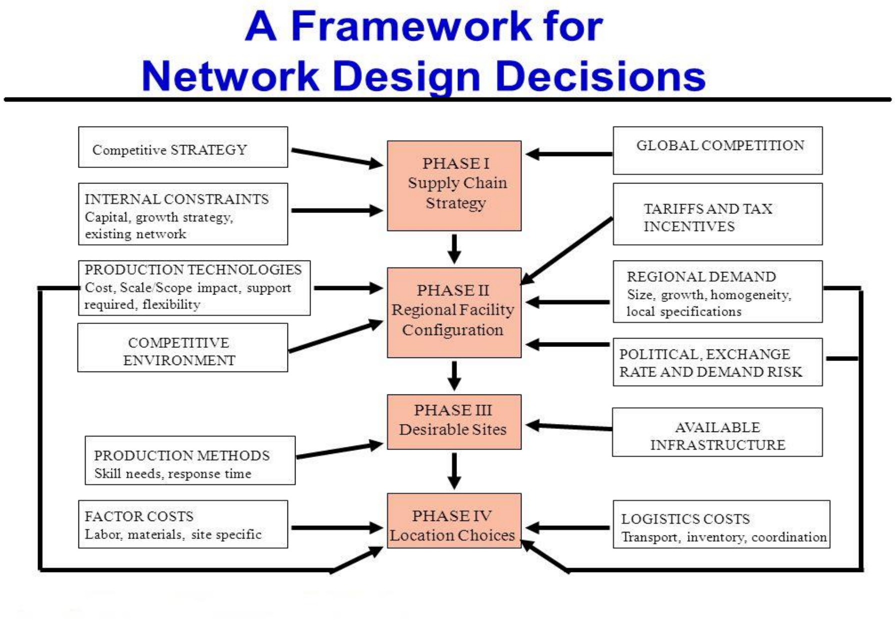

Figure 8. Network Design Decisions –phases. /24/

Figure 8 describes the framework for making supply chain network design decisions, which can be divided into four phases.

In the first phase, the first step is to define the company's competitive strategy as what the customer needs the supply chain is supposed to fulfill. The strategy of the supply chain determines what capabilities the supply chain network must include in order to support the competitive strategy. The next step is that the manager has to forecast the evolution of global competition and recognize possible barriers on available capital. Based on the previously mentioned aspects the manager has to specify the supply chain design for the company. /24, p.126/

The second phase starts with forecasting the demand in the target country or region. After demand forecast the manager has to recognize demand, political and exchange-rate risks related to the target country or region. The manager has to identify local production requirements and also matters regarding taxation, customs, and export or import. Additionally, the possibility of competitors in the same area should be inspected. /24, p.127-128/

The purpose of the third phase is to select the potential sites where the facilities could be located. The selection should be made based on the capability of the infrastructure to support the supply chain /24, p.128/

The aim of the fourth phase is to select the exact location and capacity for a facility with the restrictions brought by phase three. /24, p.128/

2.2.7 Supply Chain in Wind Power

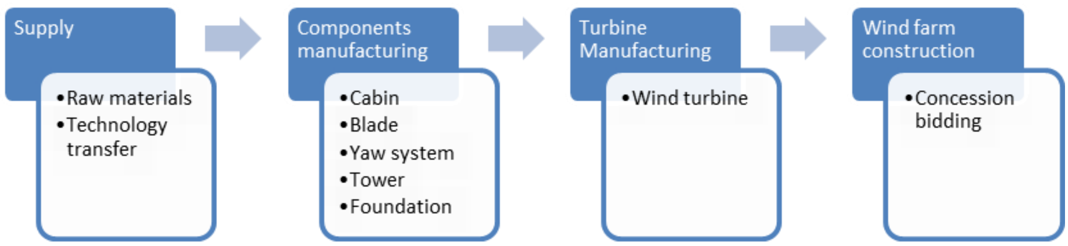

Figure 9. Upstream of wind energy supply chain. /25/

When it comes to the supply chain of wind power industry, it can be divided into two parts; upstream and downstream. The upstream consists of raw material suppliers, component manufacturers, technology servicers, turbine manufacturers and wind farm developers. Once the component manufacturer receives the necessary raw materials, it provides components or service together with the technology servicer to the wind turbine manufacturer. With complete wind turbines and engineering services the wind farm developers carry out investment, siting and infrastructure related activities to establish wind farms. /25/

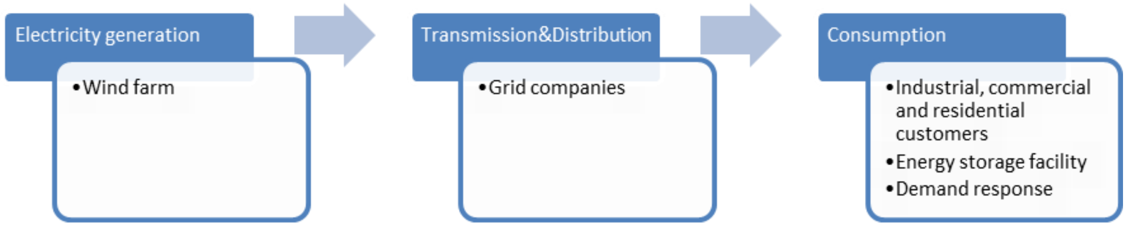

Figure 10. Downstream of wind energy supply chain. /25/

The downstream consists of wind farm operators, grid companies, end-users and future customers/distributors with energy storage facility. The electricity produced by the wind farm is transmitted to end users via a transmission system or stored in energy storage facilities. /25/

2.3 Project Development in Wind Energy

The project development of a wind power plant can be divided into three sections.

The **development** phase includes activities such as prospecting, wind measurement, wind assessment, project siting, permitting, engineering, financing, engineering procurement and construction (EPC) contracting, up to preconstruction. The development phase is estimated to last from 18 to 36 months. /26, p.302/

The activities in the **construction and installation** phase focus on the physical on-site activities, such as site preparation, the transportation of the wind turbines, foundation construction, the erection of the turbines, collecting system and substation installation, and commission The duration of the phase depends on the size of the project, but the phase is estimated to last from 3 to 12 months. /26, p.302/

In the **operation** phase the wind power plant starts to produce energy. The activities within the phase are the monitoring of the wind power plant, and scheduled and unscheduled maintenance. /26, p.302/

2.3.1 Development

The prescribed development stage can be divided into the following steps; Prospecting, Wind Measurement and Detailed Assessment, Siting, PPA, Interconnection, Engineering and procurement, and the financing of the project. /26, p.302/

The first step of the wind power plant project is prospecting, which includes activities to assess different potential sites. At the start of prospecting stage, the aim is to determine regions with proper wind resources, transmission, incentives, price for the produced electricity and road access. When it comes to large wind farms the experienced wind developers has set criteria such as, at least 7 m/s average wind speed, transmission line of 115kV within a mile and a site with normal construction costs. The developers also prefer to gain at least 0,055 $/kWh of PPA and 0.02 $/kWh from incentives. /26, p.303/

The second step in prospecting is to carry out preliminary wind assessment, which results in the knowledge of average wind speed, energy production and capacity factors. The aspects mentioned before can be evaluated from measured or publicly available wind data. Preliminary wind assessment must be carried out to make sure the site meets the financial criteria. /26, p.303/

The third step in prospecting is a site visit to determine the suitability of the site for wind farm project. Even though desktop-tools, such as Geographical Information Systems (GIS) provide data from sites, it cannot replace an actual site visit. During the site visit, the suitability is evaluated with regard to transmission, site accessibility, land ownership, setbacks and natural expediencies. The site visit should involve specific documentation of landscape, roads, transmission, wildlife and vegetation. The prospecting stage results in the selection of sites for wind measurement. /26, p.303/

In Wind Measurement and Detailed wind assessment stage the wind measurements gained on-site are used to establish a detailed wind assessment. The locations for wind measurement are identified on the grounds of a preliminary assessment. The preliminary assessment results in a wind resource map. The map is created based on computer simulations, which use numerical weather prediction or models, such as WAsP. Based on the wind resource map the locations for wind measurement towers can be determined. The wind measurement can be carried out with equipment, such as met-towers, SODAR (Sonic Detection and Ranging) or LIDAR (Light Detection and Ranging). With LIDAR or SODAR it is possible to measure at multiple sites. /26, p.303-304/

In order to measure wind the land lease, an agreement is signed with the landowner. There are two types of agreements with the landholder: Wind measurement and options. Usually the developer is after an exclusive option for a period of 2 to 7 years to perform geotechnical tests, survey land and measure wind speed. The exclusive option prevents the landholder from renting the land to other developers. In order to erect temporary structures such as met-towers local permits might be needed. After the wind measurement has been done, the land will be returned to its earlier state. /26, p.304/

At the end of the wind measurement campaign wind velocity, wind shear, energy density, energy production and others are calculated. Because the turbine selection may not be done the calculations above are carried out with multiple turbine power curves. /26, p.305/

Now the detailed financial evaluation can be carried out by using site-specific values regarding revenue and costs. Wind measurement and assessment stage results in a business plan to be taken to the investors in order to receive funding for further phases of the project. /26, p.305/

The next stage in the Development section is project siting, interconnection and PPA. This stage involves the clearing of regulatory and environmental barriers relating to the siting of the wind project. Naturally fulfilling the stage is locale-specific and therefore the timeframe varies. /26, p.305/

One of the first steps in the project siting is to execute critical issues analysis. It is a desktop-based preliminary evaluation of every environmental, regulatory and compliance related issues. The following is a list of aspects that should be taken into account;

- Required licenses, permits and regulatory approvals,
- Impact on local flora and fauna (particularly birds and bats-),
- Hydrological assessment (wetlands and areas under protection),
- Community facilities and services,

- Constraints in the land development,
- Interference with telecommunication system,
- Aircraft safety,
- Visual impact on the landscape,
- Noise emission and shadow flicker,
- Archaeological and historical assessment,
- Other locale-specific deliberations. /26, p.306/

The interconnection study is required to be submitted from wind farms that deliver power into the utility grid. In most countries the study itself is carried out by the local utility or regional transmission company or a regulatory agency. An interconnection agreement only contributes the justification to connect to the transmission line but does not justify the power transmission /26, p.240/. Because few people live in high-wind speed areas the energy gathered has to be transmitted to population centers where most of the energy is needed. Therefore, the grid might be insufficient in low population areas and must therefore be strengthened /26, p.242/. The power system operators are supposed to connect the power plant to the grid. However, the matters of technical feasibility and distribution of costs may cause problems especially if the grid must be strengthened before the wind power plant can be connected. Generally speaking, large wind farms need stand-alone transformer substations, which require financing. Nevertheless, in many cases one wind farm project cannot endure the costs mentioned before and therefore joint planning with neighboring projects may be necessary /27, p.723/. Since the interconnection stage is a long lead-time activity, it should be started immediately after the previously mentioned detailed wind assessment is completed.

PPA (Power Purchase Agreement) on the other hand is a legal contract between the wind power plant project and the utility. In case the utility buying the energy is experienced in wind projects, it may propose a standard contract. The duration of the task varies due to the fact that the PPA requires negotiations in terms of energy pricing, the potential renewable energy credits and incentives, capacity and delivery of energy, penalties and exceptions regarding to planned versus actual date of commissioning, and risks regarding to interconnection, siting and permitting. /26, p.306/

When it comes to the land lease agreements, the contract does not only include property for the wind farm but also for neighboring property, which prevents other wind development from infringing upon the wind resource /26, p.307/. A close contact to the local inhabitants and communities is important when it comes to the acquisition of the land lease contracts. The lack of local basis makes it almost impossible to develop a wind energy project /27, p.721/.

The community must be involved from the beginning of the project by developer to build support for the planned project. An effective public outreach includes a venue to listen and discuss the concerns of neighbors, such as noise level, property value and environmental value. /26, p.307/

Engineering and procurement stage involves different tasks of which some are carried out by the developer and others by the domain of a contractor.

The assessment for suitable turbines for the project can start after 1 year of met-tower data has been gathered. However, if the project has a tight schedule the suitable turbine can be evaluated with 6 months of wind data and MCP (Measure, correlate, predict) analysis, whereupon the wind turbine class can be decided. The contract with the turbine manufacturer often requires that the selected financing entity has approved the pricing, the terms, delivery conditions, warranty, supervision and others. Additionally, the turbine manufacturer insists a down payment in the range of 30% when the contract is being signed. When the turbine has been selected, the actual engineering can start of which inputs are for instance: turbine-rated capacity, blade size, tower size, weight and dimensions of the components, power curve and generator type. /26, p.307/

The project layout planning starts with the sizing of the project and the layout of the turbines with software, such as WindPRO or WindFarmer. This first-pass layout should meet constraints, such as setbacks from transmission lines, land boundaries, inhabited structures, roads, water bodies, airports, and telecommunication links and from areas where endangered species live. /26, p.307-308/

The civil engineering of infrastructure can start once the previously described micrositing of turbines is done. The first step is to implement a land survey to mark off the boundaries of the land, and identify for example transmission lines, water bodies, roads and vegetation. The second step is to visit the site with an engineering team, wind energy modeling team, and landholders. The purpose is to evaluate the suitability of each suggested wind turbine site in terms of road access, drainage, crane walk and crane pad, turbine foundation, and contiguity to exclusion areas. Moreover, substation layout, fencing and protection, and admittance from public roads to the wind farm are also being evaluated. The third step is transportation planning during which the suitability of the public infrastructure is evaluated. In most locations the infrastructure cannot support the weight and width of the transportation loads. The site visit allows planning necessary changes to the infrastructure. The fourth step is geological study for testing the soil conditions at points where the turbines will be placed. The last step in the civil engineering of infrastructure is to design the necessary infrastructure components such as crane pads for turbine erection, crane walk areas and access roads. /26, p.308/

The foundation design task is normally carried out by a foundation design consultant. The two primary drives in the designing of foundation are the soil conditions and the weight of the turbine. The most common foundation type is spread-footing foundation, which is suitable for soils with proper strength characteristics.

The deep foundation is implemented when the soil is weak, but it is also suitable for normal soil conditions. /26, p.181-183, 308/

The electrical design includes the designing of the substation, collection systems and the interconnection to the grid. Soil thermal resistivity tests are necessary for the designing of the collection system, since the correct cables are chosen based on the test results. The collection system also includes the protection system and grounding system. The protection system allows repair and maintenance work for the components of the circuit. Before the interconnection is allowed, the utility surveys and approves the protection system and substation design. /26, p.309/

The prescribed critical issues analysis step recognized the list of permits required. In most locations all levels of the government get involved when the activities for obtaining the permits start. However, some countries have a single agency, which handles most of the permitting. The most common permits include transportation, wildlife, aviation, radar and electromagnetic interference, cultural resources, land use, construction, and water and wetlands permits. /26, p.309-310/

The logistics planning stage is important because poorly planned logistics end up being costly due to the high cost of crane rentals, operators and setup, and others. The wind projects work with just-in-time manufacturing, transporting and erection. It is worth noting that the just-in-time transportation means there is no need for inventories or storages. The schedules must be matched between the crane provider, turbine provider, civil contractor, electrical contractor, transportation contractor and others. However, in wind projects the weather can play a crucial role, since rain, thunderstorms and high winds can delay the project. The logistics planning at this point is complex due to the shortage of the most critical equipment and labor. For instance, turbine manufacturing has a long lead time and vehicles to transport oversized components are in short supply and hence hard to schedule. Therefore, it is important for the general contractor to keep the schedule updated and communicate with every link within the logistics. /26, p.311/

The most usual contract forms are the Engineering Procurement and Construction (EPC) and the turnkey contracts between the owner of the wind project and the contractor. The EPC contractor provides a complete project at predetermined cost to the project owner. In addition, the project is supposed to be delivered in a set timeframe and to provide the predetermined level of production and quality. In an ideal EPC contract cost and delivery date are fixed and it includes a security deposit, which protects the project owner if the contractor does not accomplish its obligations. The amount of the security deposit is usually 5-10% of the total contract price. The tasks in EPC contracting involve preparing a document, which depicts all the details of the project, delivering the documents to potential bidders, bid receiving, bid evaluation and choosing contractor. /26, p.312/

When detailed wind assessment and financial assessment has been done, the project can be presented to investors. The financing institute has its own criteria for project evaluation and therefore it is recommendable to cooperate with the financial institute already during the wind and financial assessment. Consequently, it is important to include the financial institution within the project as early as possible to avoid the need for rework. When it comes to renewable energy project, the financing institute tries to manage three kinds of risks such as revenue risk, on time completion risk and operational risk. /26, p.312-313/

2.3.2 Construction, Installation and Commissioning

The construction and installation part can be divided into smaller sections as follows: infrastructure construction, foundation construction and turbine erection, construction of substation and collection system, and commissioning.

In the construction of infrastructure stage all civil and other infrastructure work is done before the wind turbine specific work.

When the site preparation itself starts the following tasks are taken care of; the configuration of a temporary office, public roads upgrade, the land preparation for the wind farm, the land preparation for singe wind turbines, and establishing non-permanent storage area. The public road upgrade task is carried out by cooperating with the local department of transportation to improve the public roads to be able to transport the turbine components and construction equipment. The wind farm land preparation task includes for instance the access road construction and other tasks to make the wind farm easily accessible for cranes and earth-moving equipment. The land preparation for turbines includes the construction of the following areas: crane pads for both tail and main crane, staging area for tower, nacelle and blades, assembly area for rotor, storm water drainage, the excavation and compaction of the foundation. The nonpermanent storage area is established to store for example cables, rebar, and other items. /26, p.314/

In the construction of the foundation, the first task is to dig or drill and blast the soil depending on the type of the soil. The next task is to place the outer frame and the rebar. Then bolt cage can be assembled which include conduits for cables and lightning protection. When the previous tasks are done, concrete is poured and cured. /26, p.315/

The turbine manufacturer contributes a plan for the erection with crane requirements. Usually two cranes, the main crane and a tail crane, are used in the erection phase. First, the tower is erected after which the nacelle can be lifted to its place. Depending on the manufacturer, the nacelle can be lifted with or without the generator. The final part in the turbine erection is to lift the rotor with blades on top of the tower. /26, p.316/

The next stage in construction part is to build a substation, collection system. In most cases underground power and communications cables are utilized from the turbines to the substation. The power cables are placed in trenches and filled with soil after which the communications cables can be placed over the power cables. The installation of the cables is carried out with specialized trucks. Afterwards, the substation is build, which usually enclose a pad-mounted transformer, switchgear and other equipment. The installation and testing of the SCADA system is carried out before the start of the commissioning. The SCADA system requires the installation of telecommunications equipment, SCADA server, software and configuration. /26, p.318/

The final step in the construction, installation and commissioning stage is the commissioning, which is normally a detailed process to handover the project from the contractor and wind turbine manufacturer to the owner. Apart from the contractor, the wind turbine manufacturer and the owner of the project, the other parties in the handover process are the following; operator of the wind farm, local utility (who buys the produced energy) and a third-party independent specialist who works on behalf of the owner of the project. In order to avoid problems the types of tests and results ought to be documented in the contract with the contractor and the wind turbine manufacturer. The commissioning aims to make sure that the wind power plant can be safely operated, and it produces energy reliably and with reasonable quality. In order to pass the commissioning phase some criteria must be met. Firstly, the utility interconnection criteria must be met; the operations engineers from the utility inspect the plant after which the synchronization can begin. The second criterion to pass the commissioning is that the power plant reaches 95% availability during 250 hours of continuing operation. The third criterion is that the startup, shutdown and emergency shutdown operates well. Additionally the switchgear should operate successfully in order to response to different kinds of faulty conditions. The communication of data to the SCADA system is also required. /26, p.318-320/

2.3.3 Operation

One of the aims after the wind farm has passed the commissioning is to be able to maximize the energy production during the lifespan of the project. The prescribed aim can be fulfilled by maximizing the accessibility and yield of each turbine. Another aim is to minimize costs regarding operations and maintenance. One of the aims is also the management of daily tasks, such as safe operation of the wind farm, protection assets and providing forecasts. The challenge in the aims mentioned before is that they should be completed for the entire lifetime of the project. /26, p.320/

The trend seems to be that a third-party or turbine manufacturer manages the operations and maintenance. The owner of the project can agree a performance-based contract with a third-party to manage the operations and maintenance. This act changes the risk from the owner to the professional O&M company. The project owner can also make a contract with the turbine manufacturer to manage O&M. The O&M contract with a third-party or turbine manufacturer is costly but lowers the risk of the project in the eyes of financiers. /26, p.320-321/

2.4 Summary

When compared to other West-African countries Ghana is considered as one of the more stable countries. The Government of Ghana has also set in place energy policies that are in favor of renewable energy sources, such as ECOWAS Renewable Energy Policy, and The National Electrification Scheme. From the financial point of view, there are also existing feed-in tariff and tax holidays towards renewable energy sources in Ghana. The corruption level in Ghana is lower than in other African countries, but the corruption can still be an obstacle when investing in the markets of Ghana. The corruption risk is especially high among police.

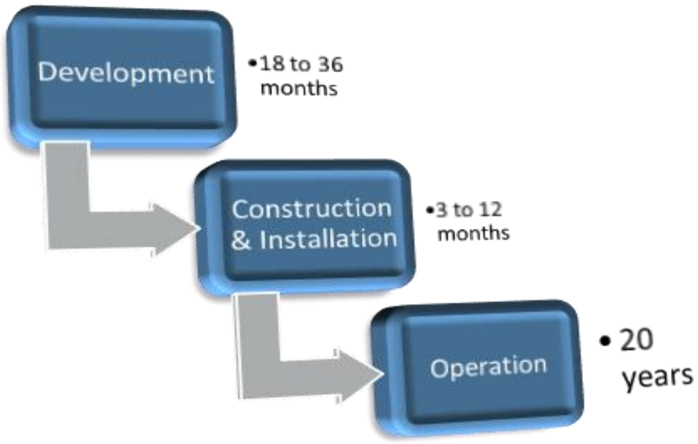

Figure 11. Project Development Stages. /26/

Figure 11 shows how the project development of a wind farm can be divided into three major stages: development, construction & installation, and operation. The development -stage starts with prospecting and wind measurement campaign. The development stage also includes identification of permits and licenses required for the project and the selection of appropriate turbine. Additionally, different kinds of surveys are carried out in order to evaluate the circumstances at the planned wind farm location. At the end of development –stage the project is presented to the investors.

The construction & installation stage starts with the construction of the infrastructure, which is followed by foundation construction and turbine erection. Once the electrical work is done the final phase in the construction & installation stage, commissioning, can start. The aim of the commissioning is to ensure that the power plant is safe to operate and it produces electricity at acceptable quality. At the end of the construction & installation stage, the power plant is handed over to the project owner.

The final stage is operation. The aim of operation is to maximize the energy production for the entire lifetime of the project. Additionally, the operation & maintenance costs are minimized.

The supply chain consists of all the links that are involved either directly or indirectly to fulfill the customer's request. The supply chain includes flows of funds, information and products between all stages of the supply chain. The primary aim is to fulfill the customer's need and also make profit for the supply chain itself. The main drivers in supply chain are facilities, inventory, transportation, information, sourcing, and pricing.

Figure 12 shows the links in the wind energy supply chain.

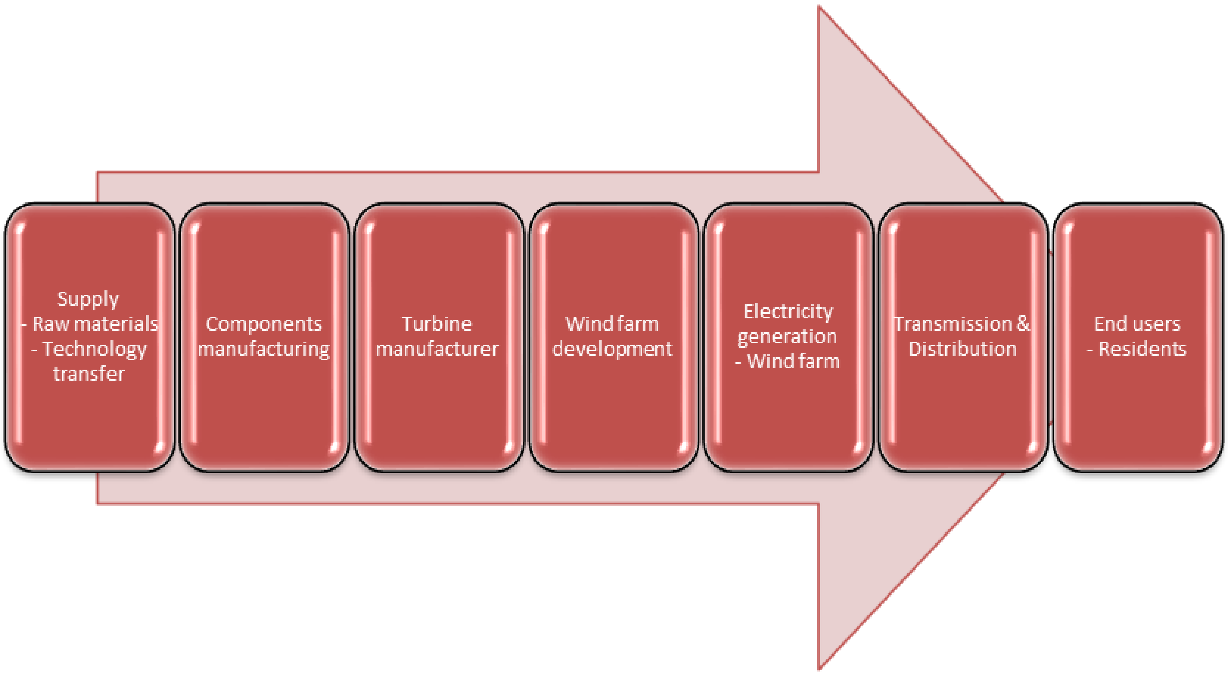

Figure 12. Supply Chain in Wind Energy.

3 METHODOLOGY

The basis of the thesis was the measured wind speed data received from Dr. Adebayo Agbejule. The data consists of hourly measured wind speed values at the height of 30 meters for one year.

3.1 Internet Sources

Some parts of the thesis were written using articles and data from various web-sites due to the fact that some details would have been rather hard to find from literature. The Overview of Ghana –chapter is totally based on internet sources, especially the CIA (Central Intelligence Agency) and World Population Review websites were often used. Also The Electricity Situation in Ghana: Challenges and Opportunities –article acquired from CGDEV (Center for Global Development) were often utilized during the country overview. The prescribed article was cho-sen as a trustworthy source because the article used reliable references such as Energy Commission of Ghana.

3.2 Literature

When it comes to literature related methodology three books were used; Wind Energy Engineergin by Pramod Jain, Wind Turbines by Erich Hau, and Supply Chain Management by Sunil Chopra. Some information was also found in renew-able energy related online magazines such as; Renewable energy supply chains, performance, application barriers, and strategies for further development.

4 CASE STUDY; SUPPLY CHAIN DESIGN FOR WIND POWER PLANT IN NKWANTA

4.1 Wind Turbine Selection

In order to select a suitable wind turbine type for the project it is necessary to carry out a comparison between various kinds of turbines. The comparison is implemented by calculating annual energy production and capacity factor for each turbine type. The investment costs of each turbine are also compared.

Some factors affecting the selection of the suitable turbine are; the annual average wind speed, transportation possibilities and grid accessibility.

The annual average wind speed gives a direction towards what kind of a turbine is suitable for the area. If an area has low average wind speed, the most suitable turbine is one that can operate in low wind speeds with acceptable availability.

Other important turbine-specific factors to take into account are the cut-in wind speed and rated wind speed. The cut-in wind speed describes the lowest wind velocity value in which the turbine starts to produce electricity. The rated wind speed illustrates the wind velocity value in which the turbine produces the maximum amount of electricity /28/. Both cut-in wind speed and rated wind speed are usually found in the turbine specifications provided by the turbine manufacturer.

The erection of small or medium size turbines with tower height of 40 to 50 meters does not present technical problems. The transportation of smaller turbines should not cause technical problems, either. Usually there is not railroad access to the wind farm site and therefore the transportation is often handled with trucks /27, p.719, 741/. The transportation of wind energy components usually requires different kinds of transportation such as roads and waterway. /29/

The grid accessibility is another important factor to consider when selecting the optimal wind turbine. Small wind farms are usually connected to medium-voltage power system; for instance 20kV medium-voltage line has a capacity to transport approximately 10MW. /27, p.737/

4.2 Wind Energy Calculations

The wind measurement data can be utilized to estimate wind speeds at different heights and to calculate annual energy production and capacity factor.

Wind shear describes the change in wind speed as a function of height /26, p.33/. There are two methods to describe wind shear; the power law profile and logarithm profile. The power law is the most common method to describe the relationship between wind speed and height; therefore that method will be utilized in the thesis work /26, p.33/. The power law can be described as follows;

$$\frac{v_2}{v_1} = (\frac{h_2}{h_1})^{\gamma}, \text{where} \quad v_2 = \text{wind speed at height } h_2 \qquad (1)$$

$$v_1 = wind\ speed\ at\ height\ h_1$$

$$\gamma = \text{wind shear.}$$

Table 3. Roughness Class, Roughness Length and Wind shear values. /26/

Description	Roughness Class	Roughness Length, m	Wind shear
Open sea	0	0,0001-0,003	0,08
Open terrain	0,5	0,0024	0,11
Open agricultural area. Only softly rounded hills	1	0,03	0,15
Agricultural land with some houses and hedgerows 8 meters high within distance of 1250 meters	1,5	0,055	0,17
Agricultural land with some houses and hedgerows 8 meters high within distance of 500 meters	2	0,1	0,19
Agricultural land with multiple houses and hedgerows of 8 meters high within distance of 250 meters	2,5	0,2	0,21
Villages, small towns, agricultural land with multiple or tall sheltering hedgerows, woods, and very rough and uneven terrain	3	0,4	0,25
Larger cities with tall buildings	3,5	0,8	0,31
Very large cities with tall buildings and sky-scrapers	4	1,6	0,39

Table 3 shows the roughness class, length and wind shear values in different kinds of terrains.

Figure 13. Terrain picture of Nkwanta./39/

Figure 14. Terrain picture near the town of Nkwanta./39/

As can be seen from the Figures 13 and 14 the terrain in Nkwanta consists of somewhat uneven terrain. There are many houses near the town of Nkwanta, but in rural areas the houses are few. Additionally, the terrain of Nkwanta includes a lot of woods. Due to the terrain the roughness class for the area is estimated to be between 2.5 to 3.0, therefore the wind shear value is chosen to be 0.23.

As soon as the wind shear has been determined, it is possible to create the following table for each turbine;

Table 4. Frequency, Power Curve and Energy production of DW54250 –turbine.

DW 54250 -turbine at the height of 50 meters	Rated power: 250kW			
Wind (m/s)	Frequency (h/year)	Power curve (kW)	Energy producti on (kWh)	
0	0	0	0	
1	379	0	0	
2	955	0	0	
3	1319	25	32975	
4	1668	100	166800	
5	1656	135	223560	
6	1366	175	239050	
7	794	240	190560	
8	334	250	83500	
9	163	250	40750	
10	46	250	11500	
11	20	250	5000	
12	12	250	3000	
13	1	250	250	
14	1	250	250	
15	0	250	0	
16	0	250	0	
17	0	250	0	
18	0	250	0	
19	0	250	0	
20	1	250	250	
21	0	250	0	
22	0	250	0	
23	0	250	0	
24	0	250	0	
25	0	250	0	
26	0	250	0	
		Estimated Annual production	997445	kWh
		Losses	204476,2	kWh
		Net annual energy yield	792968,8	kWh
		Uncertainties	126875,0	kWh
		Production after uncertainties	666093,8	kWh
		Total annual production	630568,8	kWh
		CF	28,8	

The frequency describes how many hours of each wind speed is available within one year. However, the frequency must be re-estimated when the energy production is calculated at various heights, especially in the absence of measurement data. The frequency is calculated by using the frequency function in Microsoft Excel.

The power curve is turbine specific and it can usually be found on the website of the manufacturer. Nevertheless some manufacturers do not give detailed power curve values that correspond to the wind speeds, and therefore the values must be visually estimated from the drawn curve. Therefore, the power curve values estimated from the drawn curves may not always be exact.

The energy production is simply calculated by multiplying the frequency with corresponding power curve value.

The capacity factor describes the overall availability of a wind turbine /27, p.586/. The capacity factor in the table above is calculated with the following formula;

$$\mathrm{CF} = \frac{\text{Annual energy yield (kwh)}}{\text{rated power(kW)} * 8760\text{h}} \tag{2}$$

For the sake of reality, the losses and uncertainties are taken into account when the total annual production is calculated. The net annual energy yield is calculated by subtracting the losses from estimated annual energy production. /42/

$$\text{Losses} = \text{Estimated Annual production} * 0.205 \tag{3}$$

$$\text{Uncertainties} = \text{Net annual energy yield} * 0.16 \tag{4}$$

The total annual energy production is calculated as follows /42/:

$$\text{Total annual production} =$$

$$\text{Net annual energy yield} - (\text{uncertainties} * 1.28) \tag{5}$$

Once the total annual production has been calculated it is possible to estimate how much electricity a turbine would produce per capita. Additionally the number of turbines, nameplate capacity, and investment costs can be evaluated.

Table 5. Investment costs, Electricity production and the number of turbines required for DW54250.

DW 54250 - turbine at the height of 50 meters				
Electricity production /resident	Number of turbines to produce electricity to entire town	The size of the power plant (MW)	Investment costs per turbine	Total investment costs
44,32	**8**	**2**	**500000**	**4 000 000**

The electricity production per resident described in Table 5 is the amount of electricity the turbine produces yearly. The town of Nkwanta has a population of 14 227 /30/. The electricity production per resident is therefore:

$$\text{Electricity production}_{\text{DW54250}} \tag{6}$$

$$= \frac{\text{Total annual production}}{\text{Population}} = \frac{630\ 568.8\ \text{kWh}}{14\ 227} = 44.32\ \text{kWh/person}$$

As was stated in chapter 2.1.5 the electricity consumption per capita in Ghana was 354.71 kWh in 2014. The number of turbines as in Table 5 can be evaluated when the electricity production of the turbine per capita is calculated and the electricity consumption is known.

$$\text{Numer of turbines} = \frac{\text{Electricity consumption per capita}}{\text{Electricity production}_{\text{DW54250}}}$$

$$= \frac{354.71\,\frac{\mathrm{kWh}}{\mathrm{person}}}{44.32\,\frac{\mathrm{kWh}}{\mathrm{person}}} \cong 8 \qquad (7)$$

The nameplate capacity is estimated by multiplying the number of turbines with rated power.

The investment costs in the thesis is set to be 2000 $/kW /26, p.277/. The rated power of the turbine is 250kW and the ratio used between euro and dollar is determined to be 1.221. /31/

$$\text{Investment Costs}_{\text{DW54250}} = 2000\ \frac{\$}{\text{kW}} * 250\text{kW} \qquad (8)$$

$$= 500\ 000\$ \sim 409\ 500.41€$$

Table 6 is the summary of the comparison between three different kinds of turbines with the following results:

Table 6. Summary of the comparison between three different turbines.

Turbine	***DW54250***	***DW61900***	***DW61-1MW***
Rated power	250kW	900kW	1MW
Cut-in wind speed	2,5 m/s	2,5 m/s	3 m/s
Rated wind speed	7,5 m/s	11,5 m/s	14 m/s
Hub height	50m	70m	70m
Rotor diameter	54m	61m	61m
Annual energy production	630 568,8 kWh	963 584,3 kWh	960 278,0 kWh
Capacity Factor	28,8	12,2	12,2
Electricity production/resident	44,32 kWh	67,73 kWh	67,50 kWh
Number of turbines required	8	5	5
The estimated size of the project	2MW	5MW	5MW
Investment cost/turbine	500 000 €	1 800 000 €	2 000 000 €

4.3 Supply Chain Design for Wind Power Plant in Nkwanta

As was clarified in Chapter 2.2.7 on Supply Chain in Wind Energy, the supply chain in wind industry consists of the following stages; raw material suppliers, component manufacturers, wind turbine manufacturing, wind farm development, wind farm operators, grid companies, and end-users. However, in this thesis the actual supply chain design will start from the wind turbine manufacturer and go all the way to the end users.

4.3.1 Turbine Manufacturer

According to the measurement data, the annual average wind speed is approximately 4.1 m/s in the area (town of Nkwanta). Therefore, the most suitable wind turbine would be the one that can operate in low wind speeds with acceptable availability.

A comparison between various turbine models from different brands was implemented in the thesis work. As a result it seems the most suitable stakeholder in the turbine manufacturer –stage of supply chain would be Emergya Wind Technologies B.V (EWT), which would provide the wind turbines to the wind farm project. The turbines of EWT are direct drive wind turbines meaning the rotor directly drives the generator without gearbox. EWT's selection of turbines is designed to operate in medium and low wind areas. The turbines use "back-to-back" full-power converter, which can be programmed to control power factor and voltage to meet the requirements of the local grid. /32/

EWT has delivered wind turbines for numerous different single-turbine projects but they have also provided turbines for larger projects. For instance, EWT has delivered turbines for two major projects consisting of 55 turbines in China. /32/

EWT designs and produces the turbine in-house and the assembly facility is located in Amersfoort, which is also the headquarters of the company. The blades are manufactured in the factory located in Enschede.

4.3.2 Wind Farm Development

One of the purposes of the thesis is to provide basic information about how to design a supply chain for wind power plant in Ghana. The actual wind farm developer is not named in the thesis work because that it could be anyone from private investors to the Government of Ghana itself.

Figure 15. Map of Ghana. /40/

The wind power plant will be planned into town of Nkwanta, which is located in the eastern side of the country near the border of Togo. Nkwanta is the administrative capital in Nkwanta South District, which is one of the twenty-five districts in the Volta Region. Nkwanta South District is located in the northern part of Volta Region and covers land area of 2733 sq. km, which makes it the largest district in the region. /33/

The Ghana Statistical Service states that in 2010 the population of the Nkwanta South District was 117 878 people. 74.4% of the population of the District lives in rural areas based on which the District itself is predominantly rural. /33/

When it comes to the economy of Nkwanta, the main economic activities are agriculture and forestry. In addition, there is also manufacturing and services but their role in the economy is minimal. /34, p.17/

Figure 16. Road map of Nkwanta. /34/

The map above shows the road network map of Nkwanta South-District. There are total of 209 kilometers of roads in the area. The major road goes from Kadjebi to Nkwanta but there are also several feeder roads in the District. Apart from the town road of Nkwanta the roads do not have bitumen surface, which causes problems for vehicles especially during in the rainy season. /34, p.6/

Three different wind turbine models from EWT were chosen to the wind turbine comparison because the turbines they provide can operate properly in low and medium wind speeds. Additionally, the programmable power converter used in EWT's turbines makes the turbines more suitable for the town of Nkwanta. The Figures 17, 18 and 19 illustrates the power curve of each turbine and the corresponding frequency. The turbine models DW61-1MW (Figure 19) and DW61900 (Figure 18) have a higher rated wind speed compared to the DW54250–model (Figure 17). The frequency curve is slightly different in the last two charts because the latter two models have higher hub height.

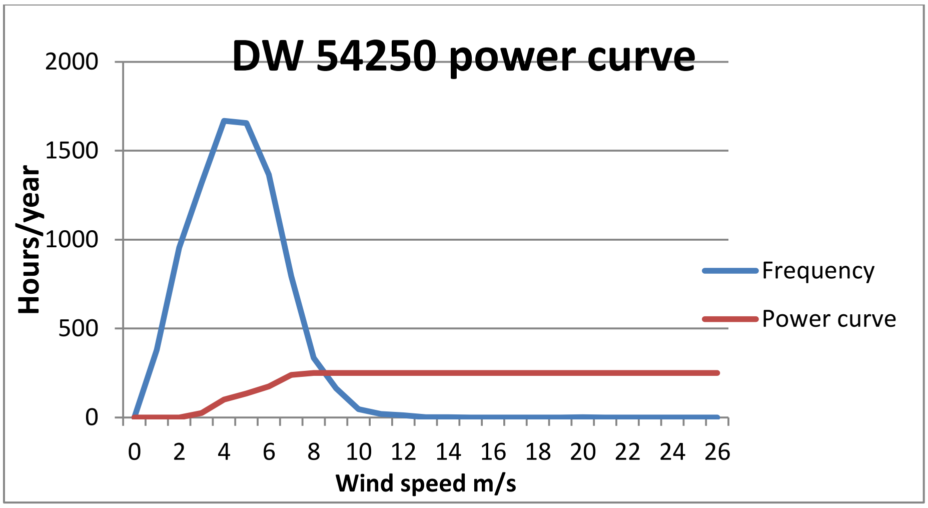

Figure 17. Power Curve and Frequency of DW54250 –turbine.

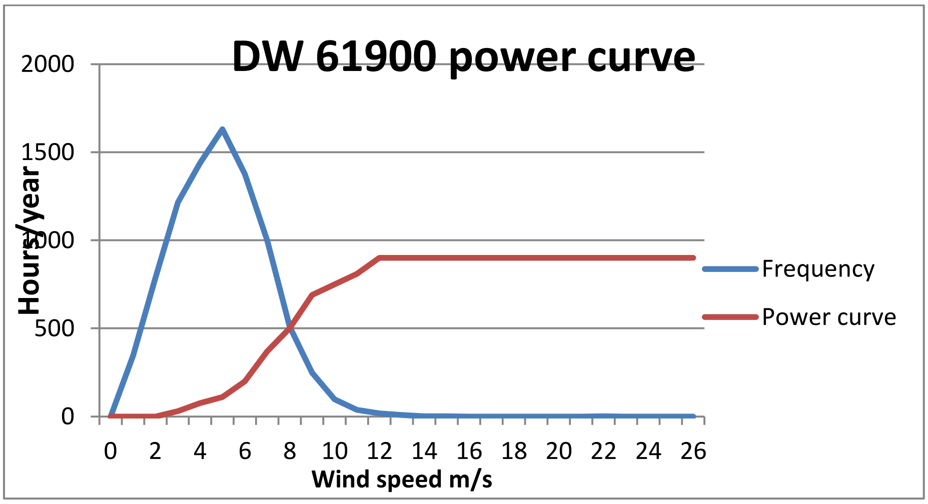

Figure 18. Power Curve and Frequency of DW61900 –turbine.

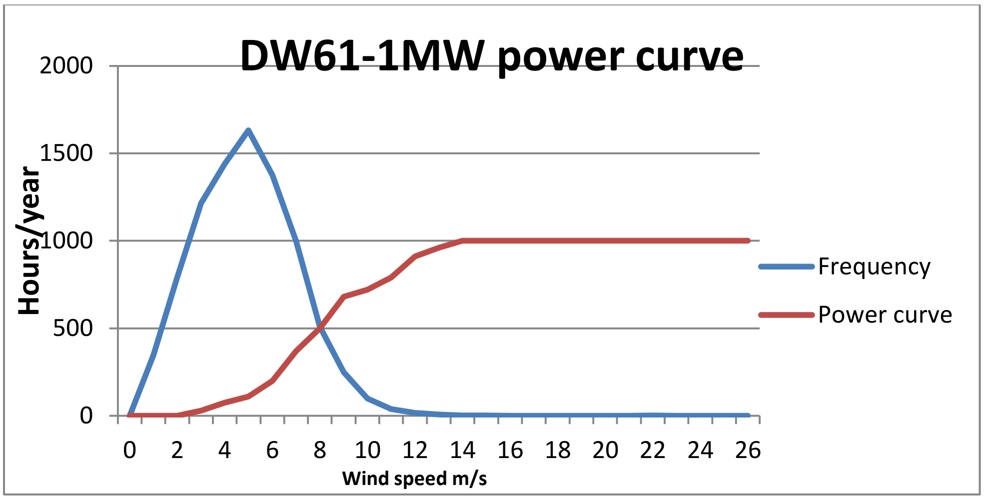

Figure 19. Power Curve and Frequency of DW61-1MW –turbine.

As can be seen from the Table 7 below all of the turbine models have a rather low cut-in wind speed. However, the DW54250 -model has the lowest rated wind speed and hence reaches the optimum wind speed earlier than the other two models. Because the DW54250 model has a lower hub height and a shorter rotor diameter than the other two models, the transportation to the site should not cause problems. The capacity factor of the DW54250 –model is also at an acceptable level whereas, the capacity factor of the other two models is rather low. Additionally, the investment costs of the DW54250 –model is lower and could more likely be funded. Due to these reasons, the turbine chosen for the project is DW54250 –model.

In order to fulfill the electricity consumption in the town of Nkwanta the capacity of the project is estimated to be 2MW.

Table 7. Summary of the comparison between three different turbines.

Turbine	***DW54250***	***DW61900***	***DW61-1MW***
Rated power	250kW	900kW	1MW
Cut-in wind speed	2,5 m/s	2,5 m/s	3 m/s
Rated wind speed	7,5 m/s	11,5 m/s	14 m/s
Hub height	50m	70m	70m
Rotor diameter	54m	61m	61m
Annual energy production	630 568,8 kWh	963 584,3 kWh	960 278,0 kWh
Capacity Factor	28,8	12,2	12,2
Electricity production/resident	44,32 kWh	67,73 kWh	67,50 kWh
Investment cost/turbine	500 000 €	1 800 000 €	2 000 000 €

As was clarified in Chapter 4.1 on Wind turbine selection, the transportation of wind farm components is executed using waterways, roads and railroads. As was mentioned before, the manufacturer EWT has factories in the Netherlands. The wind farm components would be transported by waterway from the Port of Rotterdam to the Port of Tema. From the Port of Tema the components will be transported by trucks to the site in the town of Nkwanta.

Figure 20. Waterway transportation route from Rotterdam Harbour to Tema Harbour. /39/

Figure 21. Truck transportation road from Tema Harbour to Nkwanta. /39/

4.3.3 Transmission&Distribution

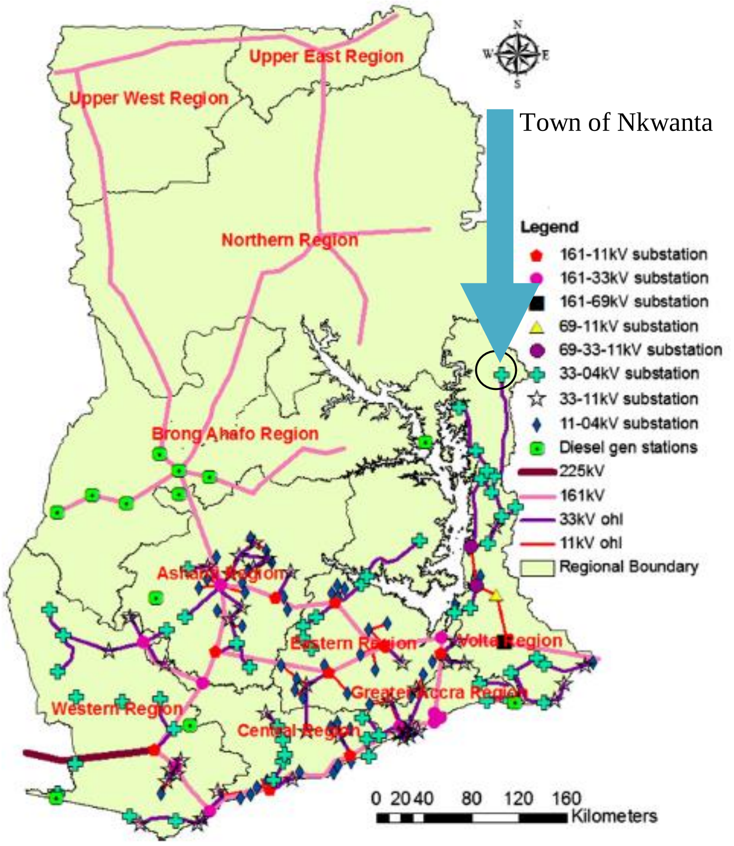

Figure 52. Electrical network of Ghana. /41/

As was defined in Chapter 2.1.5 on Technological, GRIDCo is the one transmission company who owns and operates the transmission network. Hence the electricity produced by the wind farm project is transmitted by GRIDCo. When it comes to the electricity distribution in Nkwanta South-District it is taken care of by NEDCo.

As can be seen from the map above there are 33kV overhead lines and 33-04kV substation in Nkwanta. Therefore, it is not necessary to extend the electrical network in the area for the wind farm to be able to transmit the electricity to end users.

4.3.4 End Users

The end users are the customers who buy the electricity produced with the projected wind power plant. The wind farm project is assumed to cover the whole electricity consumption of the residents of Nkwanta.

4.4 Cost Management

In this chapter the calculation methods for verifying the profitability of the project are described. The cost management calculations can be divided into two statements; income statement and cash-flow statement. Before the income statement and cash-flow statement can be evaluated, the financial structure, taxation, interest rate, and other costs must be defined.

The demand of equity is between 20 and 30%, which depends on the economic stability of the project. The financing structure of the project is the following; 70% of the investment costs are covered with debt and 30% is the estimated equity demanded by the bank. /27, p.851/

As was verified before in Chapter 2.1.2, the three first years of the project are tax free, after which the tax is reduced by 50% for the following three years. Afterwards the tax rate is 25%.

The insurance and land lease payments are determined to be as following; insurance 0.15% of the total investment cost, and land lease payments are 2% of the revenue. /26, p.280/

The Total Operating Expenses consist of all the annual expenses. The annual o&m costs include labour, material and services costs. In Ghana the annual o&m costs is 2.4% of the total investment cost /34, p. 22/

4.4.1 Debt Repayment

Table 8. Amortization table.

Years	Loan balance	Annual payment	Interest	Principal
1	286 650,29 €	42 719,35 €	22 932,02 €	19 787,32 €
2	266 862,96 €	42 719,35 €	21 349,04 €	21 370,31 €
3	245 492,66 €	42 719,35 €	19 639,41 €	23 079,93 €
4	222 412,72 €	42 719,35 €	17 793,02 €	24 926,33 €
5	197 486,39 €	42 719,35 €	15 798,91 €	26 920,43 €
6	170 565,96 €	42 719,35 €	13 645,28 €	29 074,07 €
7	141 491,89 €	42 719,35 €	11 319,35 €	31 399,99 €
8	110 091,90 €	42 719,35 €	8 807,35 €	33 911,99 €
9	76 179,90 €	42 719,35 €	6 094,39 €	36 624,95 €
10	39 554,95 €	42 719,35 €	3 164,40 €	39 554,95 €

The amount of the loan is 70% of the total investment cost, which equals to 286 650.29€. The debt is expected to be paid in ten years. The annual payment is calculated with the PMT function with Microsoft Excel when interest rate (8%), amount of loan, and payback period is known.

The repayment of the debt is calculated with annual amortized loan –method as is described in Table 8. The amortized loan is a loan with scheduled period based payments which includes principal and interest. In the amortized loan payment the interest is paid before any principal is paid and reduced. /36/

The calculation starts by multiplying the loan with the interest rate. When subtracting the interest rate from the annual payment the outcome is the principal payment. When the periodic principal payment is subtracted from the current balance of the loan, it results in the new outstanding balance of the loan. The new balance is used to calculate the amount of interest for the next period. /36/

4.4.2 Income Statement

Table 9. Income Statement.

Income statement	0	1
		year 1
Revenue		78455,5
Annual O&M costs		9828,0
Insurance		614,3
Landlease		1569,1
Depreciation		20475,0
Total Operating Expenses		32486,4
Annual income (ebit)		45969,1
Interest costs		22932,0
Income before taxes		23037,1
Taxes		0,0
Net income		**23037,1**

Table 9 shows the income statement. The revenue is calculated by multiplying the annual electricity production with feed-in tariff;

$$\text{Yearly revenue} = 630568.8\text{kWh} * 0.118\frac{€}{\text{kWh}} = 78455.5€ \qquad (9)$$

The straight-line depreciation method used in the income statement is calculated by dividing the total investment costs with the estimated project lifetime /37/;

$$\text{Straight-line depreciation} = \frac{\text{Total investment costs}}{\text{project lifetime}} \qquad (10)$$

$$= \frac{409\,500.41€}{20} = 20\,475€$$

The total operating expenses is the sum of annual o&m costs, insurance, land lease, and depreciation.

The annual income EBIT (Earnings before interest and taxes) is calculated by extracting the total operation expenses from the yearly revenue. /36/

When taxes and interest costs are reduced from the annual income (ebit), it results in the net income. /36/

4.4.3 Cash-Flow Statement

Table 20. Cash-Flow Statement.

Cash-flow statement		
	Start	year 1
Annual income (ebit)		45969,1
Taxes (-)		0,0
Depreciation (+)		20475,0
CFADS		66444,2
Interest costs (-)		22932,0
Principal payments (-)		19787,3
Equity cash flow	**-122850,1**	**23724,8**
DSCR		**1,55536436**

Table 10 states the cash-flow statement of the project. The Cash Flow Available for Debt Service (CFADS) measures how much cash a company has on hand relative to its debt service obligations in one year /36/. The CFADS is calculated by as follows;

$$\text{CFADS} = \text{Annual income (ebit)} + \text{depreciation} - \text{taxes} \tag{11}$$

The equity cash flow describes how much cash is available for the equity shareholders after all expenses and costs. The equity cash flow is calculated by reducing interest costs and principal payment from CFADS. /36/

The Debt-Service Coverage Ratio (DSCR) describes the ability of the cash flow to pay current debt obligations /36/. The formula for DSCR is;

$$\text{DSCR}=\frac{\text{CFADS}}{(\text{Interest costs}+\text{Principal payments})} \tag{12}$$

At this point the equity Internal Rate of Return (IRR), Present Value (PV), and Net Present Value (NPV) can be calculated.

The IRR is used to estimate the profitability of investments. The IRR is a discount rate, which makes the NPV of all cash flows from a project equal to zero. Therefore, IRR calculations use the same formula as NPV;

$$\text{NPV}= \sum_{t-1}^{T} \frac{C_t}{(1-r)^t} - C_o \text{ , where} \tag{13}$$

C_t = Net cash inflow during period t

C_0 = Total initial investment costs

$r = \textit{discount rate}$

$t = \textit{number of periods}$

The higher the IRR of the project is the more desirable it is to develop. /36/

With the discount rate (0.1) and future cash flows, the PV value is calculated with Microsoft Excel by using the NPV function. The PV value of the project is 223072.7€.

The NPV is then calculated by adding the PV value to the equity investment:

$$\text{NPV} = 223072.7€ + (-122850.1€) \cong 100222.5€ \tag{14}$$

5 ANALYSIS & DISCUSSION

The determination of the wind shear value is the first estimate to be made in order to calculate wind speed values at different heights. However the wind shear value used in the thesis was chosen based on pictures of the landscape of Nkwanta from Google Maps. A site visit would be required to make more accurate estimations of the wind shear, and surroundings of the village. Obviously, the chosen wind shear value affected the evaluation of wind speeds at different heights.

The power curve values may not be exact because the values for the three turbine models were visually estimated from the power curves found from the manufacturer's website. The uncertainties and losses were also taken into account when calculating the total energy production are mere estimates.

The selection of the turbine manufacturer took a long time during which different kind of turbines from different brands were visually compared with the help of power curves. Most of the turbine manufacturers provide a power curve, which enables the comparison between different kinds of turbines. The main criteria used in the turbine selection were capacity factor, cut-in wind speed, rated wind speed, hub height, energy production and investment costs. The turbine suitable for the town of Nkwanta would have not only a low cut-in wind speed but also a low rated wind speed. The suitable turbine also has a low hub height for transportation reasons, and relatively low investment costs so that the actual establishment of the project is somewhat reasonable. Additionally, the most suitable turbine should have a capacity factor of acceptable level. Taken into account the criteria and the comparison between various wind turbines the DW54250 model is the most suitable for the area.

The transportation route designed in Chapter on Wind farm development is probably rather realistic. The transportation from the Netherlands to Ghana through waterway is probably the most cost efficient way since the project is quite small, at least if the size of the project is compared globally.

Additionally the existing electrical grid and substation in the town of Nkwanta could mean that the grid extension might not be necessary.

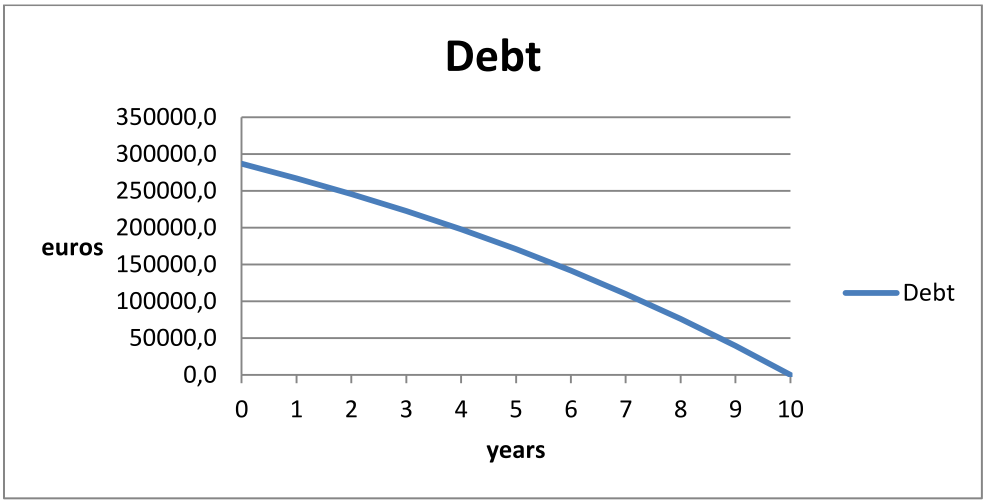

Figure 23. Debt repayment.

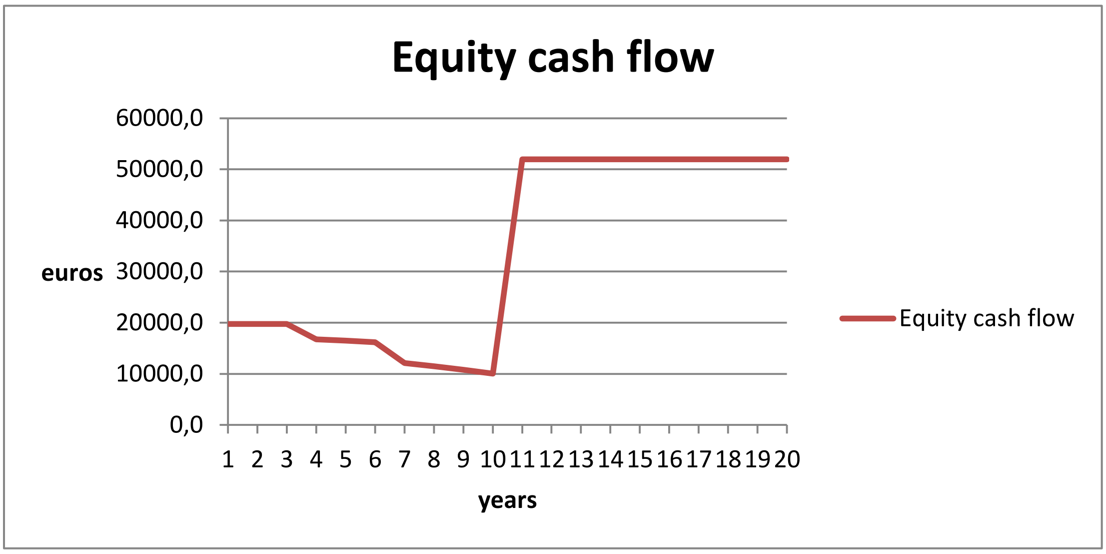

Figure 24. Equity cash flow of the wind farm project.

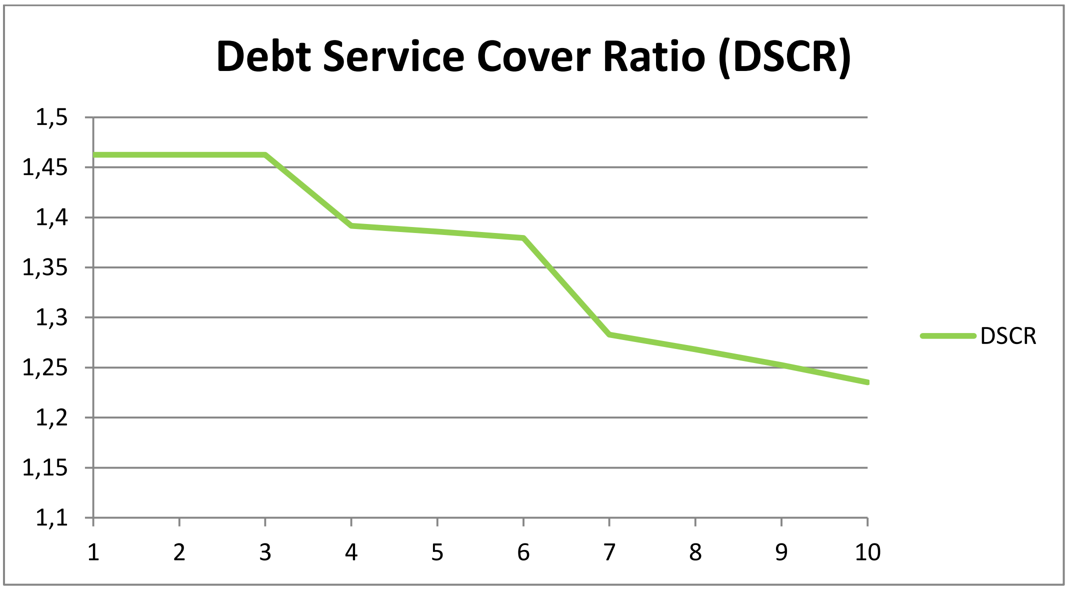

Figure 25. Debt Service Cover Ratio of the wind farm project.

As can be seen from Figure 23 the debt is paid in ten years as was planned. In addition Figure 25 shows that the DSCR ratio is nearly 1.45 in the first year and starts to decline all the way to the 10th year when the ratio is slightly under 1.25. From Figure 24 it can be seen that the equity cash flow remains the same for the first three years due to tax relief. However, the equity cash flow increases rapidly once the debt is paid at the 10th year.

Table 11. Equity IRR, PV and NPV of the project.

Equity IRR	18 %
PV	223072,7
NPV	100222,5

The equity internal rate of return is 18%, present value 223 072.7€ and net present value 100 222.5€

6 CONCLUSIONS

As was defined in Chapter 2.2 Supply Chain Design, the primary aim of a supply chain is to fulfill the customer's request and also make profit for the supply chain itself. The supply chain designed for wind power plant in Ghana can actually be economically reasonable if all the constraints regarding local infrastructure, electricity distribution, and transportation methods are taken into account when the supply chain is designed in practice.

According to the cost management results, it seems that the wind power plant project could actually be profitable in Nkwanta. Even though the average wind speed is rather low in the area, with suitable wind turbine the project would end up being profitable. The graphs in Chapter 5 Analysis & Discussion are also in favor of the project. DSCR is between 1.46 and 1.2 until the debt has been paid, which states that the project is very able to cover the debt. Additionally the NPV is more than zero, which describes the project being profitable.

In future it would be advisable to make an even larger comparison between different kinds of wind turbines in case an even more suitable turbine can be found to the area to make the project more profitable. Additionally, it would be worth to investigate whether the wind farm components could be transported via Lake Volta. If the components could be transported almost entirely through waterways, it may reduce the total transportation costs, and make the supply chain more profitable.

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