POLITECNICO DI TORINO

Department of Environment, Land and Infrastructure Engineering
Master of Science in Petroleum Engineering

INFUSING RENEWABLE ENERGY TO POWER OIL RIGS (REI): TOWARDS A SUSTAINABLE FUTURE IN AFRICA

Supervisor:
Prof. Raffaele ROMAGNOLI

Faith Eferemo OKORO
S229750

MARCH 2018
Thesis submitted in compliance with the requirements for the Master of Science degree

Abstract

Power is needed by offshore rig to accomplish various task and the major source of power on the rig. comes from internal combustion engine, which has led to additional increase in the emission of CO_2 to the atmosphere resulting to global warming. Many developing countries, have placed taxes on emission related to oil and gas production this leads to engineers searching for novel ways of producing sustainable energy. Infusion of renewable energy to power supply has become the focus with reference to saving the environment taking perspective with respect to cost of energy and reduction of CO_2 released into the atmosphere. The aim of sustainability, is the reduction of rate of depletion of natural resources to maintain ecological balance. The energy from renewables reduces the overdependence of the limited fossil fuel and thus maintains the ecological balance. This thesis major concern was on the infusion of renewable energy to power offshore rig with sustainability and reduction of emitted CO_2 as its goal in Africa. Upstream petroleum activities in Africa takes place Offshore with diesel and gas turbine as the means of generating power. Current researches have shown that there is a possibility to harness the renewables sources available in the ocean and transform them into power generation for offshore platform operations. To investigate the potential of renewable infusion Offshore Ghana, the energy demand of a rig was calculated and the ability of two renewables, (Wind and Solar) based on accessible data was analyzed to determine if it satisfies the energy demand. The Oil and gas industry is about profit maximization, for this research to be feasible based on economics the cost of energy of the renewable devices was compared to that of the fossil fuel driven power sources and a software XXX was used in simulating sensitivity analysis based on PV sizing, battery size and varying fossil fuel cost. The analysis indicates financial reduction based on saving from reduced diesel consumption and a possibility of reducing the overall carbon emissions of the rig thus achieving the goal of Sustainability in Ghana.

Dedication

I dedicate this report to God the father, the Son, and the Holy Ghost

for seeing me through the entire two years of this journey.

My Parents,

Against all odds, they believe in me, and deemed it fit to send me to

Europe, to study the course of my choice.

My Siblings,

For their support, tender love and care, they were always there

My Mentors,

Thanks for being an inspiration to me

I LOVE YOU ALL

Acknowledgement

I am pleased to acknowledge the tremendous support and encouragement of all who, in different ways contributed to the successful completion and execution of this thesis. My sincere gratitude goes to my eminent Professor Raffaelle Romagnoli for his impeccable supervision, patience and constructive criticism, which molded this thesis to be the very best.

Special thanks go to Engr. Olapade Olushola for his tired less effort in going through this result obtained by the thesis to ensure it matches known industry standard. To Benard Quaidoo, your impact in this thesis work, cannot be overemphasized, thank you for your help. To all my friends, that were always there, helping me proof read, giving me new words to reduce plagiarism, I say a thank you and I just want to tell you this SEE YOU AT THE TOP.

To those whose names were not mentioned, but you helped me out in any way, I am saying a big thank you to every one of you.

Table of Contents

List of Figures

List of Tables

CHAPTER 1

1.0 INTRODUCTION

1.1 Overview of the Oil and Gas Sector

Nowadays, most offshore oil and gas platforms are operated by internal-combustion diesel engines and gas turbines. Continuous burning of these fossil fuels leads to an increment in greenhouse gases, which is the leading causes of climate change. In Nigeria, 95% of her foreign exchange is obtained from fossil fuel, thus crude oil production has emitted about 86,000 kilo metric tons of CO_2 equivalent of greenhouse gases (GHGs) in 2015. [1] During drilling activities, the cause of greenhouse gases may vary. Power is essential for drilling activities to take place and its production has shown to be the largest emitter of greenhouse gas. Greenhouse gas is a gaseous constituent that can absorb infrared radiation in the atmosphere. These gases trap heat within the lowest part of the atmosphere (troposphere) and this increase surface temperatures, leading to a phenomenon known as the greenhouse effect. [2] This calls for the need to change power generation on rigs to more sustainable and environmentally friendly method and renewable energy fits this description. Renewable energy sources can be defined as an energy that is obtained naturally thus it is not exhausted by continued used. Sources available include; solar panel, geothermal energy, wind energy, tidal energy, hydro energy, and various forms of biomass. [3] The rig power requirements vary a lot with time and ongoing operation, thus, the right renewable energy must be chosen to fulfil the specification of the rig. The irregularity of crude oil resources has led to discoveries and demand for alternative and sustainable energy source. Large amount of CO_2 gas emission, is released into the environment during power generation which create climatic problems. Because this impact on climate, many countries started to impose tax and measures were taken to reduce its impact. This action, have made the oil industry sector to research into green technologies, which are renewable energy sources. Presently, there is an increase in the cost of fossil fuel this is propelling large companies to search for other alternatives. If renewable technologies are implemented by the oil sector, this can sustain the workers that are housed on the rig, and provide formulated plans for new, existing and ongoing renewable technologies and help towards the successful development of a future sustainable energy source in Africa.

This thesis therefore, will examine the environmental impacts associated with current oil production trends, selecting the suitable renewable energy systems based on desired location and provide the way forward for long term improvement that could result in the reduction of carbon footprint of an operating oil rig in Africa(Ghana), as a way of ensuring sustainability.

1.2 The Drilling Rig

Crude oils and natural gases are mixtures of hydrocarbon molecules, impurities and trace elements. The position, number of hydrogen on the carbon molecules, determine the fundamental properties of these hydrocarbon. Hydrocarbon are formed under high temperature and pressure. This process takes a lot of time usually over millions of years. They are formed by the decomposition of marine organisms due to compression from the weight of underlying sediment. Once oil and gas encounter a dense nonporous geological formation, the upward movement ceases. Based on density separation, water denser than oil so oil occupies the pore spaces of the geological formation. The oil and gas are collected in geological formation known as the reservoir because it has good porosity and permeability. [4] Therefore, drilling can be defined as the process of boring a hole through a sedimentary rock to reach geologic formations that contain oil and gas in economic and commercial quantity. For drilling to be possible, a drilling rig is required. A drilling rig (Fig. 1.1) is machine that is used for drilling, casing and cementing of holes in the earth subsurface. A rig can be a large structure that provides housing facilities for the workers or so small that it can be moved manually by a single operator. For onshore locations, the drilling rig can be dived to site and placed on truck or permanently on the ground while offshore, it can be put on marine based structures.

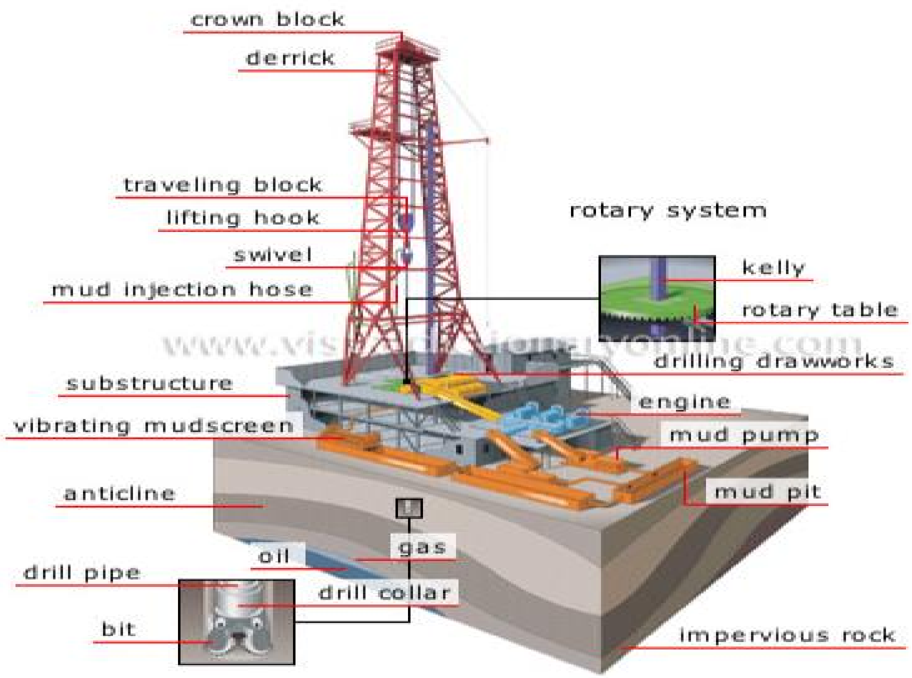

Figure1.1: Diagramatic illustration of a drilling rig [5]

Drilling rigs are designed to meet different operational requirement; thus, rigs can be classified as land rigs and marine rigs (Fig. 1.2). [8] The major distinguishing feature of a land rig is its portability and operating depth. The derrick, on a land rig is very portable and this ensures it easy movement from one site to another. The various components on the land rig includes; skid-mounted which enables the rig to be easily moved and connected in units.

The derrick is put together by pins then raised up as a unit by the hoisting equipment on the rig. The derrick enables different equipment to be lowered or removed during the drilling process. The portable mast is only used when moderate depth well is to be drilled. They are set on the truck of trailers that attached the hoisting equipment, engine and derrick as a unit and is brought to the location of interest. The mast is raised to an upright position and extension to its full height is made position by hydraulic pistons on the unit. [6]

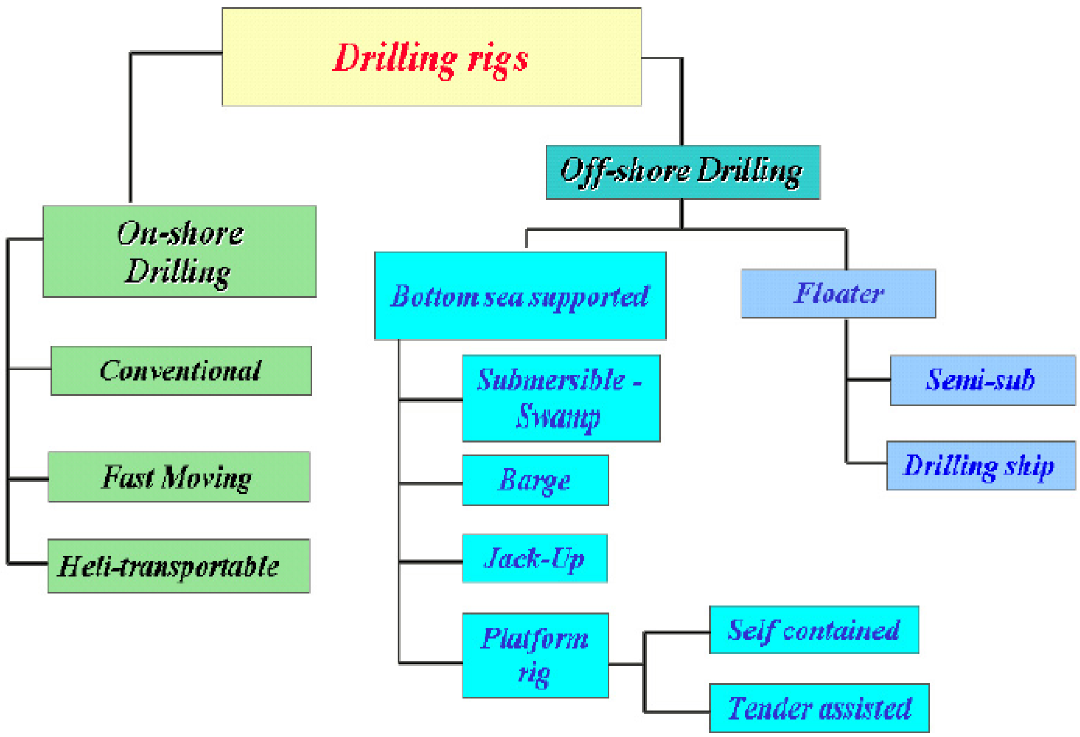

Figure1.2: Types of Drilling Rig [6]

Offshore drilling rigs can be classified into two main groups which are; floating rig and bottom sea supported rig. The differences between these two rig operations is the water depth. If the desired location, has a water depth of less than 20ft and the action of the wave is not serious, then for the drilling activities on that location, submersible drilling barges can be used to carry out the operation. The rig is gathered on the barge and it is towed to the desired location. On getting to the location, the barge is sunk by flooding the badge. After completion of the drilling activities, the water initially pumped before drilling commenced is pumped out of the barge and moved to the next location. Jack up rigs can be classified as a bottom supported type of rig having metallic legs which can be used for drilling operation with water depth not greater than 350ft. On getting to the site, the legs are dropped to the bottom of the water and the platform is raised up above the wave action using hydraulic jacks. Drill ships are vessel that are designed with specific properties and devices to carry out drilling operation in offshore location. They have an anchoring system that is set on the central turret. By the aid of a thruster, the ship can be rotated around the central torrent. This action ensures that whenever the ship faces an incoming wave, the wave action is dampened and reduced. After the well is completed, platforms are built to support the wellhead and provides a medium for installation of well safety equipment. Drilling platforms (Fig. 1.3) have huge structure and are designed using either huge steel or concrete structures.

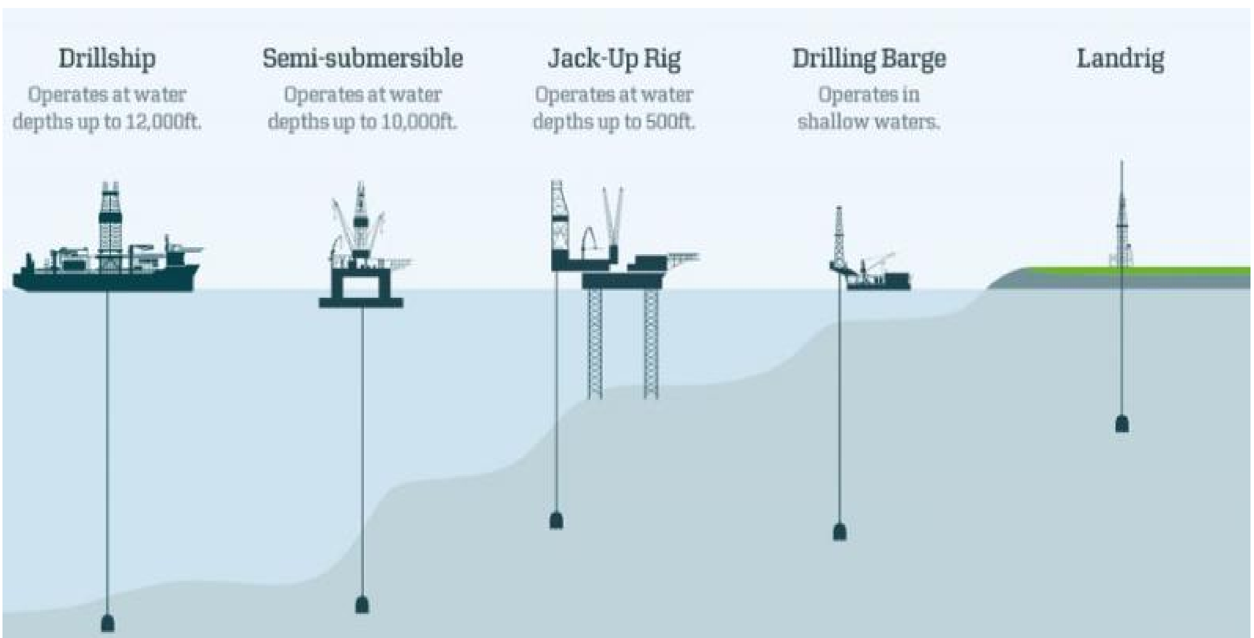

Figure1.3: Models of Drilling Platform/Rigs [7]

Drilling rigs may differ greatly in appearance notwithstanding, all rigs have the same basic drilling equipment to carry out the drilling activities. The main component parts of a rotary rig are:

- **Power system**: This provides the necessary power required to carry the drilling out the drilling operations. activities. To drill a well, the drilling rig would require A common drilling rig requires about 1000-3000 horse power to successfully carryout the operation.
- **Hoisting system**: This system helps in lowering of an equipment in and out of the well. For the success of the operation, the system needs to be composed of the derrick, tackle &block system and dead line anchor system.
- **Circulating system**: In this system, the drilling mud is pumped from the surfaced from the mud pit where the drilling mud is prepared to meet the necessary condition to prevent fracturing the well, to the drill pipe, through the drill collars which provides the weight on the bit to cut through every formation and the drill bit which drills the hole. The drilling mud helps in cooling and lubricating the bit to reduce the effect of wear and tear due to friction between the bit and the formation. The mud on reaching the bottom of the hole, is returned with rock cuttings through the annular spacing between drill pipe and the well wall. The mud with rock cuttings is separated at the surface using surface solid control system. The mud properties are measured before it is pumped back into the wellbore.
- **Rotary system**: This system provides the rotation to the drilling string for drilling activity to take place. This system includes the swivel that is placed on top of the drill sting to support it weight and provide a medium by which mud can be pumped into the subsurface while the string is in rotation. The Kelly transfers rotation from rotary table to the drill string, and the rotary drive.
- **Well control system**: Drilling is a very risky operation that puts the lives of the workers onsite, the equipment's at risk. Thus, a safety measure must be put in place to reduce the probability of accident occurring. The need for a well control safety system is a must during

drilling. The major component of this device is the blow out preventer that seat on the well head to monitor the pressure of incoming fluid. If the formation pressure is greater than the wellbore pressure, the formation fluid would flow to the surface and leads to Kick and if uncontrolled, it can lead to blowout. To prevent this from occurring, the BOP seals the portion of the well and prevent blowout occurrence.

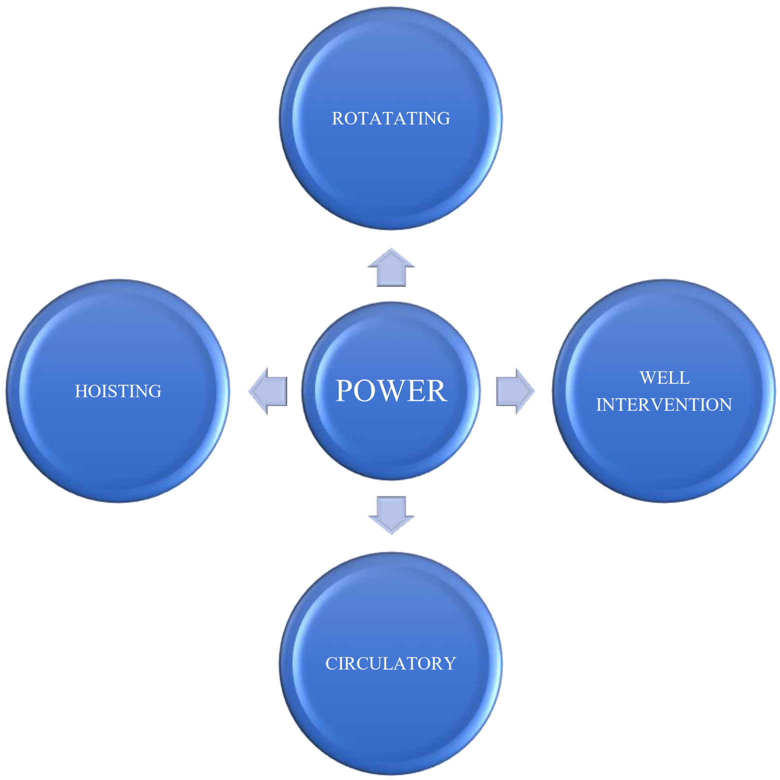

Figure1.4: Component of a Rotary Drilling Rigs [7]

1.3 Sources of Power on the Drilling Rig

Drilling rigs are generally operated in remote locations where a power supply is not available. Therefore, a method of generating the power is of key importance. Power on the various sites can be produced using Prime movers. A prime movie is any machine, device, equipment or mechanism that transforms natural energy to work. The power generated, is required to run the machines, this includes driving the main components of the rig, such as the draw works, the pumps, the rotary table and the engines of the various auxiliary facilities. Diverse forms of Power are available for the drilling activity.

- **Mechanical**: the rig makes mechanical instruments such as torque, converters, clutches. Transmission is made possible by its own engines.
- **Electrical**: the machinery is generating power using internal combustion engines
- **Hydraulically controlled**: the rig is powered by hydraulic source of power
- **Pneumatic**: The rig can be powered using air under high pressure
- **Steam**: Engines and pump that works using steam are the way by which the rig is powered.

This method is an old method that has been discontinued since the middle of 20th Century. Internal combustion engines are prime mover that leads to generation of work. Work is produced during combustion. To achieve this goal, combustion of the mixture, produces high pressure product so that expansion can take place via turbine or piston. [9] There three broad classification of Internal combustion engines. These are: (1) spark ignition engine (2) diesel engine, and (3) the gas turbine. Most drilling rig in use today make use of diesel engine, gas turbine or a combination of both engines to reduce the environmental impact.

DIESEL ENGINE

Air enters the cylinder through the valves known as intake valves. During the compression stroke, from the start to the end, the fuel is always injected inside the cylinder of the diesel engine. As the compressed heated air thoroughly mixed with the fuel spray, the fuel evaporates and ignites. To achieve reliable ignition, it occurs at relatively high pressure. Rate of combustion, is obtained by how fast the injected fuel mixes with the air in the cylinder. Injection eliminates the need to throttle the airflow into the engine and contributes to the high fuel efficiency of the diesel engine. During the mixing process, if turbulent mixing occurs, it has an impact on the combustion process and leads to pollutant formation in the steady-flow combustor. Presently, several engine configurations are in use. From the figure below, (Fig. 1.5(a)) fuel is directly injected into the cylinder. Most of the turbulence is generated prior to combustion by the airflow through the intake valve and the displacement of gases during the compression stroke. [10] [11] [12] [13]

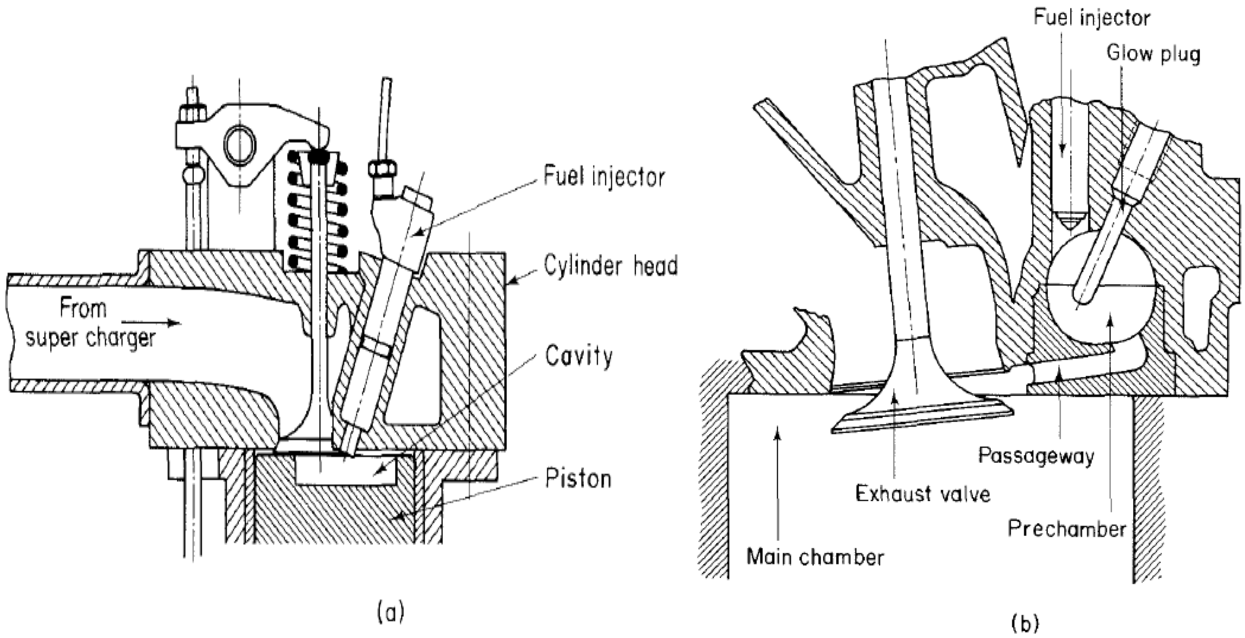

Figure1.5: Diesel Engine [13]

Prechamber (Fig. 1.5(b)), enhances the mixing of the fuel and air in the indirect injection. As the gases burn within the prechamber, they expand through an orifice valve into the cylinder. The high kinetic energy of the hot gas jet is lost as turbulence in the jet and cylinder. This turbulence enhances mixing over that of the direct injection engine. Improved mixing limits the quantity of very fuel-rich gas in the cylinder, thereby reducing soot emissions. Diesel engines may also be divided into naturally aspirated (NA), supercharged, or turbocharged types, depending on the way the air is enters the cylinder. The supercharger is a compressor that is operated mechanically with its main aim to enhances and increases the airflow into the cylinder. The turbocharger also enhances the intake airflow by passing the hot combustion products through a turbine to drive a centrifugal compressor. Compression of the air before the introduction into the cylinder results in compression and heating This may be bad due to pollutant formation especially NO, formation because it would lead to a higher temperature for which combustion can occur.

1.4 Rig Function impact on the Environment

Different operations occur on the rig and these activities may have a detrimental impact on the environment. The significance of these impacts depends upon factors such as the number and size of wells that are going to be drilled, the expanse of land that would be disturbed by drilling activities, the expanse of land occupied by drilling facilities over the life of the oil and gas field, the field's location with respect to other resources. For this thesis the focus is specifically on the environmental damages, with reference to atmospheric pollutants.

ENVIRONMENTAL DEGRADATION

All industrial activities carried out by human, have a severe impact on our ecosystem. The production of Carbon Dioxide (CO_2) in many industrial operations is the major factor why the industries are frowned upon. According to IEA research, “It has shown that 83% of Carbon Dioxide (CO_2) production is from the energy sector”. An oil platform in the UK, produces millions of tons of CO_2 during its operation. In an offshore platform in 2012, about 14.2 million tonnes of CO_2 was emitted into the environment and oceans. [14]

OIL RIGS: POWER SOURCE

The different sources of power for oil platforms, during combustion activities, result in generation of CO_2 to the atmosphere. CO_2 is a greenhouse gas with high concentration as compared to other GHG that absorbs and emits infrared radiation. GHG’s present in the atmosphere trap infrared radiation passing through the ozone layer and retain this heat causing global temperatures to rise.

[17] The gas turbines used for electricity generation can lead to production of waste heat that is not used up in the process. Some Advanced and larger rig can make use of this waste heat for combined heat and power production and re-using the high temperature to improve the gas turbines efficiency. The consequences of this activity are that some rigs may let the hot by products out into the atmosphere, and with exit temperatures as high as 500°C [18] this can affect the environments.

GAS FLARING

The process of combusting the natural gas retrieved during routine oil and gas operations is known as flaring. Flaring can occur due to different reasons, such as; at well sites during oil recovery, during pipeline and system maintenance or in emergency situations as a quick release for any gas build ups that might occur throughout the platform. The flare stack is an equipment designed to ensure safety and help burn efficiency at the tip of the stack. A high burn efficiency is required to ensure that all associated gas retrieved in the oil extraction is completely combusted and so plumes of highly toxic gases do not enter the closely located working environment. This is achieved using a specialized flare tip design that assists entrainment of air or steam into the natural gas mixture. [19] One of the main safety features in the flare stacks design is the inclusion of flash back prevention sections, to prevent the flame travelling down the flare stack towards the collecting associated natural gas. The flare stack generates a lot of noise and heat during their operation. Successful combustion results in water vapor and CO_2

GAS VENTING

Venting offshore is a process to prevent and relieve the build of retrieved gas in the oil extraction process, this is an alternative to flaring and it involves high pressure ejection of the associated natural gas retrieved in a structure like a flare stack. The gas travels towards the vent stack, at the vent stack, it undergoes high pressures to increase its escape velocity from the stack tip. This process ensures that the gas clears a distance away from the oil platform, where it can dilute with the air and dissipate so there is no risk of explosion. Venting is the preferred option when the Associated natural gas holds to much moisture and will not efficiently burn. [20] Just like the flaring process, venting can also be noisy as the pressurized gas exits the stack, however this the process is unseen, and no heat is generated.

Despite this seemingly better gas rejection system, venting can be more harmful and degrading than the by-product of flaring, as associated gas in its un-combusted form can contain some toxic gases, gases that are more detrimental to the environment in their unreacted state. In flaring, successful combustion leads to generation of CO_2 into the atmosphere and production of waste heat that cannot be utilized. venting is preferable when the moisture content is too high within the extracted gas, but the vented gas often contain gases that are more toxic such as methane (Table 1.1) which causes more harm as compared to CO_2

From the table1.1 below, it can be observed that the effects of methane in the atmosphere are 28 times more damaging as compared to that of CO2, and this would incur global warming effects at a much higher rate.

Table 1.1: Effect of Green House Gas [21]

Gas	GWP (100-yr time horizon)	Atmospheric Lifetime (years)	Increased radiative forcing (W/m^2)
CO_2	1	~100-300	1.88
CH_4	28	12	0.49
N_20	265	121	0.17

CHAPTER 2

2.0 RESEARCH IN REI IN OFFSHORE POWER SOURCES

2.1 Reforms in Offshore Platform Power Sources

Africa's oil and gas potential would tremendously grow over the next decades. In every ten hydrocarbon discoveries around the world in 2013, six out of these discoveries was found in Africa. About nine million barrels of crude oil was produced from Africa with more than 80% from Algeria, Angola and Nigeria in 2013. [23] A large fraction of Africa production is from the Offshore sector and mostly power demand for the offshore rig is powered using diesel engines and gas turbines. This add up to the already rising environmental threat through greenhouse gas emissions, heat, and noise generation. Renewables are gaining market share at a high pace in the world, and even more so in Western Europe and Africa as a continent can learn from this. [24]

The world-wide movement towards clean energy is gaining momentum and this process would further speed up the development process of renewables and drastically reduce continued reliance on fossil fuels as the only means of energy generation. The COP21 Paris Agreement was recently signed by 177 nations worldwide, showing their commitment to policies that supports clean energy. [25] In addition to governmental policies, the public opinion on the continued use of fossil fuels for the worlds energy supply is becoming more negative as well. Thus, to be relevant and not pushed aside, the oil and gas industry is incorporating renewables into the core of her operation. Thus, for an existing offshore oil and gas infrastructure to make change its operation from regular fossil fuel use to a cleaner source of energy, there are lot considerations to be made and lot of viable options are available. Choice of renewables by the oil companies would be the cheapest possible level to maximize profit outputs, and as far as fuel consumption goes. For the longer term, ways to use the pipelines, platforms and fields for other forms of energy carriers will be more sustainable towards carbon emission free energy production., this means making use of fossil fuels to power production.

2.2 Research into REI in Offshore Platform Power Sources

Operating in an acceptable and environmentally friendly manner is one of the greatest challenges faced by Offshore platforms. Renewables have proven to be a source of succor to the oil industry to overcome this challenge, thus the fast-rising growth of renewables in oil and gas industry. The use of renewables, varies based on the different climatic condition of the location of interest, thus various researches have been carried out and some researches are ongoing to help in the determination of the optimum location where these renewables can function.

In JULY 2016, a research based on the use of hywind in oil and gas platform to bring about the reduction of CO_2 and NOx Gas Emissions was carried out by Nikhila Gopal. The focus was on the possibility of integrating wind energy as a means of powering offshore platform by using Hywind technology. For this research, his case study was the North Sea and the goal was reduction of CO_2 and NOx emission and reduction of the fuel consumed on the platform. The research, was able to analyze and ascertain the role and influence of different working strategies of the gas turbines in reducing the emission of greenhouse gases. Assessment of the wind was done using MATLAB for the 2.3 MW and 6MW Hywind turbine. This was based on the interpretation of data

In his research, while trying to figure out the best method to adapt that would reduce the fuel consumed on the rig and while achieving a reduction in GHG emitted, the greatest challenge was the combination of the gas turbine and wind energy because both system cannot work together. Thus, to achieve the load requirement at the platform the task was to determine the better operational strategy for the simulation which would be feasible. Two operational strategy was considered. The first strategy deals with load sharing operation and the other with start/stop operation of the gas turbine. This simply means, one gas turbine can run while the other one is shut down. The simulation was run for both 2.3 MW and 6 MW wind turbines. The results obtained from the different scenarios were analyzed and compared to identify the better operational method to use. From the results obtained, there was drastic and significant reduction in the greenhouse gases and better results are found with the first strategy as with respect to the later. Thus, from this research it can be deduced that wind as a source of energy is the best renewable resource that can be employed in oil and gas industry to reduce the fuel consumption and lower the greenhouse gas effects.

Offshore platform is an energy intensive and it contains various energy consuming facilities.

The power consumed at a platform situated in Norway, at the Continental Shelf (NCS) is about 10 MW to hundreds of MW. The NCS is a mature petroleum region and the energy consumption for every produced unit would grow. For power generation, required for different activities, the platform is powered by a Gas turbine. Thus, generation of electricity via these gas turbines contributes to 80% of the total amount of CO_2 and NO_x emissions from offshore installations. [28]

Wei He, carried out a research to explore if it was possible to utilize an offshore wind farm as a alternative power source to different electrical grids of offshore platforms and providing any excess power generated to the grid onshore. In his research, he evaluated three wind farms with different rating these are 20 MW, 100 MW, and 1000 MW. The focus of his research was on the operation benefits that can be obtained from CO_2/NOx emission reduction, the stability of the grid, and the feasibility of technical implementation. The proposed case studies of wind farms with rating of 20 MW, 100 MW, and 1000 MW were theoretically feasible with respect to the selected specified criteria that was stated. [27]

A research on the possibility of the applicability of wind and solar energy on oil and gas platform was carried out by Y K Tiong The research mainly focused on the ability theses renewable energy (wind and solar) to generate power for offshore application. Data used for the research was provided by a company known as SHELL Sarawak Sdn (SHELL Sabah Water Platform). The required data consisted of wind speeds and solar irradiation for every 10 minutes, 24 hours a day, for over a year. The choice of equipment used is based on high availability and reliability based on the operational period. Thus, the best wind turbine and photovoltaic panel that can achieved the desired goal is chosen. From the result obtained, the highest power output that can be generated using one wind energy turbine yields 492 kW and for photovoltaic panel is 20 kW. From the result generated, feasibility of the chosen renewable energy for the offshore platform can be gotten from the platform energy demand. [30]

Renewables devices such as solar and wind are currently being used in the oil and gas sector to accomplish different tasks. The major disadvantages of this forms of energy is that they are limited based availably and thus cannot regularly meet the continuous energy demand. Thus, M. A. Zahari and S. S. Dol 2014, carried out a research on “the infusion of renewable energy in an offshore platform using Vortex Induced Vibration (VIV) in ocean flow”. Current flow in the ocean is influenced by winds and density difference. This later leads to a phenomenon known as Marine Hydrokinetic (MHK). MHK, can be captured and used in electricity generation [26] To prevent mechanical failure of vibrating structures, Engineers try to minimize the present of vortex induced vibration. In their research, the VIV effect was not minimized rather they exploited the probability of maximizing these effect and ability to transform the vibrations obtained into valuable forms of energy.

Jamie MacDonald, carried out a research on "Providing Scope for Reducing the Carbon Footprint of an Offshore Oil Rig". The research investigated the changes which can be made to current fuel sources used on offshore production platforms. In oil production, various emission is associated to it and this is a major contributor of the ongoing climate change. His research has shown that indeed renewables can play a great role in the reduction of carbon emissions of the oil and gas industry. [31]

2.3 Natural Gas Utilization

The oil field Rang Dong is located offshore southern Vietnam. The major operators of the field are JVPC (46.5%), ConocoPhillips (UK) (36%) and Petro Vietnam Exploration and Production company of Vietnam (17.5%). The field started production in 1998 and has produced about 55,000 bpd of crude oil. During crude oil production, associated gas is produced along with the crude. The associated gas from this field was used to boost crude oil production or flared for safety reasons. To reduce the quantity of flared associated gas at the offshore platform, produced gas was utilized by supplying it to local power generation plants, fertilizer plants and nearby industry areas through a sub-sea pipeline. Due to this action, from 2001 to 2011, there was a drastic decrease in the volume of about 6.77 million tons. This also lowers factor costs for such industries and helps them stay competitive in the global marketplace. [32]

In 2005, a laboratory known as Oak Ridge, carried out an analysis and discovered that from the overall CO_2 emissions from fossil fuel, about 0.5% of the gas emitted is due to natural gas flaring. Thus, this has prompted for a call to prevent this wastage of energy. Some companies, are carrying out various researches on how to transform the natural gas to liquid. Petrobras, the Brazilian state oil company is searching for different methods/ technologies to deal with all the natural gas that its offshore oil drilling is generating. It is usually more expensive and complex to bring back to the shore than oil, so most companies resort to flaring which leads to pollution of the environment. Two companies, Compact GTL and Velocys developed a technology that could transform natural gas into a synthetic liquid fuel like crude oil. If this said technology can be successfully developed by these companies, this would to a drastical reduction gas flaring. [33]

Philippe Angays carried out a research on the Monetization of associated gases from offshore oil fields by electrical power generation. When crude oil is produced, it contains associated gases. Flaring is now being prohibited and management of associated gas could be complex. From his research, it was discovered that these gases can be used for energy generation, but the downside is that the produced gas exceeds platform fuel gas requirement. Exportation of this gas using subsea pipelines could be quite expensive as the water depth increases. Thus, from his research it was discovered that conversion of this potential energy offshore in electricity and exporting via High Voltage Direct Current (HVDC) link is a way to monetize this gas production. [34]

CHAPTER 3

3.0 RENEWABLE ENERGY INFUSION(REI)

3.1 Overview of renewables in use

The climatic condition all over the differ from region to region. Majority of the countries, tend to support some renewables (wind, solar) as compared to others. For counties in the African continent, solar energy potential is highest while in countries in Europe, wind is the best energy source. Every region in the world has some renewable energy resources. The main difference of between the usage of the different renewables would be availability and cost. [3] The marine environment has a very large reserves of renewable energy resources. Offshore renewable energy can take various forms. These could be in form of dynamic energy (winds and currents), potential energy (tides), mechanical energy (waves), thermal potential (vertical temperature gradients) and osmotic pressure (horizontal gradients of salinity). [35]

Energy from the sun is the most ultimate form of renewable energy. This energy can be used either for heating or electricity generation. The source of hydropower is when water falls. This is possible because the energy from the sun causes evaporation of water to occur at lower elevation than later rain which occurs at higher elevations. Offshore renewable energy sources, provides the possibility of meeting the growing world energy demand with the goal of long term reduction of carbon emission. Some of these offshore technologies may be at its idea or initial generation phase, but other technologies like wind are in use and have shown tremendous degree of profit making realization.

3.2 Wind Energy

Ocean/sea has a large amount of resources, but the most developed form of renewable energy based on technological development, set out policy and installed capacity is the Offshore wind power. [37] Wind technology has experienced rapid growth in recent years with Europe at the peak of this fast-rising development(Fig.3.1).

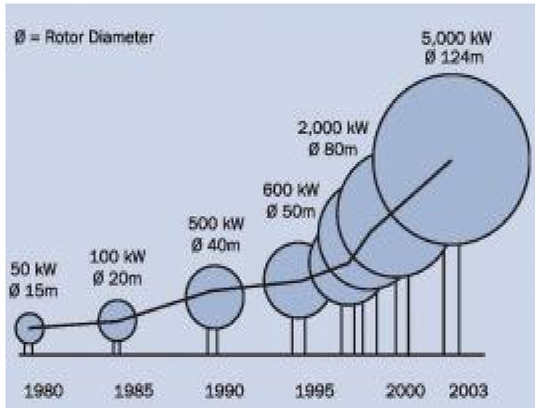

Figure3.1: Growth in the size of wind turbine design [36]

Wind turbines is growing and developing at a faster pace with new models that are strong and can utilize more wind therefore more electricity would be generated at lesser cost. Wind turbines have a working life of 20-25 years thereafter, these turbines can either be replaced with newer ones or decommissioned after its working years has been expended. Old turbines can be resold because of their high salvage value and could be used for any ground restoration work.

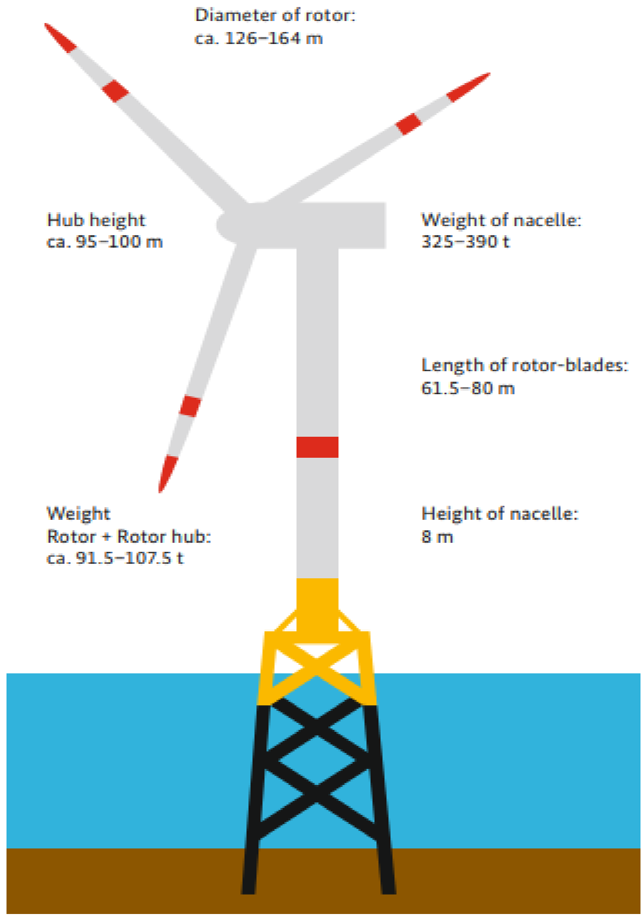

Figure 3.2: Fundamental components of a Wind Turbine [38]

Electricity is generated from wind turbine is made possible by using the kinetic/dynamic energy gotten from the wind to power a generator. This technology, produces clean and sustainable fuel source and it does not generate any emissions and it is regenerated by energy obtained from the sun. A typical wind turbine (Fig. 3.2) would generates electricity at a speed of around 3-4 m/s, (8 mph). It generates the maximum rated power of about 15 m/s (30mph). To prevent likelihood of damage from storm activities, it shuts down at about 25 m/s or above (50mph). When the wind moves over the blade, it leads to a phenomenon known as turning force. The turning force is a force that causes the blades to rotate.

The movement of the revolving blade turns the cylinder inside the nacelle of the wind turbine. This motion enters the gear box. The goal of the gear box is to increase this rotation speed that is required by the generator. It has magnetic fields that transforms the received rotational energy into electrical energy. Output power goes into the transformer. The transformer in this setup, is a device that helps in the conversion of the electricity gotten from the generator (700V) to the required voltage for the distribution system (11kV and 132 kV). Supply of electricity from the wind turbine is dependent on the following conditions. These include;

Wind speed: The power that can be harnessed by the action from the wind is a function of the cube of the wind speed. Thus, if the wind is blowing at twice the speed, its energy obtained would increase by eight times.

Wind turbine availability: Availability is the possibility that the turbine would function when required. Availability for modern machines produced in Europe is usually 98% or above.

Wind turbine arrangement: Wind turbine are arranged to make certain that no turbine takes wind from another. However, factors such as environmental considerations, visibility and grid connection requirements are given more preferences over the best wind capture arrangement.

Wind generation is usually intermittent with respect to supply. A wind turbine can produce electricity for about 70-85% of the time. The electricity obtained from this turbine often varies between zero and the maximum output based on the speed of the wind. While we see variation, the output obtained often does not get to zero completely and it also does not reach the maximum output. Thus, to maintain constant supply, an equality of generation and demand must be achieved. Excessive generation causes the system frequency to rise while an excessive demand causes the system frequency to fall. Normally, electricity system is constructed to regulate varying degree of discrepancies in supply and demand. No power station is completely reliable, and demand is also uncertain. Therefore, there must be a reserve that provide a capability to achieve balance given the statistics of variations expected over different timescales. [39]

3.3 Ocean Wave Energy

Wave Energy, as an offshore based renewable energy form, utilizes the power that can be obtained through waves for electricity generation. The power converts the oscillatory movement of the waves into electricity by the application of special equipment that is put on top of the surface of the sea and converts mechanical energy into electrical power (Fig 3.3).

Figure 3.3: Pelamis Wave Energy Converter [40]

Waves are produced due to the influence of solar energy. When radiation from the sun touches the earth surface, they warm it up. This action leads to differences in temperature between the air masses and makes the air move from hotter to lower region producing winds as a result. As these wind moves across the sea surface, a portion of the wind kinetic energy is given to the water below producing wave. Waves can generally propagate over a great distance with very little energy loss. As the wave approach the shore, depth of water reduces drastically, and the wave speed reduces as a result, but the wave increases in size. When the wave hits the shore a large amount of its kinetic energy is released this energy can be used in electricity generation if it is captured by a turbine.

The wave energy differs from region to region, this could be due to the location of the different region on earth and the season. The wave strength and the span over which the wind can blow are the conditions that affect the wave energy. A wave is the fluctuating motion over the sea which varies with time (Fig 3.4). Waves have a high peak known as crest and the bottom known as trough. Differences between them is known as peak to peak amplitude. Wave amplitude is the center of the two points and it corresponds to the real seal level. (calm sea)

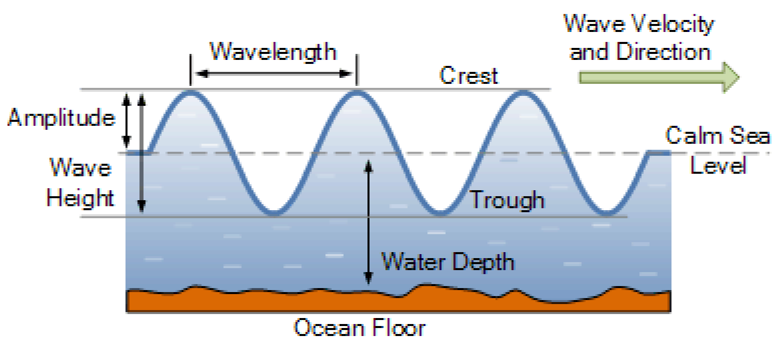

Figure 3.4: Diagramatic illustration of an ocean wave [41]

The weather condition at any moment, influences the amplitude of the sea wave. In a cool weather, amplitude would be small and larger in a stormy weather condition. The wave period T, distance measured in seconds amid each crest. This is an important characteristic feature of a wave. For a calm sea, the wave period is longer as opposed to a shorter one for stormy sea. The frequency is the reciprocal of the wave period.

Wave energy conversion device, can be divided based on the span amid it and shoreline. Based on this division, the devices are: Shoreline devices, Nearshore devices and Offshore devices (Fig 3.5).

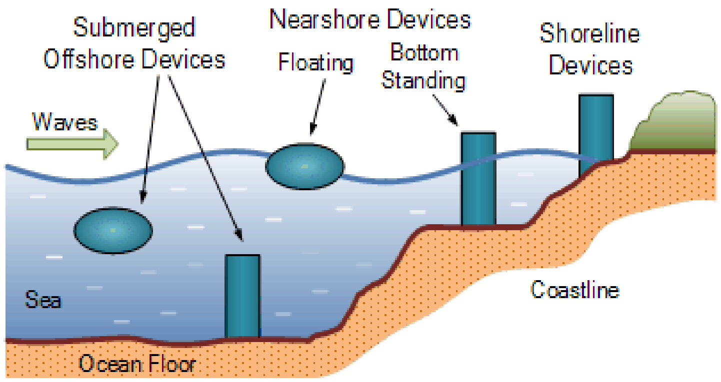

Figure 3.5: Wave Coversion devices [41]

Shoreline devices: These devices can either be fixed or encapsulated on the shore. This simply means the device can either be in or outside of the water.

Nearshore device: These devices are used to get wave power from the breaker zone and beyond it (20) ft.

Offshore devices: They are device that are whose operation is required in the innermost part of the sea. They are used for collection high energy and density waves beyond the breaker point.

Wave energy is at its peak close to the surface and reduces with depth, thus good equipment design is necessary to provide the most optimum capturing method. Presently, the main methods of capturing wave energy are:

Point Absorbers: They could be ducks, floating bags, etc. They are little vertical device that can either fixed or attached to a string that can absorb wave energy. These devices convert the fluctuating motion of the wave for electricity production.

Wave Attenuators: They are of cylindrical sections joined together but allows for rotation and yaw relative to each other. The device is positioned ensuring alignment with the wave. A wave attenuator generates electricity by converting oscillatory motion to hydraulic pressure wave action pressurizes the piston through the accumulators that turns the hydraulically powered turbine generator to produce electricity.

Oscillating Water Column: This device converts the energy obtained from waves to air pressure. The device is like a cell under water. The wave motion above the structure causes the stored water in this cell to oscillate in a vertical direction. When the waves enter and eventually leaves the chamber, the water in the cell to bobble and this shows a piston like motion in air. The air is compressed and decompressed and moved to the turbine for electricity production.

Overtopping Devices: This device converts potential energy to mechanical energy. The device used can either be fixed or floating. They make use of ramps and as waves moves over this ramp, the potential energy of the water stored is used by the turbine for electricity production.

3.4 Tidal Energy

Tidal energy is a type offshore renewable energy exploit the energy within the oceans tides to generate electricity. The solar system is bounded by gravity and it consists of the sun and other object (earth, moon) that moves around its orbit. Movement due to gravity of the moon and sun with regards to the earth leads to large amount of water to flow over ocean making intermittent deviations in the moving bodies of water. The vertical deviation or shift of the water is called tide.

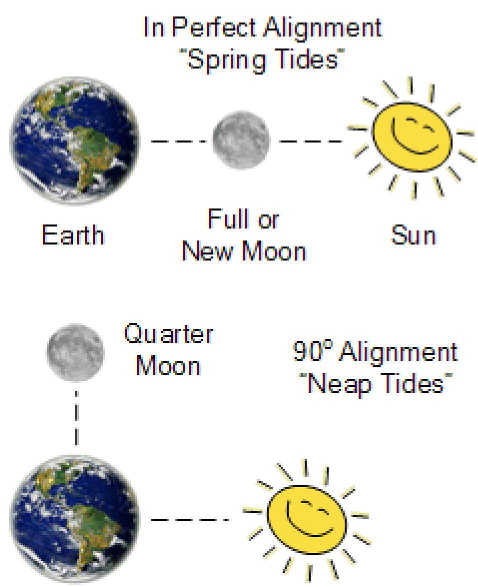

Figure3.6: Alignment of the Moon and Sun on Tides [42]

High tide occurs when the moon and earth gravity lines align with each other, this makes the gravitational forces so strong that huge volume of water moves pass the sea to shore. When the earth and moon gravity lines are aligned at 90^o to each other, this makes the gravitational force so weak that water moves away from the shore to another part on the earth leading to low tide. Tides occur due to rotation of the earth. Spring tides always occurs during the full moon. If moon is in perfect alignment with the earth and sun, gravitational pull is stronger than normal this leads to the much higher tides and lower tides for the different cycle (Fig 3.6).

If the movement of gravity of the moon and sun is against each other, it leads to a small quantity of water over the ocean creating a much more weaker tide for either high or low tides. It occurs during a quarter moon. Tides occurs every 12hrs and 24 min and it is known as diurnal cycle. Tidal energy helps in the transformation of water movement into a cleaner source of energy. This movement of water is made possible by gravity pull accompanied with strong tidal current. The movement of water is exploited using turbine. The energy can be harnessed when water is flowing and when it is dwindling. Energy generated by tides can be carried classified in two ways.

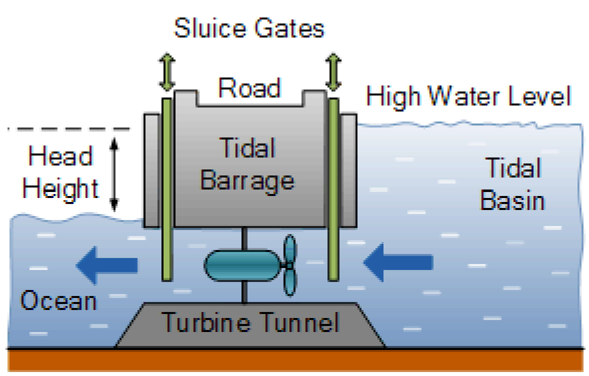

Figure3.7: Tidal Barrage Power Generation Process [42]

Tidal Barrage: Power generation is obtained by building of a barrier over the front of the tidal inlet, making a reserve. This barrier, has numerous tunnels and inside the tunnels, are turbine that rotates the water as they move over them producing electricity. Electricity can be generated both for approaching and exiting tides (Fig 3.7).

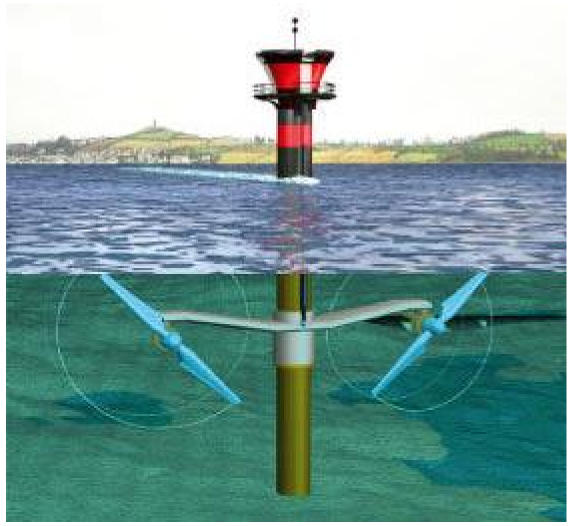

Figure3.8: Tidal Stream Power Generation Process [42]

Tidal Stream: Helps in reduction of the environmental impact due to usage of tidal barrage. This system works by placing turbine below the surface of the ocean. This method employs the same mechanism as wind energy generation (Fig 3.8). Tidal stream is generated when huge volume of water is moving fast caused by tidal flow which causes the speed to increase as it nears the shore.

3.5 Solar Energy

The sun gives out radiation like electromagnetic rays to the earth. Radiation that gets to the earth, is dependent on the time of the day, season, and the location on the earth. The radiation that enters the earth in one hour, is greater than the world demand for energy in a year. The sun rays that get to the outermost atmosphere is about 1.37 kW/m^2. It goes above the cloud where it is reduced before it gets to the surface of the earth. The radiation that finally gets to the earth surface comprises of direct rays of about 70% and diffused sun rays of about 30% (Fig 3.9).

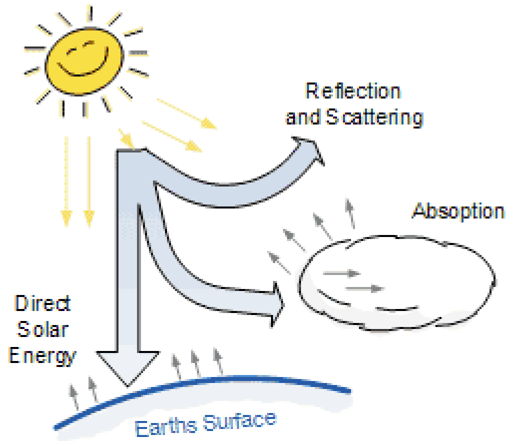

Figure3.9: Solar Radiation [43]

The sun location at any point in the sky affect the capability of the set-in place system required for conversion of sun rays to electricity generation. Some methods currently in use for conversion of sun energy to electricity generation is the photovoltaics and the other is the application of Solar hot water.

Photovoltaic (PV) cells is a device that simply converts the energy obtained from the sun based on a special effect to direct current electricity. This device, consists of silicon with impurities added to create spaces with the structure of their lattices. Silicon atoms have four valence electrons in their atomic structure that are shared with opposite atoms which makes its orbital full. The implication of this is that it has a stable structure. Electron are displaced and sent out when the rays from the sun strikes the silicon in the PV cell making them free. This makes the material behave like a semiconductor under subjection to the rays from sunlight. Silicon semiconductor material have positive and negative part merged to form a junction. (PN). Thin strips of metals are set on the PV cell surface to collect the free electrons from the positive connection (Fig 3.10). The negative connection, is at the of the PV cell and it is usually built from either aluminum or molybdenum metal. This characteristic of silicon semiconductor makes it easier to extract current inflow and outflow from cell. PV cell usually have an open circuit voltage within the range of 0.5

to 0.6 volts. On a dull day, current demand would be reduced. The cell would generate full voltage with the minimum current. This shows the dependence of the output voltage (V_{OUT}) on the load current (I) demands of the PV cell.

$$Pmax = Vout \times Imax \qquad (1)$$

Where,

W Watt

V Volts

I Amperes.

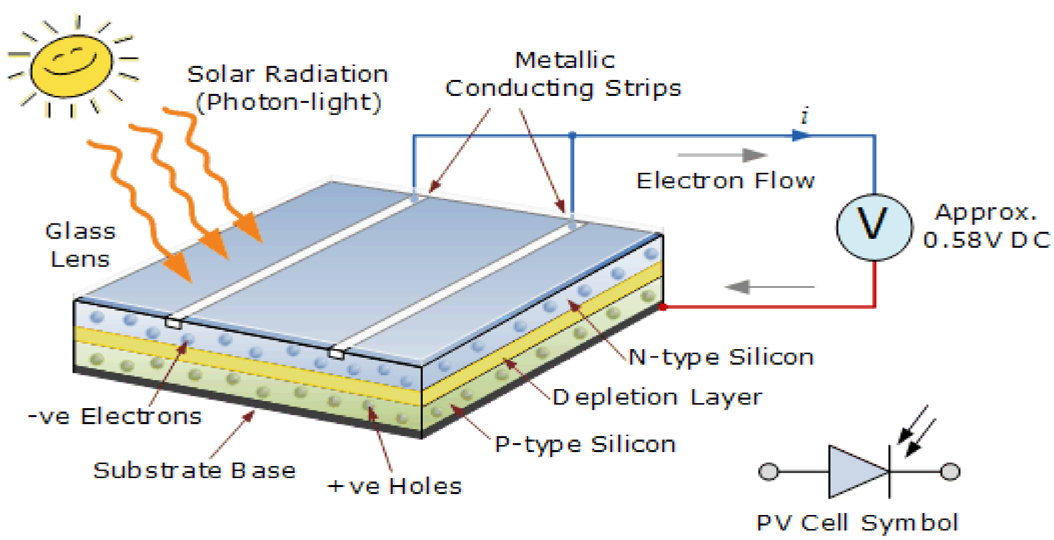

Figure3.10:A Photovoltaic Solar Cell [44]

If the current demand increases, more sun light must maintain the full output voltage. There is a maximum current that PV cell can release irrespective of strength of the sun radiation on that day. It is represented as I_{MAX}. This value is dependent on the surface area of the cell, bulk of sunlight reaching the cell, efficiency of electricity generation process and kind semiconductor material used. The current-voltage graph shows where the maximum power is gotten based on the current and voltage selection (Fig 3.11). This is based on the cell working under standard condition of sunlight and temperature.

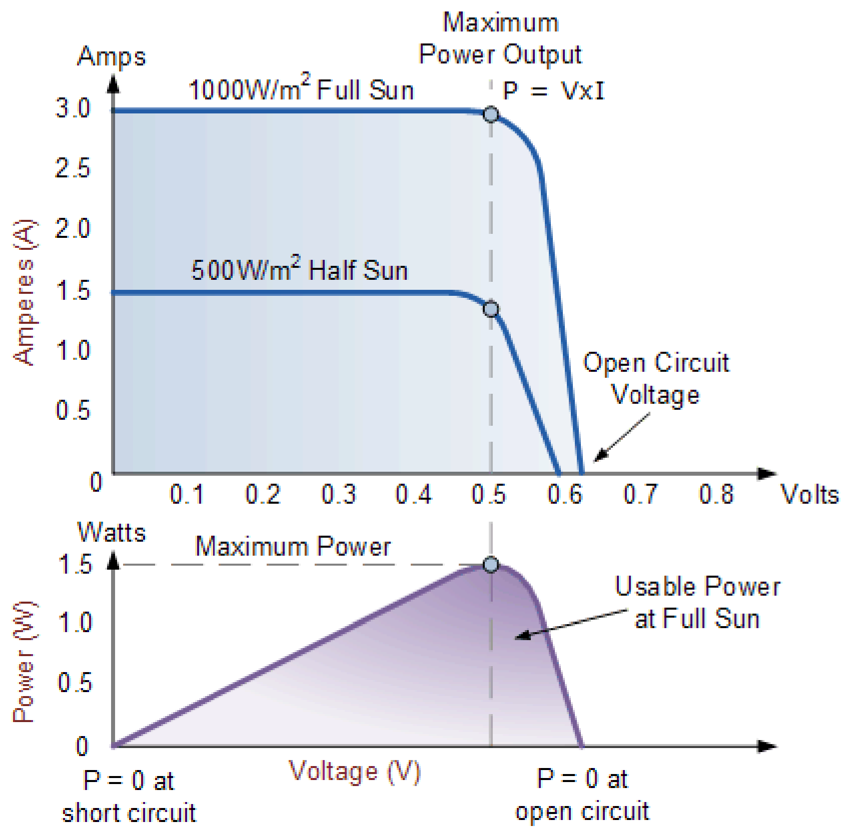

Figure3.11:Photovoltaic Solar Cell I-V Curve Characteristics [44]

To obtain the optimum power, the front of the PV cell should be facing the sun. To generate more power, an increment of the photovoltaic effect is needed to produce a cell that can easily convert radiation from the sun to electricity.

The silicon exposed area of the cell has electrical contact that creates the contact between the semiconductor and external load and anti-reflective coating that boost the efficiency of its sunlight absorption. These cells do not store energy just conversion of radiation to electricity.

Solar Thermal energy, is a different concept from photovoltaics. In this method, the rays from the device is used to fixate the sun rays, which is used to create heat and leads to production of steam which powers a generation producing electricity.

Figure3.12: Solar Thermal Collectors [45]

The quantity of heat that can be produced by this device is dependent on the device design, surface area of the collector tube and the climatic condition of where the device is to be used. There are several configurations of these device. They are: Flat Plate, Evacuated Tube, Integral Collector Storage (ICS), Thermosiphon and Concentrating Solar Power (CSP).

CHAPTER 4

4.0 **CASE STUDY ANALYSIS**

4.1 Case study overview

X oil field, is in Ghana deep-waters of depth ranging from 1000-2000m (Fig.4.1), it is among the major field in the country. The field was discovered in 2009, and it is in Cretaceous basin. This basin is situated in the transform margin of West Africa. The basin was formed due to rifting and drifting of the Atlantic margin. Rift section is made up the Upper Cretaceous layer while the drift portion comprises of slope and basin floor channel systems and stratigraphic traps. The source rocks for the hydrocarbon deposit includes the Turonian-Cenomanian section and Albian shales. Drift section helps in the provision of enough overburden pressure for the maturation of the organic matter and it also provide the trap (stratigraphic) to prevent further migration of hydrocarbon. Exploration of hydrocarbon commenced with the initial drilling of 10 oil wells. The field, covers an expanse of above 800 sq. km (310 sq. mi) and lies around 20 kilometers (12 mi) west to the closest oil field.

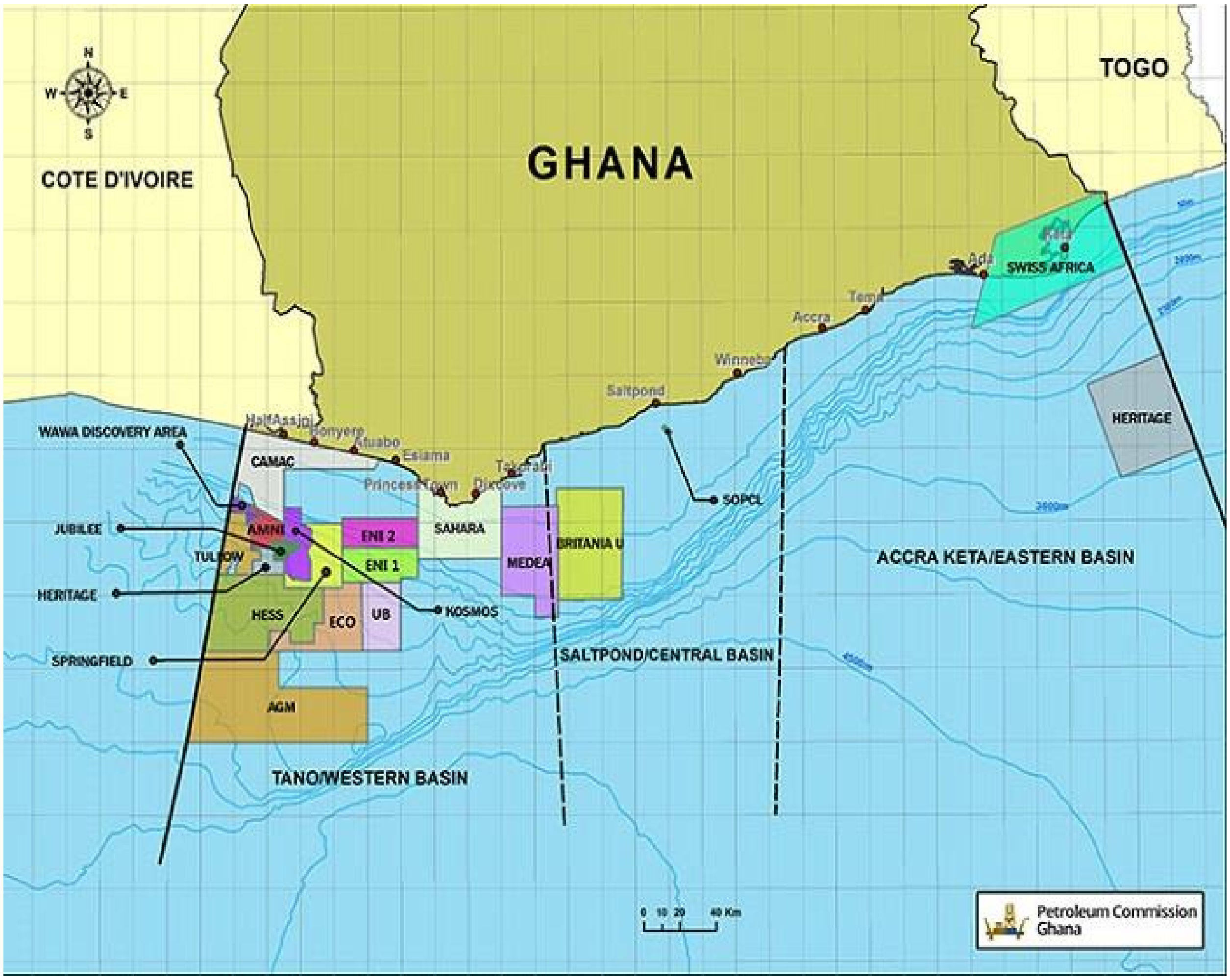

Figure4.1: Field X Location [46]

4.2 Rig specification analysis

Rig specification analysis was carried out during this thesis, to define the offshore rig energy demand required. The offshore rig used during the drilling activity of this field was Eirik Raude semi-submersible rig. The maximum water depth for this rig is 3048m and the range of water depth for this field is with 1000 – 2000m, which fulfils the required condition. Due to data confidentiality issues, there was limited access to offshore rig energy demand profile thus an operating hostel energy requirement was manipulated to fit that of a living quarters of an offshore rig. To ensure credibility of the data, it was compared to the energy demand of 176 person on the rig. The living quarters was taken to be on a different platform and about 88 people carry out daily a 12hr shift. The housing could take about 200 people and the living quarters undergoes two 12hrs shift within the 24hr (1 day). The platform where the drilling activities takes places, covers the shift for 24hrs but the living quarters shows a fluctuating demand in energy after change in shift.

The suitability of any renewable energy system, was based on the climatic condition and thus accessing the energy potential of this renewable to see if it can effectively satisfy the required demand of the rig. The size of the living quarters was obtained from an offshore accommodation module sale (Table 4.1). The living quarters comprises of bedroom, recreational area, kitchen, bathroom and showers, offices, and gymnasium.

Table 4.1: Rig Specification Analysis [47]

Specification	Dimension	Material Used	Accommodation Capacity
Technical	20.8mx32.4mx20.3m	Steel, weight (1653 tonnes)	200
FEATURES			
60 cabins for 2person (12.4 or 9.25m^2)	20 cabins for 4person (13.9 or 10m^2)	Helicopter Deck designed for Sikorsky S61N	Male/Female Locker Rooms
48.01m^2 Tea room	180m^2 Mess room	48.01m^2 Fitness Area	58.82m^2 Health Office
124m^2 Recreational Room	100m^2 Smokers Recreational Room	240m^2 Control Room	3, 36m^2 Office Areas

4.3 Energy Requirement

For effective analysis, the energy demand for the rig was divided into two sections; energy demand for living quarters and energy demand for drilling activities. For the living quarters, the energy to do with cooling, water system, etc. The energy demand was assumed to be a constant value for simplicity of calculation because fluctuating demands pose a challenge during the simulation. The energy for the drilling activity, was also calculated based on the diesel required to fuel the generator for the rig. The renewable devices potential energy was evaluated and compared to see if it was able to meet the demand base on the climatic conditions.

LIVING QUARTERS ENERGY DEMAND

The energy data of an operating hostel, was manipulated, to give a breakdown of the energy usage (Table 4.2). The total energy was obtained based on words of mouth from a previous staff of the company that operates Field X. Better understanding of the data was possible with comparison to the energy demand of the hostel. This data was cross referenced against the living quarters for about 176 people on the rig.

Table 4.2: Assumed Hourly Living Quarter Demand

Distribution	% of Total Energy Use	kWh
Kitchen	6	24
Laundry room	3	12
Heating, Ventilation and Air Conditioning	55	220
Lighting	12	48
Elevators	5	20
Safety Systems	7	28
Chillers	4	16
Sewage System	3	12
Water System	4	16
Radio Communication	1	4

Total	100	400

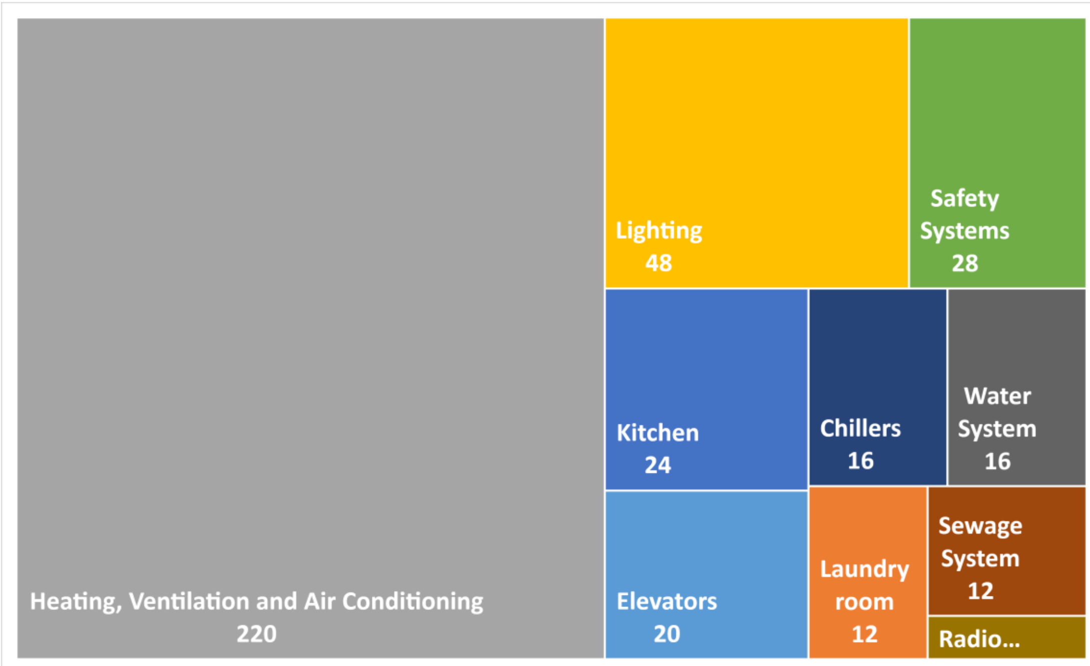

Figure4.2: Chart Showing Ratios of Energy Usage in Living Quarters

DRILLING OPERATION ENERGY DEMAND

The rig platform, demands the most energy. Most of the energy is required for circulatory system, well control system, hoisting and rotating system. In addition to this electrical requirement such as lightening, and safety system also make use of energy. Most of the energy offshore, comes from generators and gas turbine that works with fossil fuel.

Table 4.3: Specification for Power Supply of the drilling rig [48]

MACHINERY AND SYSTEMS	
Main Power Source	6 x Wartsila 18V32 diesel engines, rated 7,500kW each, (10,200hp), total 61,200hp

	6 x ABB ASG 900 XUB generators, rated 7,300kW each, total 43,800 kW
Propulsion	6 x Rolls Royce UCC7001 azimuth thrusters
DP System	DP Class 3 Kongsberg

The energy demand was calculated based on information from a previous staff. Many offshore platforms are fitted with aero derivative gas turbines and dual fuel generators for all energy needs. For this thesis, the rig, makes use of just generators for its drilling operation. Eirik Raude rig main source of power is a diesel engine. The rig has 6 Wartsila 18V32 diesel engines, with a power rating of7,500kW and 6 ABB ASG 900 XUB generators, rated 7,300kW. The living quarter's power consumption is 3.5GWh yearly and so the yearly average power consumption of rig equates to 63.8GWh

4.4 Climatic Condition of Field X

The climatic condition of Ghana is affected by two air masses, the air mass over the Sahara Desert (tropical continental) and the other over the Atlantic Ocean (maritime). These air masses meet at a zone known as the Inter-Tropical Convergence Zone (ITCZ) and they characterize the climatic conditions in this region. Thus, there are two season the dry and rainy season. The rainy season occurs from May till July and from September and November. Dry season occurs the throughout the remaining months. Solar radiation is usually higher in the dry season as compared to the rainy season. The hottest time of the year occurs in months of February and March with the temperature of about 35℃. Around July and August, these are the cooler month with the temperature approximately about 26℃.

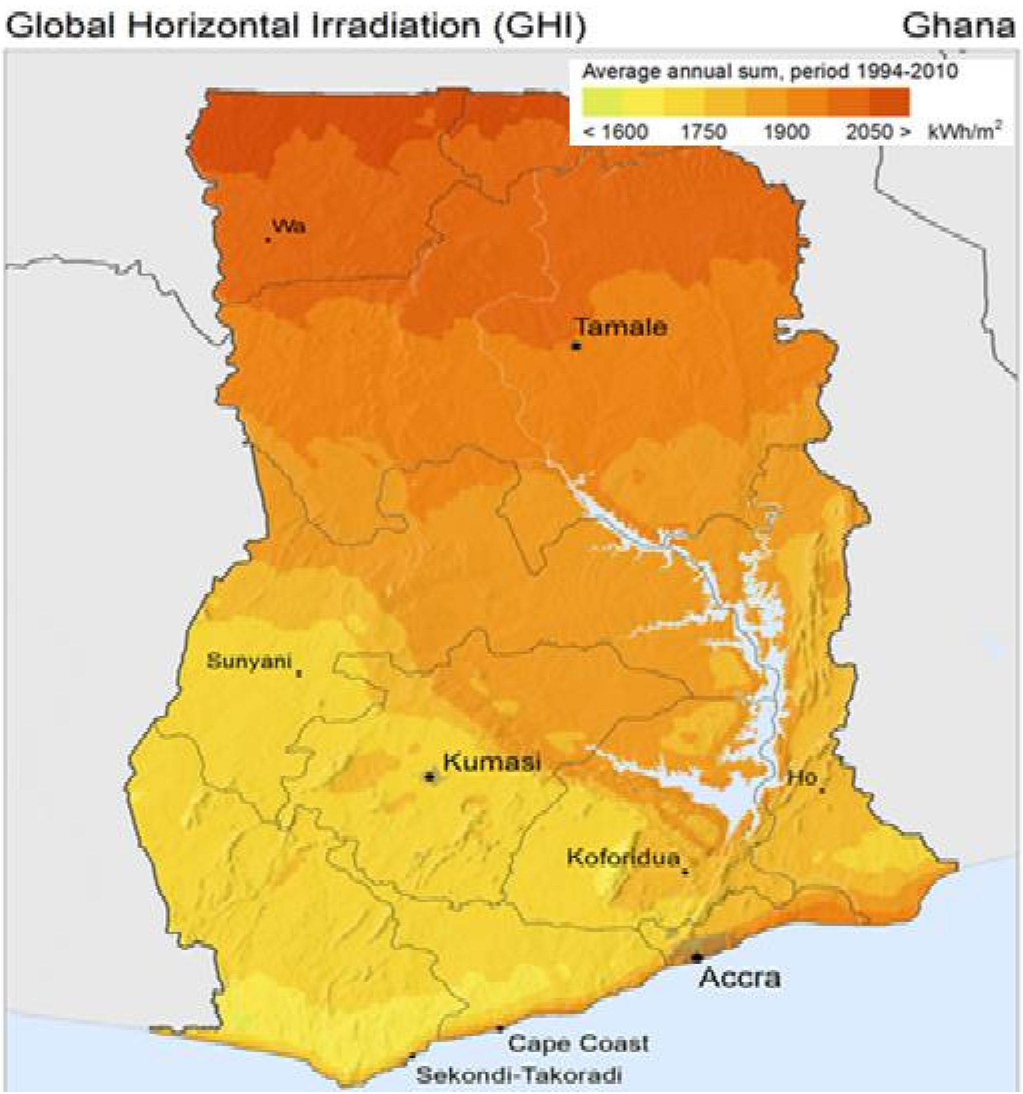

Figure4.3: Solar Resourse map of Ghana [49]

Offshore wind data sources from three locations around the field, show the same south-western wind direction. The offshore wind has an average minimum speed within the range 3.7 - 4.0 m/s and maximum winds speeds of 8.8 - 10.8 m/s (Fig. 4.4). Throughout the different season, there was no noticeable change in the wind speed and directions for over a year.

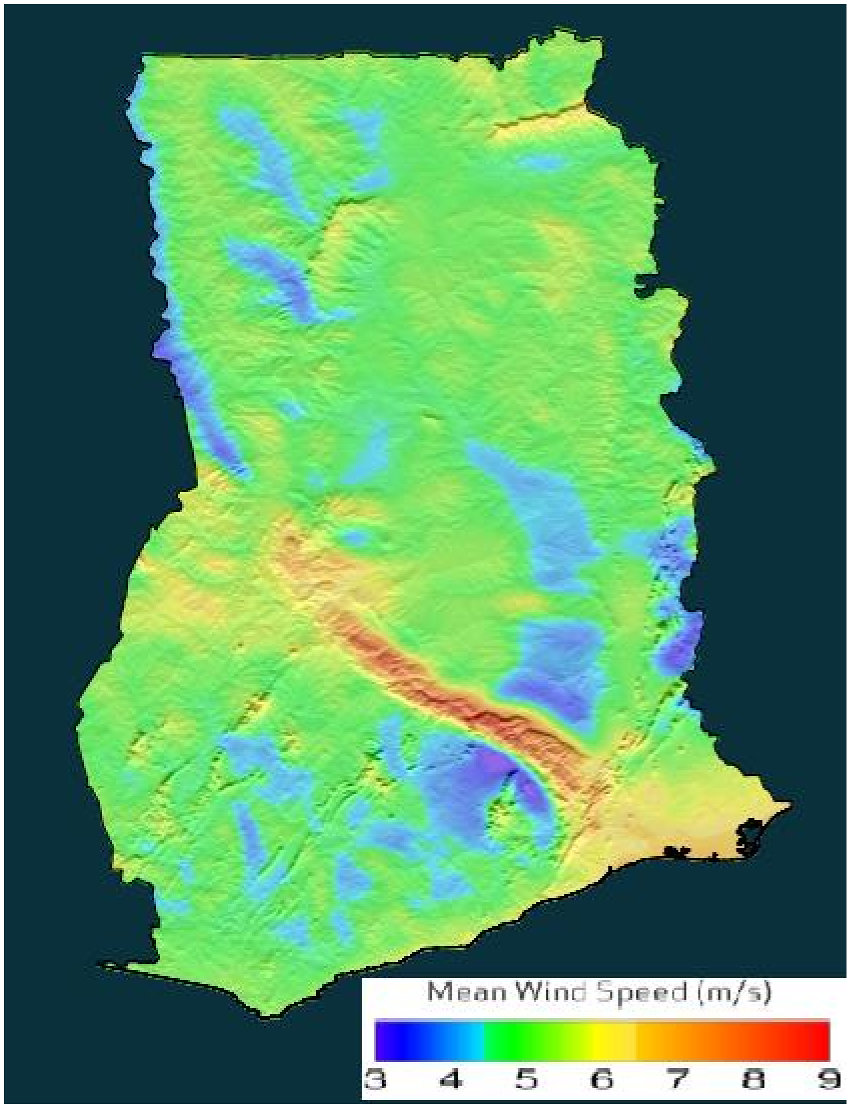

Figure4.4: Wind Resourse map of Ghana [50]

The main current along the coast of Ghana is the Guinea Current, which is an extension of the Equatorial Counter Current. It is controlled by westward wind stress. Current reduces around February to April and from October to November. When this occurs, the current direction changes. The current velocities ranges from 0.5 m/s to 1.0 m/s and 0.05 m/s to 1.02 m/s.

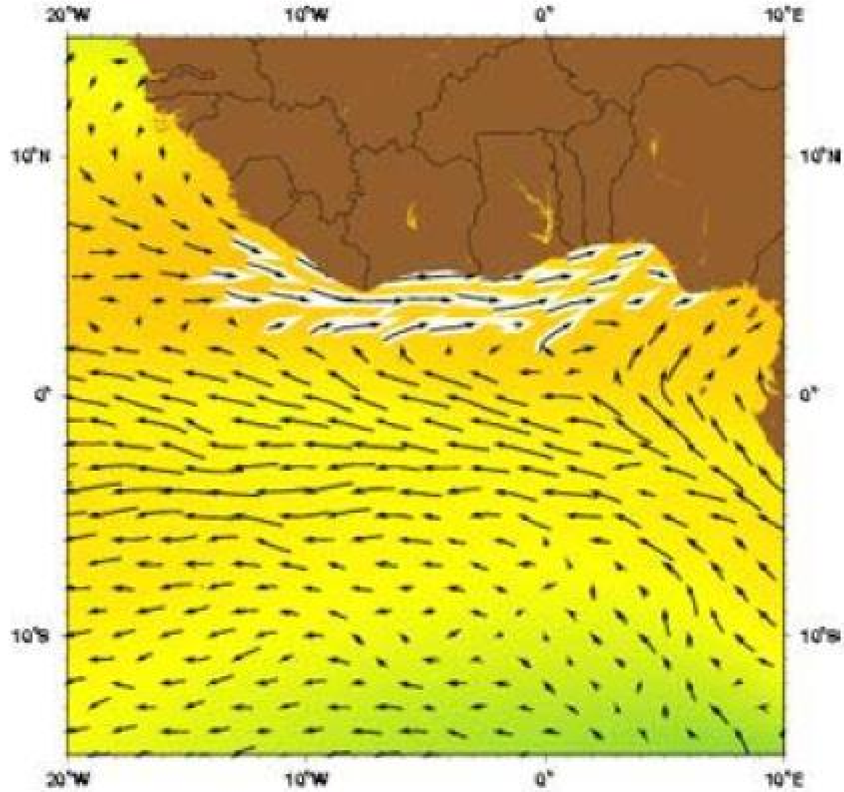

Figure4.5: Guinea Current [51]

The Guinea current is at its maximum strength (1m/s) due to the South-West Monsoon Winds from May till July and for the other part of the year, it is weaker (Fig 4.5). Tidal current direction is mostly from north or north-east with a velocity less than 0.1 m/s. The maximum obtainable velocity is about 0.5 m/s. Some waves, may lead to longshore current. They are usually in the west to east direction which shows that the wave is reaching the shore. The current velocity ranges from 0.5 and 1.5 m/s and it increases during stormy sea. The average velocity is about which is about 1 m/s. Waves that get to the shores of Ghana are from the Antarctica Continent and it is produced by winds occurring locally. The height of the wave is between 0.9 m and 1.4 m and the maximum possible height is 2.5 m (Fig 4.6). The obtainable wave amplitude is 1.0m, but in stormy seas, 3.3m is possible. Peak wave period is within the range of 7 to 14. Wave direction is from the south or south-west. The wavelength is between 160 and 220 m and wave period are 12 second.

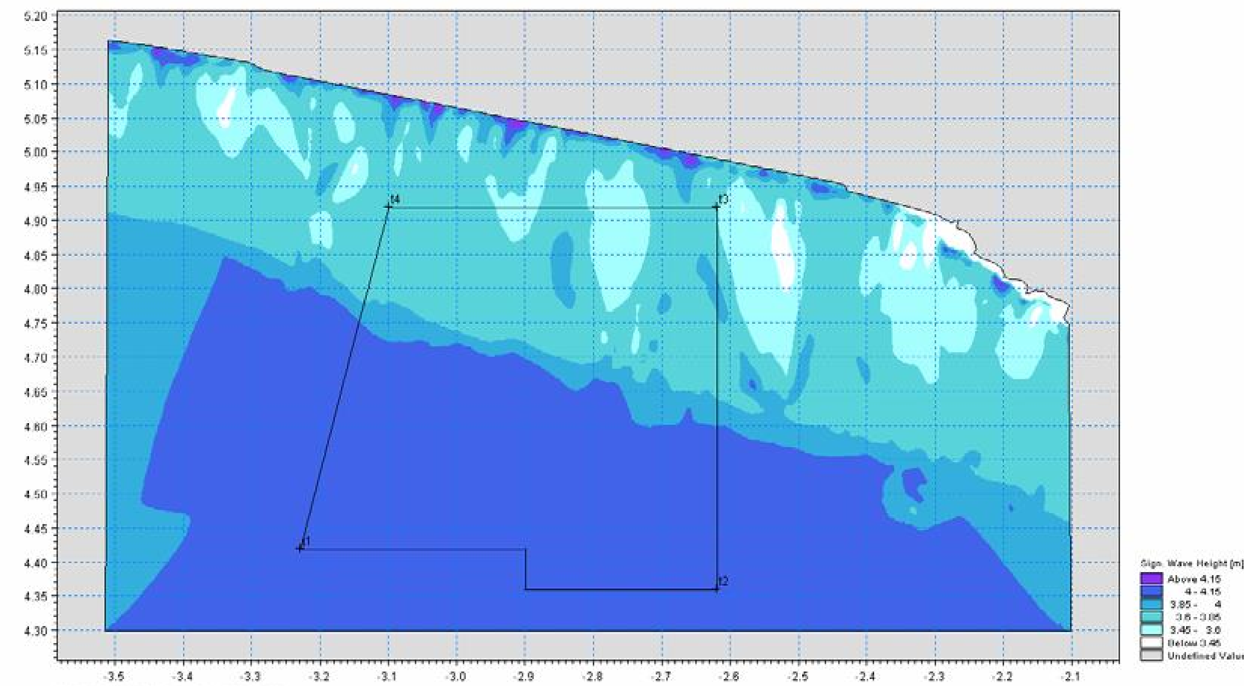

Figure4.6: Wave Height Offshore Ghana [51]

Tides on the coast of Ghana is semi-diurnal and it has two high and low tide levels every day. The tides increase from west to east for Neap and Spring tides. The current obtained from tides are low and do not have any impact on the coastal process.

4.5 Applicable Renewables

The basis of renewable choice, is hinged on the ability to provide the required portion of energy. If a renewable device is chosen to supply at least 20% of the total energy demand, then this renewable would work with no disturbance because an alternative method for energy provision would be set up in place. When full dependency sets in, there might be a problem of intermittency hence there is need for a storage device when renewables is employed.

The oceanic condition, offshore Ghana, favors Solar and Wind. Africa as a continent, has sunshine throughout the whole year. Ghana has an average direct horizontal irradiation of 2000kWh/m^2. The sun as a source of energy, is an easily accessible and the market is growing in Ghana as the country is has installed 200 MW capacity incorporated into the energy mix. Wind turbine, generates electricity at a speed of around 3-4 m/s, (8 mph). Ghana offshore wind has an average minimum speed within the range 3.7 - 4.0 m/s and maximum winds speeds of 8.8 - 10.8 m/s, so this would be a suitable renewable for drilling rigs. Annual prediction of tides is computed and published by the Ghana Port, Harbor and Authority(GPHA). These predictions have been stopped since 2000, thus the use of tide as a renewable source of energy is not possible, due to lack of data. Also, for wave as a source of power, the only data available was obtained about 40 years ago and with the apparent changes in the climatic condition, the data does not have the required integrity for it be used in this thesis.

4.6 Software Used

For this thesis, an excel spreadsheet simulator was used called XXX. For the conversion of radiation from the sun to a source of energy, using PV cells, has low efficiency. Thus, for proper analysis and prediction of the optimum configuration in terms of economic and technical feasibility, this software was used.

This simulator, works on the sizing logic, by the reduction of percentage power from the diesel generator set and infusion of renewable energy (Solar PV) by selection of the best possible configuration taking into consideration optimization cost and technicalities. Different scenarios were obtained by adjusting the battery and PV cell size.

CHAPTER 5

5.0 **RESULT AND DISCUSSION**

5.1 Cost/Price Analysis of Fossil Fuel

Rig design are different, and they operate with diverse machinery required for energy production. Most rigs function using natural gas and diesel for energy production. For this thesis, the focus was on the use of diesel for energy generation. The fuel needed for producing electricity for the living quarters and drilling activities were calculated and analyzed.

LIVING QUARTERS

Energy requirement from the living quarters, is mainly electrical and it is provided by diesel engines. The diesel engine efficiency and power obtained, cost of diesel was used in the estimation of the fuel cost for energy provision of the living quarters. Daily fuel and annual fuel usage was calculated. The engines on the rig used 45MW 6 x Wartsila 18V32 diesel engines. The efficiency of the diesel generator providing electricity is 40% [52]. The load requirement of the rig living quarters was estimated to be around 400kW. The energy consumption for a day 9.6MWh. The price of diesel is 0.20$/kWh [53], the price per liter is 1.05 U.S. Dollar [54] and applying the ratio of 19kWh/liter of diesel. [55] The cost of diesel of diesel in generating 10MWh for a day would cost i **2000** U.S. Dollar. Thus, the total cost of fuel for the living quarters per year, disregarding any subsidies was **730,000** U.S. Dollar.

DRILLING OPERATION

Calculation of the fuel usage on the Eirik Raude Rig, was possible based on the estimation of diesel consumption data provided by the former staff of the field located in Offshore Ghana.

There are 6 45MW diesel engines with 4-5 running each day, with the addition of emergency diesel generators on standby. Thus, the rig power demands were calculated follows using the pricing figures as shown above.

Total Rig diesel generator fuel consumption equals 175MWh per day

The cost of diesel fuel is 20¢/kWh

Thus, cost of diesel each day yields,

0. 20 × 175000 = 35,000 US Dollars

The total diesel cost annually yields

(35,000 × 365) - 730,000 = **12,045,000** US Dollars

5.2 Economic Analysis

The goal of every oil and gas company is profit making, thus companies try to unnecessary high capital-intensive project, like renewables installation if the reward is not great. Thus, for comparison of renewables against conventional fossil fuel engine, the cost of energy for each device must be calculated and compared adequately.

$$\text{Cost of energy } \frac{\$}{kWh} = \frac{PV\ (CAPEX) + PV\ (OPEX) + PV\ (D\ Costs)}{PV\ (Energy\ Production)} \tag{2}$$

Where,

PV	Present value
C	Capital expenditure
O	Operating and maintenance cost
$PV\ (CAPEX)$	$\sum_{k=1}^{n} Annual\ CAPEX\ \times\ Discount\ Factor$
$PV\ (OPEX)$	$\sum_{k=1}^{n} Annual\ OPEX\ \times\ Discount\ Factor$
$PV\ (Production)$	$\sum_{k=1}^{n} Annual\ Energy\ Production \times\ Discount\ Factor$

$$Annual\ CAPEX \quad = \frac{CAPEX}{MW} \times Installed\ Capacity$$

$$Annual\ OPEX \quad OPEX\ Multiple\ \times (1+i)^{n}$$

$$Annual\ Energy\ Production = \ Installed\ Capacity\ \times\ Capacity\ Factor\ \times 8760$$

The equation above, estimates the cost of energy from a renewable device. The component of these equation includes the capital cost which is highly capital intensive (Table 5.1), operation and maintenance cost throughout the use of the renewables (Table 5.2) and decommissioning cost.

Table 5.1: The capital cost breakdown for a renewable energy project [56]

CAPITAL COST	
Expenses	Associated Components
Structure	Cost of materials and Number of Renewables
Mechanical and Electrical	Generators, Turbines and Energy Conversion Device
Project Management	Project Initiation, planning and Implementation/Development phase
Anchorage	Structure of steels
Connection to the grid	Cables and Transformers
Installations	Equipment's for lifting

Table 5.2: The operating and maintenace cost breakdown for a renewable energy project [56]

OPERATING AND MAINTENANCE COST	
Expenses	Associated Components
	Cost of replacing worn part

Planned Maintenance	Cost due to servicing of the equipment
	Cost of Stopping equipment due to change in weather condition
Unplanned Maintenance	Downtime cost due to pending repairs
	Cost of alternative equipment due to failure
	Cost of unplanned repairs

Expenses may differ from project to project this relates to the varying energy consumption and other factor that may influence the cost incurred during the project. Basically, irrespective of the cost of the different project, structural facility, mechanical and electrical component are the most capital-intensive part of the project (Fig 5.1). Unplanned maintenance usually constitutes the highest cost for the operation maintenance of renewable device

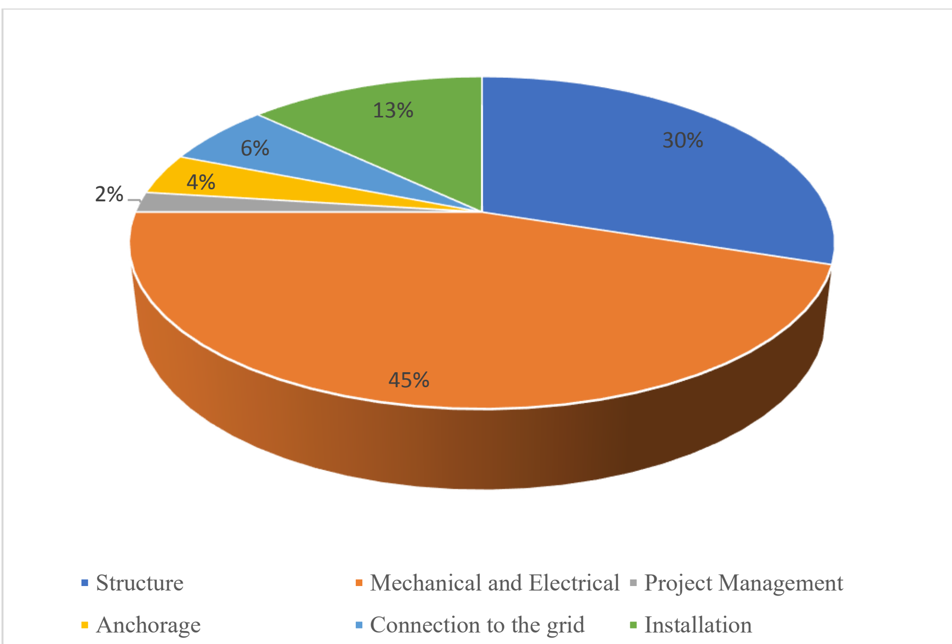

Figure5.1: Chart of capital cost breakdown for a renewable energy project [56]

To obtain the cost of energy for the different renewable device, the capacity factor, which is the ratio of real output that can generated by the renewable device over a period to output it can generate if it was working at its full capacity over the same specified period. For this thesis, the weather data obtained for each case study was analyzed and production figure was obtained for the solar and wind power generation device. The efficiencies and availability were inputted in this calculation. The operating and maintenance cost were included in the calculation for each device. For better comparison of the cost of energy between the renewable and fossil fuel device, the capital and operating cost were estimated per kW. The average lifespan of the renewables for this thesis was taken to be 20 years. The average energy figure obtained, and calculated energy prediction was done based on a yearly basis analysis. Real time data, shows a fluctuating trend of the energy data and investment in a renewable device would be required for constant energy supply.

To obtain the cost of energy for the different renewable device, the capacity factor, which is the ratio of average power generated by the renewable device to maximum possible power that can ever be obtained from this device as determined by the producer. For this thesis, the weather data obtained for each case study was analyzed and production figure was obtained for the solar and wind power generation device. The efficiencies and availability were inputted in this calculation. The operating and maintenance cost were included in the calculation for each device. For better comparison of the cost of energy between the renewable and fossil fuel device, the capital and operating cost were estimated per kW. The average lifespan of the renewables for this thesis was taken to be 20 years. The average energy figure obtained, and calculated energy prediction was done based on a yearly basis analysis. Real time data, shows a fluctuating trend of the energy data and investment in a renewable device would be required for constant energy supply.

WIND TURBINE ANALYSIS

Wind turbine can either be onshore or offshore. For this thesis, offshore wind turbine was analyzed. The case study analyzed, the offshore wind has an average minimum speed within the range 3.7 - 4.0 m/s and maximum winds speeds of 8.8 - 10.8 m/s. Based on this information, some wind turbine characteristics can be obtained (Table 5.3).

Table 5.3: Wind Turbine and Annual Average Wind Speed Characterization [57]

Average Annual Wind Speed at 80-m Hub Height (m/s)	<=5.5	7.4	8	8.4	>=10.0
Specific Power (W/m^2)	200	237	245	255	325
Machine Rating (MW)	2	2	2	2	2
Rotor Diameter (m)	113	104	102	100	89
Hub Height (m)	80	80	80	80	80
CAPEX ($/kW)	1,735	1,653	1,640	1,623	1,539
OPEX ($/kW/year)	51	51	51	51	51
Capacity Factor	27%	39%	43%	45%	49%
Discount Factor	5.7%	5.7%	5.7%	5.7%	5.7%
COE ($/MWh)	93	61	55	53	47

The main difference in the wind turbine type is based on the capital expenditure which is because of rotor diameter difference which is influence by the speed of the wind. For this thesis the capital expenditure can be broken down into wind turbine, the balance of the plant and the financial cost entailed in the project.

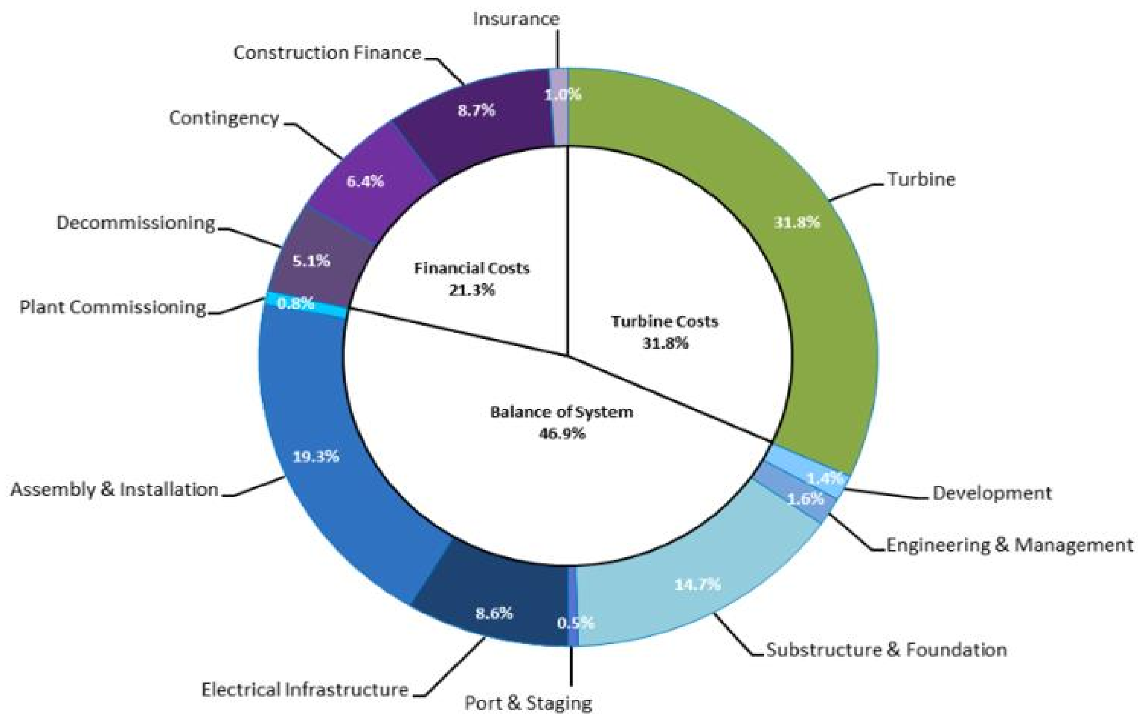

Figure5.2: Chart of capital cost breakdown for a wind renewable energy project [57]

For this thesis, based on the data provided, the optimum wind speed was calculated to be 6.825m/s and from the table above the COE ($/MWh) and CAPEX from interpolation was estimated to be 67 $/MWh and 1677.85$/kW respectively. For better comparison, the cost of energy was also calculated using the formula from equation 2. The energy produced annually is 3748 MWh.

$$\text{Cost of energy } \frac{\$}{kWh} = \frac{\$3,633,700+\$1,158,717.44+\$80,000)}{74,960,000} = 0.065\frac{\$}{kWh} = 65\frac{\$}{MWh}$$

From the cost analysis of fossil fuel, the cost of energy per kWh required to power the diesel engine is $ 0.3/kWh, about 5 times more cost of energy from the 2MW wind turbine. Assuming the wind turbine is required to fulfil the energy consumption of the living quarters, it produces an excess energy of about 0.25GWh annually. This thesis assumed the best-case scenario, whereby the wind condition is always suitable for energy generation. A storage device would be required for constant supply of energy to the living quarters. The total cost for the wind project was estimated to be about \$4,880,000. The payback period of this renewable would be about 5 years, and this is based on the price of fossil fuel which fluctuates, and this analysis was done with worst case scenario. This would mean about 15years of clean renewable and sustainable energy generation.

SOLAR PANEL ANALYSIS

LIVING QUARTERS

For Solar PV cells to used, the numbers of PV cells must be known because Solar PV cells has an efficiency of about 12%. Thus, for estimation of the number of modules needed, can be obtained from the equation below.

$$\text{Number of Modules} = \frac{kWh\ (per\ day)}{hours\ of\ sunlight\ (per\ day) \times PV\ cell \frac{rating}{1000}(kW)} \quad (3)$$

About 5 hours of sunshine is the estimated amount of obtainable in Ghana. A solar PV cell of 365W was used. To satisfy the energy demand for the living quarters of 9.6 MWh/day, the modules required would be:

$$\text{Number of modules} = \frac{9600kWh}{5\ hours \times 365\ /1000(kW)} = 5261 \text{ modules}$$

The most common dimension for solar PV is within the range of 1.6 m by 0.9 m thus the area yields 1.44 m^2. For 5261 modules;

The required space was 5261 × 1.44 m^2 = 7576 m^2

About 7576 m^2 would be needed for the modules without any space between the panels.

Solar PV cell is a capital-intensive project with the cost of solar panel accosting for the highest cost of the project (Fig.5.3).

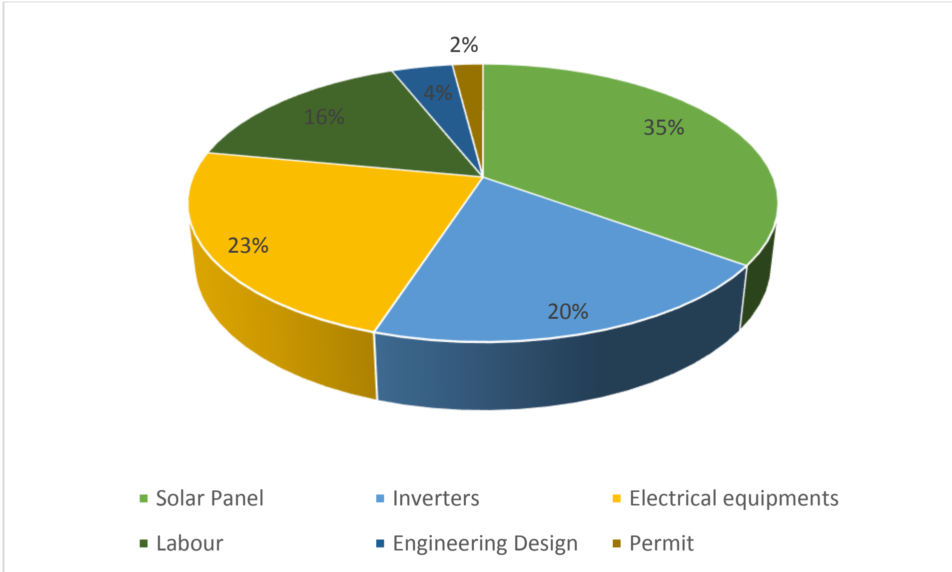

Figure5.3: Chart of capital cost breakdown for a Solar PV renewable energy project [58]

The cost of energy using solar as the source of energy can be calculate based on the following assumptions.

Table 5.4: Solar Power Economic Asumptions for Living Quarters [58]

Capacity, (kW System)	3.3
Time frame of Operation, (Years)	20
CAPEX, ($/W)	3.25
OPEX, ($/YR)	100
Energy Consumption, (kWh/year)	3500
Energy Generation, (kWh/year)	3,795 (1,150kWh/kW)
Rate of Inflation, (%)	1.5
Discount rate, (%)	3.25 (Nominal Discount Rate = 4.8)

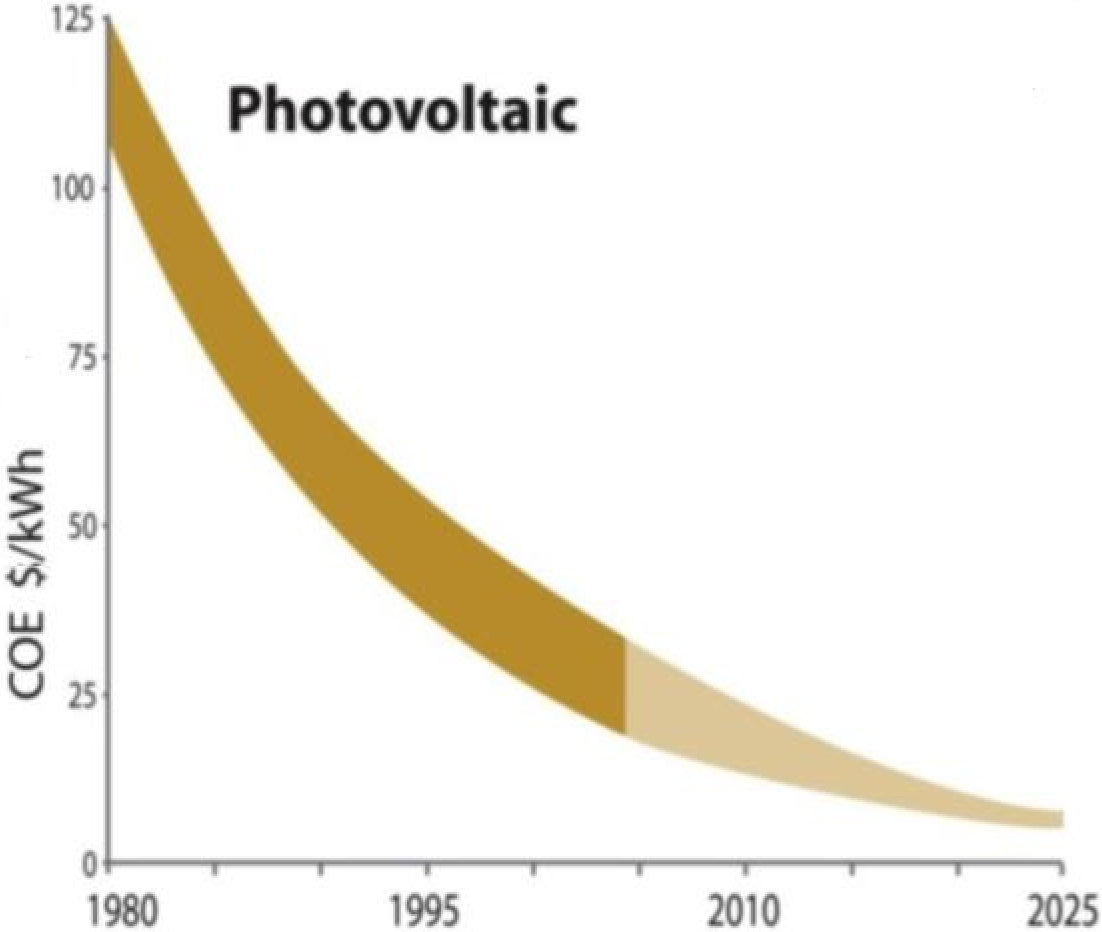

Figure5.4: Chart of decling cost of Solar Energy [3]

Figure 5.3, shows a declining trend in the cost of energy for solar system. From the graph, it can be observed that the COE for 2018 can be estimated to be about 0.24$/kWh. For better comparison, the cost of energy can be calculated from equation 2. Thus the

$$\text{Cost of energy } \frac{\$}{kWh} = \frac{\$7,381,661.25}{49,211,075} = 0.14\frac{\$}{kWh}$$

From the CAPEX estimation, the cost of the solar panel is about 85% of the total cost since the number of modules were taken into consideration, during the calculations. From the cost analysis of fossil fuel, the cost of energy per kWh required to power the diesel engine for the drilling rig is $0.3/kWh, which can be estimated as about twice the cost of energy from the solar panel. For uniformity of the thesis, the average life span was taken to be 20years, although the solar panel that is sold commercially, has an average life span of about 30years.

DRILLING SECTION

The energy requirement for just the drilling activities, exclusive of the living quarters, was calculated to be 165.4 MWh/day, the modules required calculated using equation 3 would be **90,631** modules. The cost of energy using solar as the source of energy can be calculated based on the following assumptions.

Table 5.5: Solar Power Economic Assumptions for Drilling Activities [58]

Capacity, (kW System)	55
Time frame, (Years)	20
CAPEX, ($/W)	3.25
OPEX, ($/YR)	100
Energy Consumption, (kWh/year)	60,371
Energy Generation, (kWh/year)	63,250 (1,150kWh/kW)
Degradation, (%/year)	0.5
Inflation Rate, (%)	1.5
Discount rate, (%)	3.25 (Nominal Discount Rate = 4.8)
Grid Electricity	$0.0600/kWh + 2.5%/year

Thus, the cost of energy can be calculated from equation 2. This yield:

$$\text{Cost of energy } \frac{\$}{kWh} = \frac{\$107{,}513{,}023.8}{453{,}330{,}000} = 0.237 \frac{\$}{kWh}$$

From the cost analysis of fossil fuel, the cost of energy per kWh required to power the diesel engine for the drilling rig is \$0.3/kWh, which is 1.3 times the cost of energy from the solar device. To make profit from this venture, excess electricity generated would be sold to the government because this is a capital-intensive project.

5.3 Technical Analysis

Based on the data obtained from a previous worker with this company, a load profile was generated. The load profile (Fig.5.5) was built from equation and certain assumptions.

$$\phi = HHv \times \rho \times \zeta \tag{4}$$

Where,

ϕ Power Input, (kWh/l),

HHv Higher heating value, (44 MJ/Kg),

ρ Density, (0.91 kg/l),

ζ 0.278Kwh/MJ.

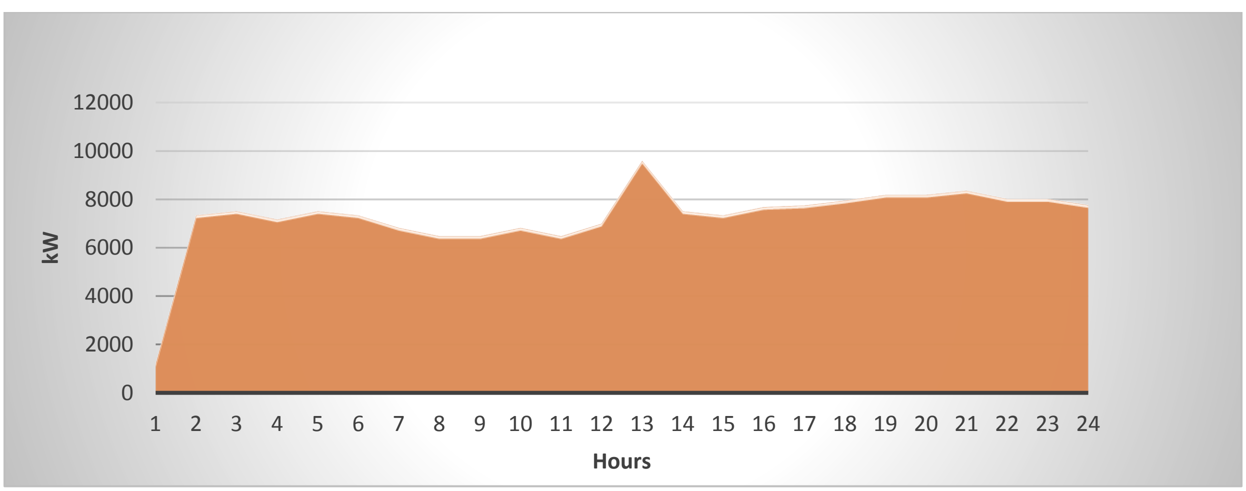

Figure5.5: Load Profile of the Offshore Rig

Different simulations were made using the XXX software by changing the battery rating and the size of the expected PV farm for diesel price at 1,0, 1.25, 1.5, 1.75 and 2.0 $/L and the results for each scenario is displayed in turns in the Table5.6 below. The simulation was carried out for a year.

Table 5.6: PV Solar Plant Simulations

GOAL (load total covered)		Battery is for stability			Optimal configuration	
Peak load	kW	**9589**	**9589**	**9589**	**9589**	**9589**
Diesel genset	kW	10,000.00	10,000.00	10,000.00	10,000.00	10,000.00
PV plant	kWp	6,000.00	6,000.00	8,000.00	10,000.00	10,000.00
BESS Nominal capacity	kWh	2,750.00	5,500.00	5,500.00	5,500.00	13,750.00
PCS power	kW	9,900.00	11,700.00	11,700.00	11,700.00	27,900.00
RES production to the load	%	100.0%	100.0%	100.0%	100.0%	100.0%
Load covered by RES	%	14.2%	14.2%	18.9%	23.6%	23.6%
Load covered by Diesel	%	85.8%	85.8%	81.1%	76.4%	76.4%

Liters of diesel saved	L	3,776,797	3,777,024	4,444,607	5,112,189	5,112,871
Capex	$	10,040,108	11,248,084	13,649,196	16,119,208	20,999,872
IRR	%	47.10%	41.46%	39.77%	38.40%	28.79%
Pay back	y	2.74	3.08	3.18	3.27	4.29
Total LCOE	$ / MWh	265.86	267.64	260.34	253.10	259.73

For this simulation, the assumption made by the software was that the renewable energy device, (SOLAR) RES, works at its full capacity. The battery, is required for stability of the solar device. From the result obtained it shows there is no full transition to fully renewables, but renewables support and supplement the diesel generators in powering the oil rig. In addition to this, the larger the solar farm, the lower the cost of energy.

Table 5.7: Sensitivity Analysis for Varying price of fossil fuel

Project IRR	**1.00**	**1.25**	**1.50**	**1.75**	**2.00**
	38%	49%	61%	73%	86%
Pay Back Time	**1.00**	**1.25**	**1.50**	**1.75**	**2.00**
	3.3 y	2.6 y	2.2 y	1.8 y	1.6 y

From Table 5.7, it can be observed that, when the cost of fossil fuel increases, the payback time decreases, while the internal rate of return increases. The reason for this trend is that when the cost of fossil fuel increases, the company would spend an additional cost as compared to when fossil fuel was cheaper. If renewables replace the fossil fuel, the additional cost from consumption of fuel is saved and can be used to finance the renewable device.

5.4 Energy Cost Analysis

Levelized cost of energy (LCOE), is an assessment that help provide a means for the comparison of the cost of electricity produced from different sources. It can be obtained by the ratio of the sum of capital expenditure and operating cost over the period of operation of the device to the total energy output of the device over the operating period.

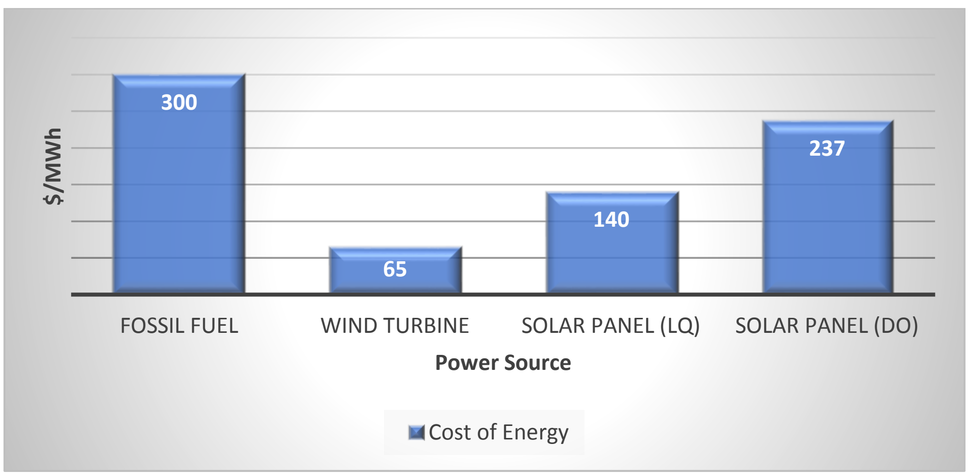

Figure5.6: Comparison between different power sources

During the analysis of COE for this thesis, the best-case scenario was chosen for the wind device and about 5hours of sunshine was used for solar renewable energy source. From the analysis, the size of the renewable device can adequately provide the needed energy for daily operation on the rig with the inclusion of a storage device. Comparison of the result of COE against known industry solution providers, indicates the similarities between the result (Fig.5.6) (Fig. 5.7).

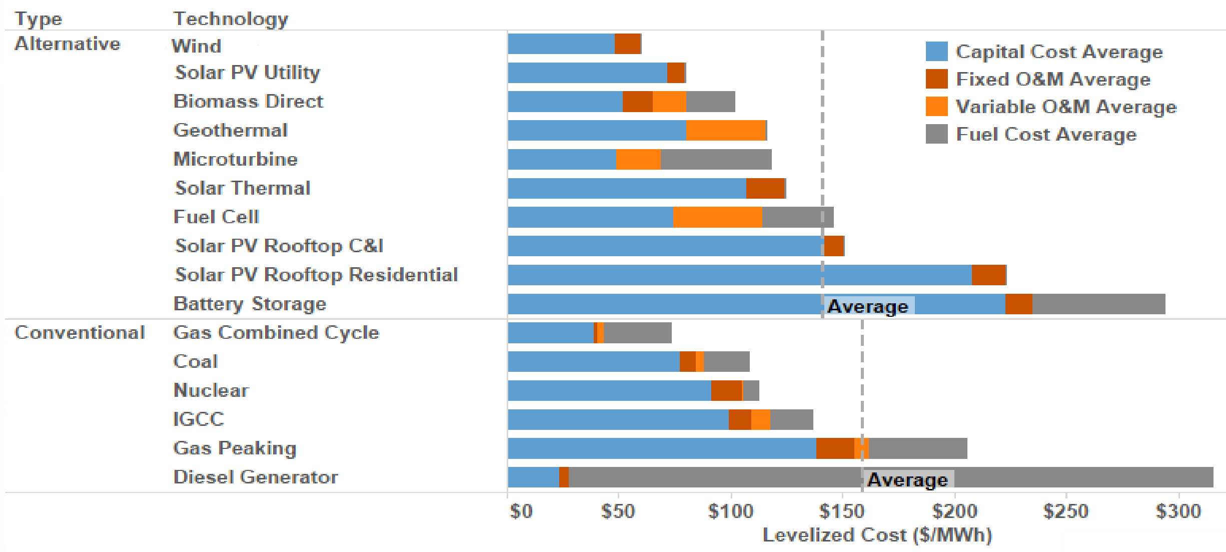

Figure5.7: Comparison of the costs of renewable and conventional energy sources [57]

The energy demand of the living quarters does not always follow the peak energy production, there might be noticeable fluctuations due to changes in energy demand (Fig. 5.8).

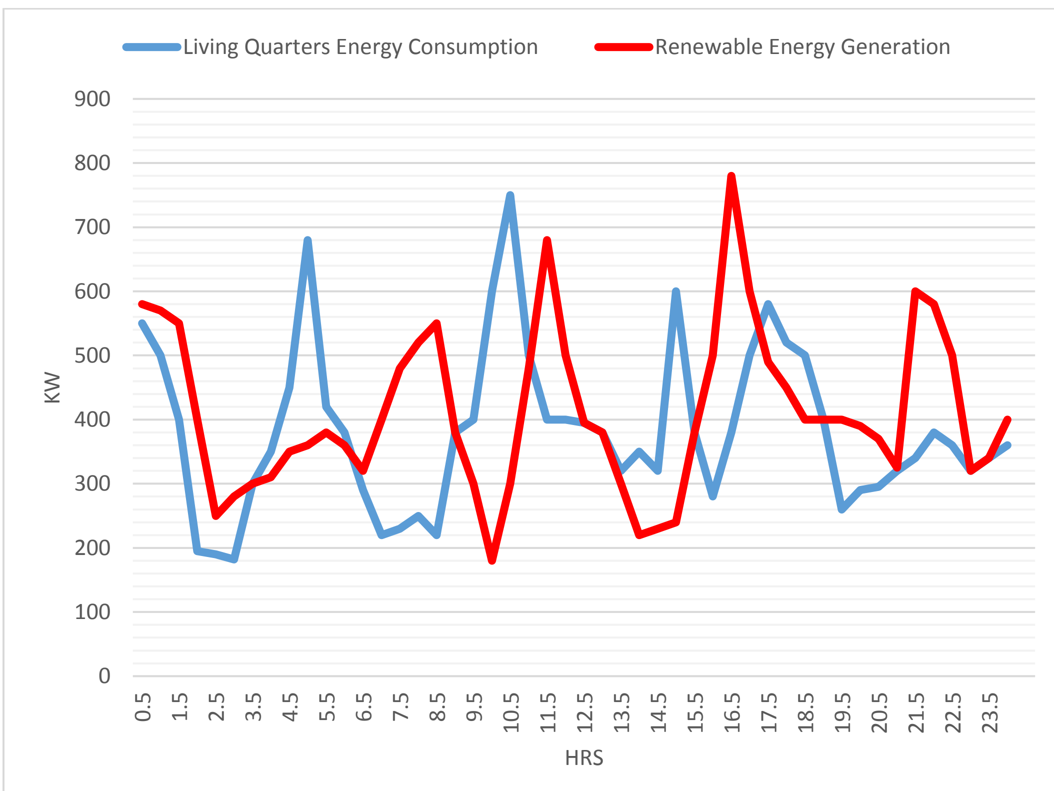

Figure5.8: Energy Demand Prediction and Renewable Supply

The bulk of the electrical load is from heating, and to reduce waste of energy, storage of hot water can be used. This method is cheaper and efficient. The efficiency, is dependent on the temperature of the tank where the water is stored. A 500l tank with a temperature of 60°C requires an energy of 11.3kWh while keeping same tank at a temperature of 80°C, requires an energy of about 23kWh. The floor of the rig can be used to keep these storage tank and provide the required heat when necessary. The major challenge for offshore facility is space thus this affect the electrical storage options. The most used option is lead acid batteries because the higher efficiency batteries are usually expensive because they function based on precious and rare metals.

If the power produced from the renewable device is more than required for the living quarters, the excess can be used for drilling operation or send to the national grid and this is dependent on a positive financial assessment or profit margin.

5.5 Environmental Impact Analysis

Infusion of renewables in offshore platform can drastically reduce the emission of carbon from this sector and reduce the impact of global warming. For this thesis study, if the production of power for the living decks was to be completely supplied by renewable sources, the carbon emission can be calculated when power generation was supplied by fossil fuel and compared against supply by renewables.

The energy requirement for the living quarters was 9.6MWh and 3.5GWh annually. The amount of CO_2 emission generated per kWh by this source can be obtained by the multiplication of the CO_2 emission factor of the fossil fuel (diesel) and by the efficiency of the generator. The higher the efficiency, the lower the CO_2 emission generated to the atmosphere. The result obtained, is divided by 10^6.

0.76kg of CO_2 emission is generated when 1kWh of diesel is combusted. To produce a useful form of energy, 1.9kg of CO_2 is generated for every 1kWh of energy from diesel. Thus, about 0.0020 metric tons (Mt) of CO_2 to the atmosphere yearly. The living quarters accounts for about 5.5% of the total energy consumption on the rig. The total CO_2 emission generated by Ghana is 0.55 metric tons, thus the living quarters of one rig contributes to 0.36% of the total CO_2 emitted. With the addition of renewables, a decline would be experienced in the CO_2 generated into the atmosphere and reduce the impact of global warming in the world.

CHAPTER 6

6.0 CONCLUSION

Based on the analysis of modification of offshore system for renewable energy infusion to power the rigs, it was discovered that few of these renewables are been used in the industry for a region like Africa, it can be due to lack accessible data. From the economic analysis and comparison of the cost of energy between the fossil fuel and renewables, it was discovered that renewables as power sources can be infused into the power generation of oil rigs. From the results obtained, it was also discovered that renewables cannot be solely relied on 100% as the only source of power for oil rig. A storage device is important for the use of renewables to ensure constant supply of power whenever it is required.

From this thesis work, it is obvious that various factors hinder the growth and development of renewables as a source of power, but cost does not influence it. Based on the result obtained from the analysis of the cost of energy, it shows that the use of fossil fuel as an energy source, cost more than the use of renewables. Different regions have different climatic conditions, and this has an impact on the type of renewable device that can be use in any location. The analysis, using the XXX simulator shows about 19% reduction in the fuel consumed when renewables is integrated into the offshore platform. Interpretation of the results clearly indicates that the bigger PV farm, the lower the cost of energy. The price of fossil fuel is never constant. Any change in the price, reflects on the cost of running the diesel generators required to produce power. If renewables replace the fossil fuel, the additional cost from consumption of fuel is saved and can be used to finance the renewable device and thus decrease the payback time.

Sustainability has to do with maintaining the ecological balance. This has to do with the prudent use of natural resources that can meet the need of this present generation, without endangering the ability to meet the needs of future generation. Sustainability, has to do with economic development, social development and environmental impact. With respect to the environmental impact, Ghana emits about 0.55 metric tons of CO_2. It was calculated from the results that about 0.0020 metric tons (Mt) of CO_2 from the Living quarters of the rig is emitted to the atmosphere yearly. The living quarters accounts for about 5.5% of the total energy consumption on the rig, thus this oil and gas rig contributes to about 0.36% of the total CO_2 emitted in Ghana. If renewables are infused, there would be a reduction in the GHG emitted into the atmosphere.

The oil and gas industry, is very resilient, and thus this industry has come to stay and is not leaving soon. To reduce the environment impact of oil and gas activities, the industry should embrace the infusion of renewable energy as a power source as it would reduce cost of operation and reduce the carbon emitted into the environment thereby reducing the impact of global warming. A sustainable Africa is the key and this is attainable by renewable energy infusion.

REFERENCES

1) Energy Commission of Nigeria (ECN). Energy Implications for Vision 2020 and Beyond. Available online: http://www.energy.gov.ng/index.php?option=com_docman&task=cat_view&gid=39&Itemid=49&%20limitstart=45 (accessed on 5 February 2018).

2) Department for Environment, Food and Rural. Available online: http://www.lordgrey.org.uk/~f014/usefulresources/aric/Resources/Teaching_Packs/Key_Stage_4/Climate_Change/01t.html (accessed on 10 February 2018)

3) David Timmons, Jonathan M. Harris, Brian Roach. (2014). The Economics of Renewable Energy.Global Development and Environment Institute Tufts University Medford, MA 02155 http://ase.tufts.edu/gdae 2, 5–15

4) Richard S. Kraus. Exploration, drilling and production of oil and natural gas. http://www.ilocis.org/documents/chpt75e.htm (accessed on 10 February 2018)

5) Drilling Equipment. Available Online: http://ffden2.phys.uaf.edu/212_spring2011.web.dir/Dan_Luo/web%20page/Drilling%20rig.html (accessed on 10 February 2018)

6) Inger R, Attrill MJ, Bearhop S, Broderick AC, Grecian WJ, Hodgson DJ, Mills C, Sheenan E, Votier SC, Witt MJ, Godley B (2009) Marine renewable energy: potential benefits to biodiversity? An urgent call for research. J Appl Ecol 46:1145–1153

7) Drilling Course. Available Online: http://www.drillingcourse.com/2015/12/drilling-rigs-types.html (accessed on 10 February 2018)

8) Types of Drilling rig and Structure. https://www.linkedin.com/pulse/types-drilling-rigs-structures-ali-seyedalangi/ (accessed on 10 February 2018)

9) Rig Types. Available online:

http://www.unimasr.net/ums/upload/newuploads/uploads2009/uploadsOct/UniMasr.com_d8d5f84f7f85ab04e9f487f6c0186382.pdf(accessed on 10 February 2018)

10) (M.E.), William Robinson (1890). Gas and Petroleum Engines: A Practical Treatise on the Internal Combustion Engine.

11) Pulkrabek, Willard W. (1997). Engineering Fundamentals of the Internal Combustion Engine. Prentice Hall.

12) Desantes, J. M., Arre`gle, J., Lo´pez, J. J., & Garcı´a, J. M. (2006). Turbulent gas jets and diesel-like sprays in a crossflow: A study on axis deflection and air entrainment. Fuel, 85(14–15), 2120–2132.

13) Ismail, H. M., Hg, H. K., & Gan, S. (2011). Evaluation of non-premixed combustion and fuel spray models for in-cylinder diesel engine simulation. Applied Energy, 90(1), 271–279.

14) Heywood, J. B. (1988) Internal combustion engines fundamentals. New York, NY: McGraw Hill.

15) Desantes, J. M., Benajes, J., Molina, S., & Gonzalez, C. A. (2004) The modification of the fuel injection rate in heavy-duty diesel engines. Part 1: Effects on engine performance and emissions. Applied Thermal Engineering, 24, 2701–2714.

16) Oil & Gas UK. Environment Report. (2013). http://oilandgasuk.co.uk/wp-content/uploads/2015/05/EN027.pdf (accessed on 1 February 2018)

17) Beacon. (2018) What is a Greenhouse Gas? Available online: http://beacon.berkeley.edu/GHGs.aspx (accessed on 1 February 2018)

18) J. Palsson, A. Selimovic and L. Sjunnesson. (2000). Combined solid oxide fuel cell and gas turbine systems for efficient power and heat generation. Journal of Power Sources, vol. 86, no. 1-2, pp. 42-448.

19) J. Hong, C. Baukel, M. Bastianen, J. Bellovich, K. Leary and John Zink Company. (2012). New steam assissted flare technology. pp. 1-5.

20) Oil and Gas Industries. Flaring and Venting. Available Online: http://oilandgas.livingearth.org.uk/key-challenges/flaring-and-venting/(accessed on 1 February 2018)

21) A. Kayode Coker (2007). Ludwig's Applied Process Design for Chemical and Petrochemical Plants, Volume 1 (4th ed.). Gulf Professional Publishing. pp. 732–737. ISBN 0-7506-7766-X

22) T. J. Blasing. (2014). Recent Greenhouse Gas Concentrations. Carbon Dioxide Information Analysis Center.

23) Alex Vines. (2014). Africa's oil and gas potential: Boom or hype? Available online: http://edition.cnn.com/2014/09/18/business/africa-oil-gas-potential-boom-hype/index.html (accessed 2 February 2018)

24) Energy and Corporate Africa. 2013. Africa Offshore Basins Expanding from West Africa to East Africa. Available online: http://www.energycorporateafrica.com/africa-offshore-basins-expanding-from-we.(accessed 1 February 2018.)

25) Matthijs Ruoff. (2016). The future of the Dutch offshore oil and gas infrastructure: Relevance and role in a carbon emission neutral energy system.

26) A. Vinod, A. Kashyap, A. Banerjee, and J. Kimball. (2013). Augmenting Energy Extraction from Vortex Induced Vibration Using Strips of Roughness/Thickness Combinations," Int. J. Marine Energy Technology Symposium.

27) W. He, K. Uhlen, M. Hadiya, Z. Chen, G. Shi and E. d. Rio. (2013). Case Study of Integrating an Offshore Wind Farm with Offshore Oil and Gas Platforms and with an Onshore Electrical Grid. Journal of Renewable Energy.

28) OLF. (2005). Offshore renewable power for O&G Installation, feasibility study.

29) Nikhila Gopal. (2016). Use of Hywind in Oil and Gas Platforms to Reduce CO2 and NOx Gas Emissions.

30) Y K Tiong, M A Zahari, S F Wong and S S Dol. (2015) The Feasibility of Wind and Solar Energy Application for Oil and Gas Offshore Platform. IOP Conference Series: Materials Science and Engineering, Volume 78, conference 1. Available Online:

http://iopscience.iop.org/article/10.1088/1757-899X/78/1/012042/pdf(accessed 1 February 2018.)

31) Jamie MacDonald. (2014). Providing Scope for Reducing the Carbon Footprint of an Offshore Oil Rig

32) JX Nippon Oil & Gas Exploration. (2005). Available online: http://www.nex.jx-group.co.jp/english/newsrelease/2005/e71_enpr_060207.html(accessed 1 February 2018.)

33) Michael Graham Richard. (2010). Turning Wasteful Gas Flares into Useful Liquid Fuel. Available online: https://www.treehugger.com/clean-technology/turning-wasteful-gas-flares-into-useful-liquid-fuel.html(accessed 1 February 2018.)

34) Philippe Angays. (2017). Monetization of associated gases from offshore oil fields by electrical power generation. Available Online:

http://ieeexplore.ieee.org/document/6581599/authors(accessed 1 February 2018.)

35) Jean Dubranna. (2016). An overview of marine renewable technology. Available Online: http://parisinnovationreview.com/articles-en/an-overview-of-renewable-marine-energy (accessed 7 February 2018.)

36) EWEA (2004). Wind Energy - The Facts. An Analysis of Wind Energy in the EU-25, Executive Summary. Available Online: www.ewea.org

37) Offshore (2013). Global Offshore Wind Farms Database. Available Online: http://www.4coffshore.com/offshorewind/.(accessed 7 February 2018.)

38) Sigmar Gabriel. (2015). The energy transition – a great piece of work Offshore wind energy. Available Online:

https://www.erneuerbareenergien.de/EE/Redaktion/DE/Downloads/offshore-wind-energy.pdf?__blob=publicationFile&v=2(accessed 7 February 2018.)

39) BWEA. (2005). Wind Turbine Technology. Available Online: https://www.nottingham.ac.uk/renewableenergyproject/documents/windturbinetechnology.pdf (accessed 7 February 2018.)

40) Energy Informative. (2013). Available Online: http://energyinformative.org/wave-energy/(accessed 7 February 2018.)

41) Wave Energy. (2010). Available Online: http://www.alternative-energy-tutorials.com/wave-energy/wave-energy.html(accessed 7 February 2018.)

42) Tidal Energy. (2010). Available Online: http://www.alternative-energy-tutorials.com/tidal-energy/tidal-energy.htm (accessed 7 February 2018.)

43) Solar Energy. (2010). Available Online: http://www.alternative-energy-tutorials.com/solar-energy/solar-energy.htm (accessed 7 February 2018.)

44) Photovoltaic Solar Cells. (2010). Available Online: http://www.alternative-energy-tutorials.com/solar-power/photovoltaics.html(accessed 7 February 2018.)

45) Solar Thermal Energy. (2010). Available Online: http://www.alternative-energy-tutorials.com/solar-hot-water/solar-hot-water.html(accessed 7 February 2018.)

46) Africa PORTS & SHIPS Maritime News. (2017). Available Online: https://africaports.co.za/2017/05/25/africa-ports-ships-maritime-news-11/ (accessed 7 February 2018.)

47) Offshore Accommodation Module with Helideck for Sale. Available Online: http://www.worldoils.com/marketplace/equipdetails.php?id=486. (accessed 7 February 2018.)

48) Ocean Rig. (2013). Available Online: http://www.ocean-rig.com/fleet/semi_submersible_rigs/vessel/5 (accessed 7 February 2018.)

49) Solar Gis. (2018). Available Online: https://solargis.com/maps-and-gis-data/download/ghana (accessed 3 February 2018.)

50) Vortex, Ghana Wind map. (2017). Available Online: http://www.vortexfdc.com/ghana-wind-map (accessed 3 February 2018.)

51) Environmental and socio-economic baseline. (2007). Available Online: https://www.tullowoil.com/Media/docs/default-source/operations/ghana-eia/environmental-impact-statement/jubilee-field-eia-chapter-4-pt1.pdf?sfvrsn=2(accessed 3 February 2018.)

52) Wärtsilä technical journal. (2007). Available Online:

http://twentyfour7.studio.crasman.fi/pub/web/pdf/magazine+pdfs/ID0207-WWW-HQ.pdf (accessed 3 February 2018).

53) Electricity Local. (2018). Available Online:

https://www.electricitylocal.com/resources/statistics/ (accessed 3 February 2018).

54) Global Petrol Price.com. (2018). Available Online:

https://www.globalpetrolprices.com/Ghana/diesel_prices/ (accessed 3 February 2018).

55) Carbon Trust, "Conversion Factors,”. (2011). Available Online: https://www.carbontrust.com/media/18223/ctl153_conversion_factors.pdf (accessed 3 February 2018).

56) Entec UK Ltd. (2006). Cost Estimation Methodology: The Marine Energy Challenge approach to estimating the cost of energy produced by marine energy systems.

57) EIA. (2017). Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2017. Available Online: https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf (accessed 3 February 2018).