University of Strathclyde Engineering

Department of Mechanical and Aerospace Engineering

Providing Scope for Reducing the Carbon Footprint of an Offshore Oil Rig

Author: Jamie MacDonald

Supervisor: Cameron Johnstone

A thesis submitted in partial fulfilment for the requirement of the degree

Master of Science

Sustainable Engineering: Renewable Energy Systems and the Environment

2014

Copyright Declaration

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: Jamie Stewart MacDonald Date: 06/09/2014

Abstract

Emissions associated with oil production condemn the oil industry; greenhouse gases and environmental damages are the main association with refined oil and its effect on our planet. The fear of global warming has led to many countries placing restrictions on the emissions associated with oil production. Consequently a new market has opened up as engineers search for a sustainable energy source for the future - a hunt that is primarily focussed on the possibilities of renewable energy. In the light of this, this thesis investigates the changes which can be made to current fuel sources used on offshore production platforms. Through a four part analysis this thesis will demonstrate the huge potential that renewables have to reduce the carbon emissions of the oil and gas industry - an industry which is almost uniquely well financed to research and develop their practices.

The investigation is comprised of four chapters; the first two assess current methods of energy generation on offshore platforms. The second half of this research builds on the first to suggest ways in which renewable energy can take the place of current unsustainable power sources.

Recent research conducted by Wei He [1] and Kolstad [2] found that there is an industrial appetite for integrating some well-developed renewable devices, but there was no evidence found of such projects in action. Resultantly, this thesis falls within a research lacuna and supplies a gap in the existing knowledge. As there is little existing research on this topic the investigation used a combination of research methods. To investigate the potential for renewables in the oil and gas industry, the energy demands of a sample rig were calculated, and the ability of several reviewed renewables in satisfying this energy demand was analysed. The cost of energy of the renewable devices was compared and contrasted with that of the fossil fuel driven power sources, showing the financial savings applicable whilst reducing the overall carbon emissions of the sample rig.

Acknowledgements

Firstly I would like to thank Paul Strachan for granting entry to the Sustainable Engineering course, an opportunity for which I am very grateful.

I would like to thank Cameron Johnstone for overseeing this project, and his assistance and ideas throughout.

Thank you to my parentals Stewart and Carol MacDonald for being sound and helping with everything en mi vida.

A special thanks to A Lizzle for her grammatical witchcraft, help throughout the year and a deece 3 years.

Lastly I would like to say that everyone in the Sustainable Engineering course is dyno. You have kept me going with our late night study sessions, Livingstone Tower pop quizzes and extreme chess tournaments. It’s been emotional.

Table of Contents

<u>List of figures</u>

List of tables

Notations

AC – Air Conditioning

Ah – Amp Hours

AG - Associated Natural Gas

C_4H_{10} - Butane

CO_2 - Carbon Dioxide

CHP - Combined Heat and Power

CO - Carbon Monoxide

C_2H_6 - Ethane

FPSO - Floating Production Storage and Offloading

GHG - Greenhouse Gas

GW - Gigawatt

GWh – Gigawatt hour

HVAC – Heating, Ventilation and Air Conditioning

H_2S - Hydrogen Sulphide

kg – Kilogram

kW – Kilowatt

kWh – Kilowatt hour

LNG - Liquefied Natural Gas

LPG – Liquefied Petroleum Gas

CH_4 - Methane

Mt – Metric Tonnes

MW – Megawatt

MWh – Megawatt hour

N_2 - Nitrogen

N_2O - Nitrous Oxide

O&M – Operations and Maintenance

C_3H_8 – Propane

p.a. – Per Annum

PV – Photovoltaic

SO_2 - Sulphur Dioxide

TWh – Terawatt hour

WEC – Wave Energy Converter

Chapter 1

1. Introduction

Historically oil rigs have had a bad reputation and negative connotations associated with them because of the work that is carried out on them, but the function of an oil rig as a work and living space is something that can be reviewed, developed and upgraded to meet changing policies and a worldwide demand for a more sustainable and less damaging fuel source. The majority of offshore oil rigs make use of diesel generators for the high powered machinery on-board and gas turbines for heating and electricity needs. Yet there is various renewable technologies, and more specifically offshore technologies, being developed throughout the world, and implementation of such technology on-board an oil rig could help reduce the rigs overall carbon footprint and potentially lead to savings within the companies that own the offshore platforms.

The dwindling of oil stocks has created a worldwide demand for an alternative sustainable energy source; oil and gas companies have the revenue to research such alternatives, a lot of which are renewable energy sources. The present moment is characterised by rising costs in using fuel for production and so large companies are more motivated than ever to look for an alternative. Implementing renewable technologies which could sustain life on-board the rig could provide a screening and development process for new and existing renewable technologies, helping towards the successful development of a future sustainable energy source.

This thesis therefore, will look at the impacts associated with current oil production trends. Both reviewing suitable offshore renewable energy systems and offering potential solutions for improvements that could lead to a reduction in the carbon footprint of an operating oil rig

2. Current Power Sources on Offshore Oil Rigs

Many offshore oil rigs and platforms consist of detached living and working areas, sometimes located on separate platforms on larger rigs, *Figure 1* [3]. Heavy duty drilling and extraction machinery operates in the working area and is usually powered by high-performance diesel generators. The majority of electricity and power for other operations, including demands made in the living and recreation areas, come from small-scale aero derivative gas turbines. In optimal conditions oil rigs must function constantly. 24 hour operations are desired in order to maximise output, and so the fuel sources required to power all facilities on-board have to be constantly replenished. This can come from pipelines running to land from platforms located relatively close to shore, or from fuelling ships that make the journey out to the platform in order to refill all fuel stores. The constant refuelling process only adds to the overall carbon emissions of an oil rig as the fuelling ships burn through 10's of tons of fuel [4], a seemingly counterproductive move given that their sole purpose is to provide more fuel to the rig to burn through.

Figure 1 Image of North Sea Oil Rig [3]

2.1. Diesel Generators

Diesel generators provide essential power for drilling and extraction machinery on-board an offshore platform. The higher efficiency associated with diesel fuel is one reason for this utilisation, as well as the fact that many drilling rigs will have access to cheap fuel from the petrochemical companies they are supplying the crude oil. The functionality and durability of these generators is yet another reason why they are still the favourite for machinery power generation.

Because diesel engines play such an integral part in the production of oil, many companies accept the high fuel bill that comes with running these generators. However many old and especially new diesel generators can be retrofitted to operate on a dual fuel mixture, in which the engine makes use of a diesel and natural gas combination, significantly reducing the fuel bill as more of the cheap natural gas can be used in place of the significantly higher priced diesel fuel. Dual fuel diesel generators arise from normal diesel generators, but with the addition of a dual fuel hardware that allows for addition of natural gas and air into the combustion chamber, *Figure 2* [5]. When operating in dual mode, natural gas enters the intake system and is drawn into the cylinders, where an injection of diesel fuel into the compression stroke allows for combustion which in turn ignites the natural gas mixture [6]. Depending on the ratio of diesel to gas looking to be used, some newer diesel generators can function off the shelf utilising a dual fuel mix, with about 30% of liquid petroleum gas (LPG) to the diesel blend.

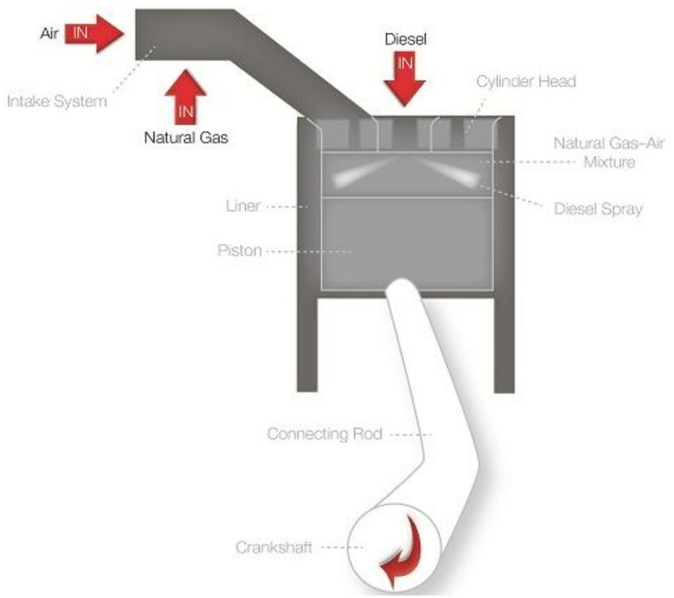


Figure 2 Function of a Dual Fuel Diesel Generator [5]

As depicted in the figure above, additional single fuel and dual fuel diesel generators are essential for emergency power requirements, in situations when one of the gas turbines or hybrid diesel generators may have failed or in an emergency situation when all gas intakes have to be closed for safety reasons. Back up emergency generators provide vital emergency lighting and safety systems, without which there is a serious potential for injury or worse.

2.2. Gas Turbines

In addition to the diesel and dual fuel generators on-board, many offshore platforms make use of aero-derivative gas turbines for electricity and heating requirements on the platform, because of their economic and space saving values. Gas turbines allow for continuous and relatively efficient power generation in spaces that other high intensity power production may not be suitable. The gas turbines are fuelled by natural gas usually in the form of liquefied natural gas (LNG), which is transported to the platform by piping or supply ships. Whilst the gas turbines play a lesser role in power production in the sense that they provide power mostly for electricity needs as opposed to the fuel thirsty production machinery, nonetheless they are required to run 24 hours a day, seven days a week like the diesel generators, and so multiple turbines are often run at one time to allow for maintenance and repairs to take place without halting operations..

Smaller deep water rigs tend to outsource the gas required to power the turbines on-board because of their hard to reach location or lack of infrastructure for onshore fuelling pipe connections, however advances in purification methods and the realisation that the gas being flared is a viable fuel source has allowed some rigs to make use of the associated natural gas (AG) extracted in the mining process directly. Near shore rigs can transport the impure gas extracted on shore for treatment and decontamination into a usable fuel that can then be fed back offshore to the platform and run through the turbines. When located further offshore, some larger and more technologically advanced platforms can process the gas retrieved on-board for use in power generation [7]. The development of microturbine technology since the 1990's has allowed, depending on the gases present, the ability to make use of the AG retrieved with little to no treatment [8]. Microturbines are small and compact gas turbines that can fit easily onto almost any offshore platform that does not have direct access to power from on shore or a nearby power source such as a floating production storage and offloading ship (FPSO). They range in size from 200kW to 1MW systems [9], and would allow for rigs to swap between LNG and AG retrieved when available, as high levels of waste gas might not always be accessible.

3. Impacts Associated With the Functions of an Oil Rig

From the outset the physical existence of an oil platform as working structure, both onshore and offshore, is a noteworthy pollutant to the natural landscape they are situated in. In spite of environmental degradation being the overwhelming focus in pollution associated with oil rigs, there are other forms of pollution associated with oil and gas platforms that can have less long term negative effects. Visual and sound pollution, depending on their location, can have significant effects on populations within their vicinity, effecting human populations and local wildlife, sometimes having an effect on that areas ecosystem. But in keeping with the subject at hand, the large offshore oil and gas platforms located in many different waters across the globe have a detrimental effect in all the oceans they are located, having a potentially severe immediate effect on the environment surrounding them. The placement of offshore rigs disturbs the sea life neighbouring it and as the drilling bits dig deep into the ocean bed, it can release toxic gases and liquids buried deep beneath that can affect ocean life and associated sea creatures. The extraction and processing of oil to produce fuel for the world, in itself, burns thousands of gallons of petrol, diesel and gas in the process, expelling vast amounts of greenhouse gases and other pollutants high into the atmosphere and into the surrounding lands, which in some cases can be the settling location for human life. The impacts caused by these structures are wide-ranging, and many are outside the scope of this paper. For the purpose of this investigation the focus is specifically on the environmental damages, with particular reference to atmospheric pollutants.

3.1. Environmental Degradation

With almost all industrial processes having a detrimental impact on our environment, the production of Carbon Dioxide (CO_2) in their operations is the greatest factor condemning them. Oil rigs operate to provide materials to fuel many mechanical and manufacturing processes on earth, with oil production reaching 90 million barrels per day in 2013 [10]. In doing so the world's oil platforms produce millions of tons of CO_2 in the course, emitting 14.2 million tons of CO_2 offshore alone in 2012 [11], only for the factories and operations they are supplying to have the same negative effect on our environment, as they combust the fuel oil supplied to them to produce yet more CO_2.

3.1.1. From Oil Rigs Power Source

As above, the main sources of power generation on-board offshore platforms are diesel and dual fuel generators as well as gas turbines. Both of these processes result in addition of CO_2

to the atmosphere as the fuels are burnt for the energy harnessed within. CO_2 is a greenhouse gas (GHG) and like all greenhouse gases it 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 [12]. On top of this, the aero-derivative gas turbines used for electricity generation on-board produce a lot of waste heat in the process. Whilst some more advanced and larger rig structures make use of this waste heat for combined heat and power production (CHP), as well as reusing these high temperatures to improve the gas turbines efficiency, many rigs simply let the hot by products out into the atmosphere, and with exit temperatures as high as 500°C [13] this can affect the surrounding environments.

With all the atmospheric pollutants rigs produce, some severe consequences can arise from the exposure of crude oil extracted to the environments surrounding. Despite strict safety measures in place, oil spills still occur, and the effect they have can be vast and disastrous, costing millions of pounds to rectify, such as the BP Deepwater Horizon spill that was estimated to have poured 4.9million barrels of oil into the Gulf of Mexico [14] and cost upwards of $40Billion in clean-up costs and fines [15] [16]. Stormy seas when the rig requires refuelling can also spell disaster. The oil platforms offshore refuel straight from large refuelling ships that extend fuel lines to the rig for offloading. Unexpected storms and rough seas can cause the connection between both to be severed and end in gallons of fuel being dumped into the ocean as the boats lines are ripped away from the rig.

3.1.2. From Gas Flaring & Venting

Flaring and venting in the past occurred with much more intensity than now as oil companies disposed of the seemingly useless and burdening gas that was retrieved in the process of oil extraction. The carelessness of these actions led to the pointless disposal of a much needed fuel, but the disposal outweighed any costs of treatment required and so senseless pollution of the earth's atmosphere occurred. As policies have become stricter and the potential harvested within this gas has been realised, many companies, such as *General Electric* (*GE*) [17], make use of associated natural gas for on-board power generation, or as a separate means of capital. But not all functioning rigs can make use of this AG and many have to flare or vent the gas retrieved for safety reasons or lack of infrastructure to store or transport the valuable fuel onshore for transformation.

3.1.3. Definition of Terms: Flaring

Flaring is the process of combusting the natural gas retrieved in the course of routine oil and gas operations, and the overarching goal of this process is to convert the raw substances present in the retrieved AG into their safest possible form, which in this case is CO_2 and water vapour. Whilst technology has developed, and refining this impure AG has become possible, many smaller or distant platforms lack the infrastructure for processing or transporting the AG recovered on-board and so have to resort to flaring or venting when the gas builds up. Flaring occurs for a multitude of 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 gas is collected from the underground wells where the oil is present, and travels up towards the surface where it enters the flare stack located at the extremities of offshore platforms, *Figure 3*. As *Figure 3* demonstrates, flare stacks are tall, sometimes angled, visible structures. Not only is a flare stack a visual pollutant, stacks generate a lot of noise and heat during their operation.

Figure 3 Flare Stack on an Offshore Rig [18]

The flare stack itself is a complex design to ensure safety and help burn efficiency at the tip of the stack, *Figure 4*. A high burn efficiency is required to make sure that all associated gas retrieved in the oil extraction is completely combusted, and so plumes of highly toxic gases do not find their way into the closely located working environment. This is achieved with a specialised flare tip design that assists entrainment of air or steam into the natural gas mixture [19]. Addition of air and or steam into the AG helps create a smokeless flame and enhances burn efficiency, with air entrainment achieving the highest level of combustion [20]. One of the main safety features present in the flare stacks design is the inclusion of flash back prevention sections, to stop the flame travelling down the flare stack towards the collecting AG. Just below the flare tip there is a section to prevent flashback into the rest of the stack, with a secondary prevention located at the bottom of the stack in the form of a water seal drum [21]. As seen in *Figure 4*, resting at the bottom of the stack is a vessel used for drawing any oil or liquid present in the gas mixture out prior to combustion, known as a knockout drum, allowing continuous and uninterrupted burning of the AG as it enters the stack .

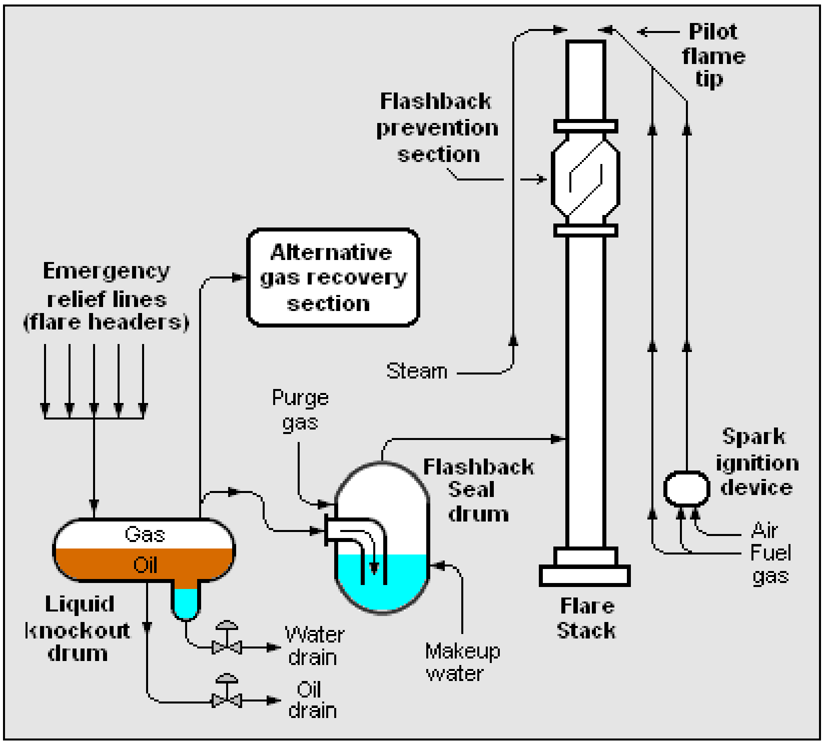


Figure 4 Flare Stack Schematic [22]

Successful combustion of the AG mixture results in water vapour and CO_2, a damaging greenhouse gas, but arguably less harmful than the un-combusted AG mixture being let off into the atmosphere (vented).

3.1.4. Definition of Terms: Venting

Venting offshore is a process to prevent and relieve the build of retrieved gas in the oil extraction process, the alternative to flaring, and it involves high pressure ejection of the AG retrieved in a structure similar to a flare stack. The gas travels towards the ‘vent stack’ were it undergoes high pressures to increase its escape velocity from the stack tip. This ensures that the gas clears a distance away from the oil platform, where it can naturally dilute with the air and dissipate so that it becomes non-flammable and there is no risk of explosion. Venting is the preferred option when the AG holds to much moisture and will not efficiently burn [23].

Like the flaring process, venting can be noisy as the pressurised gas exits the stack, however other than 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 AG in its un-combusted form can contain some toxic gases, gases that are more detrimental to the environment in their unreacted state.

3.1.5. Impacts Associated with Gas Flaring/Venting

The impacts and effects of gas flaring and venting are not too dissimilar in the sense that both result in considerable pollution of the atmosphere. However the severity of pollution from the end products of both differs greatly. In flaring, successful combustion of the AG recovered results in addition of CO_2 to the air, a well-known greenhouse gas, in addition to many kW’s of waste heat energy that could be otherwise utilised. Conversely, when the process of venting is favoured because the moisture content is too high within the extracted gas, the vented gas can more often than not contain gases that fair worse than the after effects of CO_2.

The associated gas retrieved from the oil extraction is composed of light hydrocarbons including methane (CH_4), ethane (C_2H_6), propane (C_3H_8) and butane (C_4H_{10}) [24], *Figure 5*, as well as water vapour, hydrogen sulphide (H_2S), Nitrogen (N_2) and CO_2 amongst other impurities.

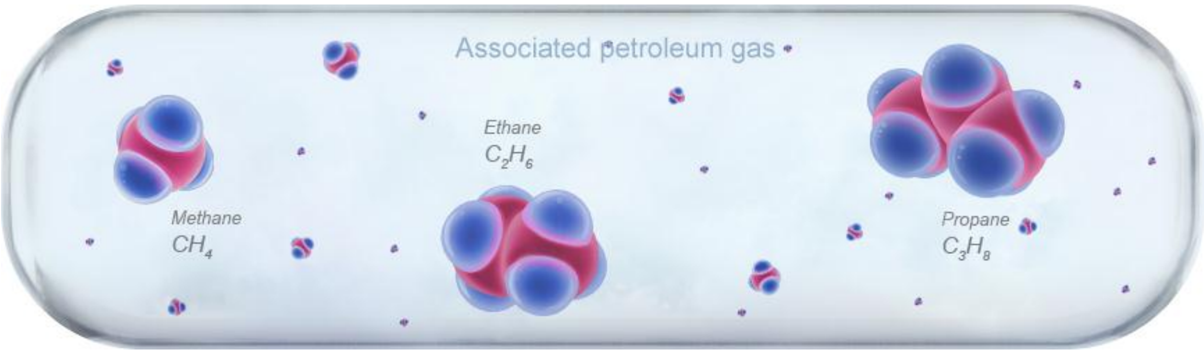


Figure 5 Elements of Associated Petroleum Gas [25]

The by-product gases released in flaring depend on how efficiently the AG is combusted. The intended product of combustion is water vapour and CO_2, the safest form the components of the AG can be converted to. However, 100% efficient oxidisation of the gaseous substance at all times is unlikely, resulting in some of the harmful hydrocarbons getting released without combustion, as well as part combustion. Consequently carbon monoxide (CO) and various other potentially harmful gases such as sulphur dioxide (SO_2) and nitrous oxide (N_2O) [26] are produced: causes of acid rain. The intentional release of CO_2 into the atmosphere may seem irresponsible, however methane present in the hydrocarbon mixture causes more harm to our environment than it would if it was oxidised to produce CO_2, *Table 1* [27].

Table 1 Effect of Greenhouse Gases [27]

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

[1] "The Global Warming Potential (GWP) provides a simple measure of the radiative effects of emissions of various greenhouse gases, integrated over a specified time horizon, relative to an equal mass of CO_2 emissions."
[2] "Changes in radiative forcing since 1750 represent changes in the rate per square meter, at which energy is supplied to the atmosphere below the stratosphere."

As can be seen from the table, the effects of methane in the atmosphere are 28 times more damaging than that of CO_2, and would incur global warming effects at a much higher rate, hence the importance of utilisation of this AG be it flaring or processing for use as a fuel for power generation.

Chapter 2

4. Existing Reforms to an Offshore Platforms Power Source

The knowledge that offshore oil and gas platforms are harming our planet is not new. Whilst papers have been submitted which underline this fact like ‘The Potential Impacts of Oil and Gas Production’ [28] [29], few academics around the world, such as Svendsen et al [30], have investigated the ways in which renewable energy could be utilised to power these large and energy-zapping rigs, with the average production platform consuming 1500-2000 gallons of diesel per day [31]. Despite some progress in renewable energy research, the existing discourse is undeveloped. Remaining at the hypothetical stage, offshore rigs continue to operate on priorities which maximise economic profit – whatever the cost, environmental or otherwise. The realisation of the associated natural gas’ energy potential has had an impact in reducing overall fuel wastage and greenhouse emissions on some high output rigs. Yet despite restrictions and regulations in regards to pollution control becoming tighter by the day, these barriers do not lessen the oil companies’ main interests to operate at the cheapest possible level to maximise profit outputs, and as far as fuel consumption goes, this means making use of fossil fuels to power production.

4.1. Addition of Renewables

The majority of investigative papers published that analyse the possibility and potential for a renewable energy solution to the power supply of offshore platforms look at the possibilities afforded by wind power. The wide-scale and longitudinal research carried out by Wei He et al [1] and Kolstad et al [2] exemplify this point, as their papers recommend making large wind farms to create power for a large cluster of platforms. This proposal would likely be achieved through creation of a microgrid, where interconnection of clusters of oil platforms in existing oil fields would occur, and this microgrid would then be connected to a large offshore wind farm [2]. Existing case studies confirm that Wei He [1] and Kolstad’s [2] recommendations have great potential to generate hundreds of MW’s renewable energy. For example the offshore capacity alone of the UK is in the range of 3500MW’s with 26TWh of renewable wind energy produced so far [32]. Yet despite the environmental benefits associated with these proposal’s, this layout would require retrofitting multiple offshore platforms located in an oil field, and that oil field would presumably have to be positioned near if not next to a large offshore wind farm. Although Wei He and Kolstad’s ideas are promising, questions must be asked relating to the quantities of remaining oil reserves in existing oil fields which have multiple rigs extracting from them. Moreover, the longevity of such sites (like the Miller oilfield that produced from 1992-2007 [33]) is called into question and resultantly troubles the viability and validity of retrofitting reform.

Wei He et al [1] take advantage of the advancements in offshore wind technology, looking at how new structures sustaining floating wind turbines, which permits 2MW turbines to be situated in far deeper water than previously achievable, allows them to be positioned in the vicinity of deep sea offshore rigs. Floating turbine technology would enable immediate power to that rig or rigs, as well as potentially supplying the onshore grid with the excess renewable energy. The investigation reviews the operational benefits in reducing harmful gas emissions, the electrical stability of the offshore grid and the technicality of the proposed project. Whilst this is a viable solution to the carbon footprint reduction of offshore rigs, the infrastructure and revenue required for such a project would require tens of millions [34]. There would be associated benefits with such a project, like the ability for it to show any petrochemical companies involved in a new light, yet it does not seem to be a feasible investment for any oil company that might become involved, particularly with the short lifespan predicted of the world's remaining oil supplies. The financial investment involving installation of a single floating turbine in interconnection with a larger rig found in deeper seas might be a more acceptable cost to part with for any oil companies involved, as the fuelling costs for such structures is multi-million pounds per year. Whilst the investment for such a project would be high, the payback period in line with the years of mining remaining in these locations might provide a reasonable and suitable energy alternative for these mega rigs.

Another, more unconventional, power production solution in the industrial sector is a solar powered system developed by *Seldon Energy* [35] that boasts the ability to provide interruptible 24/7 power for smaller scale start-up rigs, or function as long term power relief system, helping reduce the diesel generator load of an existing site. However reliability of diesel generators for machining requirements, along with the questionable scale to which this technology can function is one reason it has not been deployed in high numbers. An alternative company supplying offshore rigs with solar power in the oil and gas industry is *WhisperPower* [36]. *WhisperPower* has provided 3 solar power systems to NAM (Nederlandse Aardolie Maatschappij BV), a joint venture between Shell and Esso formed in 1947 [37]. The system powers navigation lights, alarm/detection instruments and remote communication system on an unmanned oil/gas rig. The solar system comprises of a 1200Ah

Battery, 12kW generator, 10kW inverter and 10kW's of solar panels. This is definite progress in reducing the carbon emissions linked with the oil industry, as small as it might be in the grand scheme of operations. Yet combination of these existing technologies could be the key to providing a significant reduction in greenhouse gas production, reducing the carbon footprint of the world's offshore rigs.

4.2. Utilisation of Associated Gas

There is great potential for utilising associated natural gas which is retrieved in oil extraction. Over the years, companies such as *BP* [38] have begun to exploit recent advances in technology to harness the energy found in AG, which is then supplied as a fuel for many offshore production platforms. Not only does processing this gas help to convert the toxic mixture into a less harmful by-product, this process reduces the carbon footprint of some rigs that make use of their own processed natural gas as a fuel source; instead of flaring or venting gas as well as burning separate natural gas and diesel fuel for power, the AG can be utilised for power production and would cut down the overall carbon emissions associated with production on that rig. However, this technology is highly dependent on location and infrastructure, and so the alternatives such as microturbines, that make use of the raw AG extracted, could be the solution to the problem of wastage of this valuable natural fuel resource.

Microturbines function exactly like their larger gas turbine and aero-derivative counter parts, only on a much smaller scale and with the ability to utilise impure gases for fuel, *Figure 6* [39]. The contaminants present in the AG mixture effect the energy density of the fuel, however it is still able to provide a reliable source of power if there is a constant source of waste gas contained within the retrieved oil gas mixture [9].

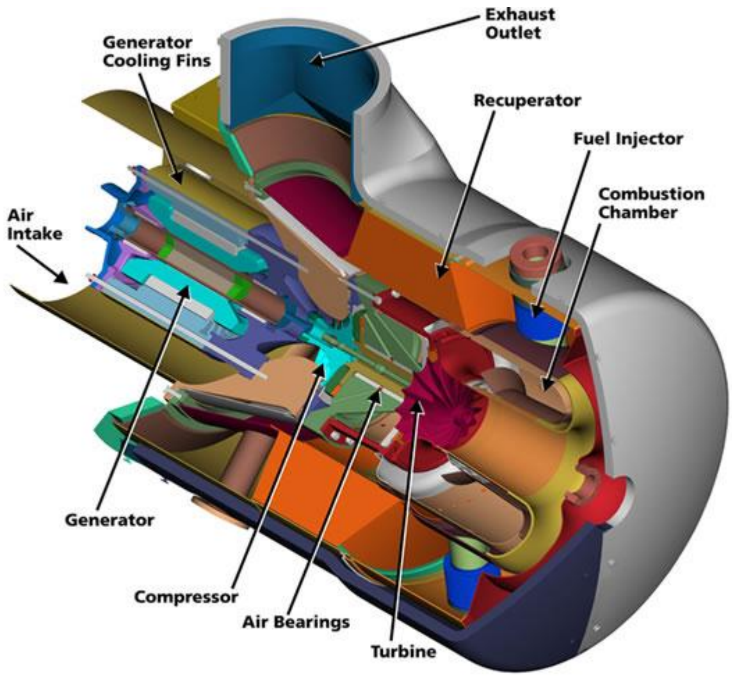


Figure 6 Schematic of a Microturbine [39]

As the gas is extracted from the crude oil, it is transported towards the combustion chamber of the microturbine, *Figure 7* [40]. Here it is met with hot, high pressure air after compression, and the air gas mixture is then combusted and expanded through the turbine to perform work, turning a generator to provide electricity. The hot exhaust gases from the turbine exit are then transferred through a heat exchanger to capture and re-use in raising the inlet air temperature, which increases efficiency and withdraws some waste heat from the exhaust gases.

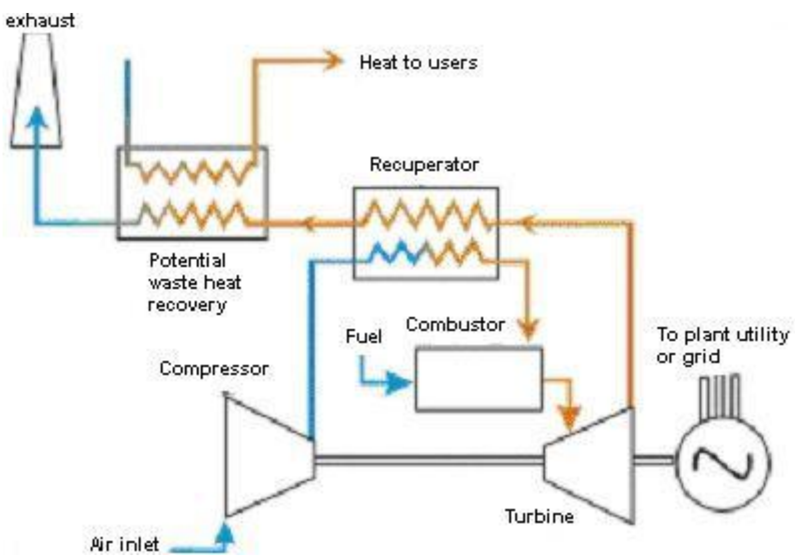


Figure 7 Internal Process of Microturbine [40]

The use of microturbines as a power source is growing within the oil and gas industry, and becoming the standard power source on many small scale rigs as an electrical power generation source. One such client making use of this technology is the *West Newport Oil Company*, as described in the Los Angeles Business Journal [41].

> On a marshy oil patch next to a gated Costa Mesa community, Chatsworth manufacturer **Capstone Turbine Corp.** has finally found a home.
> There, at the West Newport oil field, tiny **West Newport Oil Co.** is using a Capstone turbine generator. Fuelled by natural gas that comes up along with crude oil, the generator produces electricity that helps power oil pumps and other equipment.
> That natural gas, which comes in quantities so small it's not worth selling to a utility, normally would be "flared off" or burned at the site. Instead, West Newport uses the by-product to produce about one-third of the well's electricity needs.
> "The (small) amount of gas we produce, it's just a problem," said **Tom McCloskey**, operations manager for the oil company. "So we like to use what little gas we do produce to produce electricity in-house. It's a great advantage to produce your own electricity."
> It's the same story at oil and gas fields near and far, from Signal Hill in Los Angeles County to the deserts of southwest Texas to Russia's vast Siberian wilderness.

Quote from the LA Business Journal [41]

5. Review of Applicable Offshore Renewable Devices

Whilst the current market for retrofitting offshore platforms to make use of renewable energy sources is near non-existent, the functionality of these devices to produce immediate clean energy is something that must be considered for offshore power consumption. Many of the offshore devices in working order or in their testing and development stages make use of the natural resources out at sea (e.g. wind, wave and tidal currents) to create some form of movement in the renewable energy device, which either instantaneously converts the momentum into electricity via a gearbox and generator, or in the cases of some wave powered devices, make use of hydraulic fluid which is pumped and turns a generator again producing electricity. The assortment of offshore devices available has been reviewed for their applicability to power generation on an offshore platform and will analyse wind turbines, wave powered devices, tidal flow stream devices, as well as the application of solar PV systems for use in areas with warmer climates and higher direct and diffuse solar radiation.

5.1. Wind Power

Wind turbines both onshore and offshore are currently one of the most common and well harvested forms of renewable energy available. Wind turbines as a source of electricity generation have been in use for well over 100 years, where the technology was first developed by James Blyth of *Anderson's College* (now *Strathclyde University*) in Glasgow in 1887 [42]. Since then energy providers have been using wind turbines to generate electricity- preferred for their ability to function both on and offshore, making wind turbines an important resource in our hunt for sustainable energy generation. The power achievable from wind power has slowly increased as the technology has become more advanced; currently some onshore turbines are capable of 7.5MW rated power output [43].

However offshore wind turbines are significantly more powerful than their smaller onshore counterparts. The reasons for this relates to the development of the sub-structures and jackets they are resting upon, enabling offshore turbines to produce 10MW of rated power [44], 2.5MW more than the rated power of the largest onshore wind turbine. Techniques for supplying wind powered renewable energy to offshore rigs has been investigated but have not been seen as economically viable at this stage due to the large input revenue. Coupled with the financial barrier is the fact that clients are wary about investing in a project which has an unknown lifespan due to the diminishing amount of oil.

Exploration to look for new oil wells is ongoing and there is undoubtedly, still, a vast amount of oil to be harvested with 2013 oil reserve predictions at over 1500 Billion Barrels [45]. In the light of this it could be argued that renewable energy solutions should be of interest to stakeholders involved in new-build offshore rigs – where the investment may still be financially worthwhile to investigate the impact of adding a single large floating turbine, or a few smaller turbines to help with the power supply to living quarters and on-board electricity demands. Such an approach could also provide additional revenue for the companies involved as any excess, and unused energy could be transported onshore and input to the national grid. Depending on the lifespan of certain wind turbines, such a project could also serve as research into the potential of wind power at the oil wells location, giving real time information, which could later be used as a site location for an offshore wind farm to give a constant source of renewable power.

Implementation of wind turbines for power to existing or newly discovered oil fields would be a great advancement in reducing carbon emissions offshore, however smaller rigs making use of such vast structures is not quite feasible when at low production some of these mega turbines can still be producing 3MW of power. For smaller, self-sufficient rigs it may be more suitable to take advantage of the vast range of small scale wind turbines available for local power production. There is no shortage of wind turbine designs and different functionalities, and many are suited for mounting on top of buildings or in business estates etc. Therefore these devices could easily be mounted on an outer portion of an oil platform, or on top of the living quarters, the area that will require purely electricity for its energy needs. This solution would provide instantaneous power to the living area, and in stormy conditions or when there is a lack of wind, other natural technologies could be utilised, or if slightly larger the rig could make use of an array of devices for constant power generation.

5.2. Tidal Power

Tidal flow turbines remain in their early stages of development and do not have a very high rated power in comparison to the offshore wind turbines available. Resultantly, these turbines are not yet deployed in large numbers around the world. Tidal flow turbines are designed and function like an underwater wind turbine, where the tidal currents pass over the blades rotating the hub and turning a gearbox to spin a generator [46]. Like all renewable technology, tidal turbines rely on natural forces for power generation, except the forces related with power production in tidal flow turbines is not intermittent like wind, wave and solar. The wind does not always blow and the sun is not always shining, however tidal currents are influenced by the phases of the moons movement, and so can be reliably predicted [47] [48]. Another benefit to newly designed tidal turbines is that they can function in forward and reverse. This means that wherever they are positioned they can make use of incoming and receding currents, as the rotor functions both ways.

Tidal current devices require a minimum operating depth of approximately 15-40m, and so this makes them more suited to power supply on platforms slightly nearer to shore. Such a position would imaginably result in platform's receiving a minimal share of the power produced, as other land based applications would favour this renewable energy source located so close to shore, with the realisation that all power generated might be put into the main electricity grid. The tidal power potential of the world is vast, and the UK has the highest power potential in its surrounding coasts and seas at a rated potential of around 10GW, representing 50% of Europe's complete tidal potential *Figure 8* [46].

Figure 8 Tidal Potential of the World [46]

5.3. Wave Power

Wave power is a somewhat different type of renewable energy generation because it makes use of various movements and turbines for is electricity generation such as utilisation of hydraulic pumps that move as waves pass over them, which in turn produces electricity. It is an intermittent production device, and makes use of the wind conditions and their effect on the ocean's surface. Wave devices vary greatly in size in shape. Some are best used near to shore where waves break, creating great forces on the wave device, where as other, potentially more suitable devices for this investigation, can be used in deeper waters as they raise and move with the rolling waves far offshore. The greater suitability of deep-water wave devices is their ability to provide onsite generation, with all production fed directly to the rig.

In many cases deep water wave devices are harnessed to the sea bed and rest on the ocean's surface, reacting to the movement generated by passing waves. Whilst conditions in the North Sea are particularly suited to this type of energy generation because of the turbulent seas, some devices can understandably only function in certain conditions and are not well suited to rougher seas and stormy weather. The North Sea is notorious with rough seas and this would limit the energy potential of such devices as the *Pelamis* sea snake, where as other newly developed deep sea wave devices are in built with programs to react to changing weather and are durable enough to cope with rough seas.

The first *Pelamis P1* system was launched in 2004 and since then *Pelamis* have developed and created the P2 device, *Figure 9*. The device works by converting the wave energy interacting with the device into kinetic movement in hydraulic fluids throughout the *Pelamis* device. As shown in *Figure 9*, the P2 is constructed of 5 cylindrical floating sections measuring 180m in length and 4m in diameter and has a rated power of 750kW.

Figure 9 Pelamis P2 Being Tested in Open Water [49]

The two most suited devices to deep sea wave power generation that have emerged from recent advancements are the *Wave Dragon* and *AquaGens SurgeDrive* technology. Both systems are floating devices but generate power in very different ways. Firstly the *Wave Dragon* is one of the only developed wave devices that can be freely expanded depending on the wants of the consumer. The *Wave Dragon* makes use of a floating reservoir situated above sea level and created by the buoyancy of the device. There is an angled flexible edge that acts as a ramp and elevates the ocean waves into the reservoir. Here gravity plays its part and the waters want to flow back downwards towards the ocean cause it to flow down through multiple turbines to generate electricity at the source [50]. This system is extremely unique in the renewable energy market, as most offshore devices take extreme precautions to avoid the elevation of waves over the device, known as overtopping, *Figure 10* [51]. One of the huge benefits of this wave system is that it is preferred in deeper waters where there is greater movement in the waves generated by the wind. For example a rig located in the North Sea will incur some very rough and choppy seas, which happens to be the ideal setting for the *Wave Dragon*. To cope with the changeability of the sea surface and its constant alternation between choppy and rough seas, the *Wave Dragons* floating components are controlled by air cavities, which can fill and deflate to cope with the changing seas and therefore change in wave height. As it stands the wave dragon is still in its testing stages, however the single unit currently in testing is rated at 1.5MW.

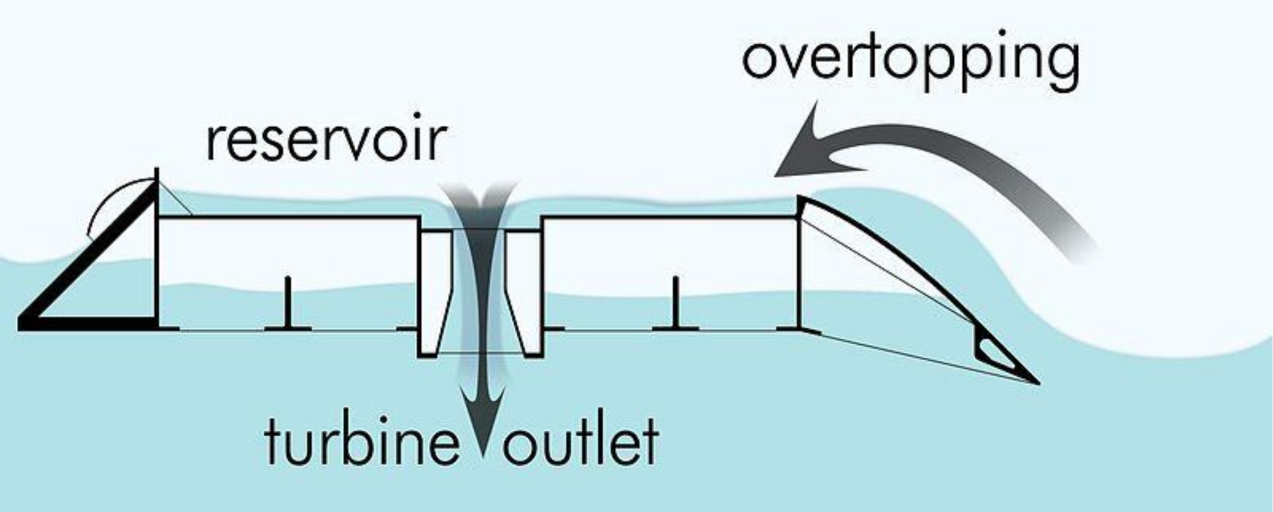


Figure 10 Functionality of the Wave Dragon [51]

Another example of a more suited wave power device is the *SurgeDrive* created by *AquaGen Technologies*. The *SurgeDrive* is comprised of a centrally located standing structure, similar to a very small oil rig substructure with only a helipad for landing to allow maintenance, *Figure 11* [52]. Surrounding the central rig is a number of floating buoys that rise and fall with the passing waves, and it is this movement that, once transferred to cables resting on the sea bed below, converts the pure wave forces into electricity via an energy conversion module [52].

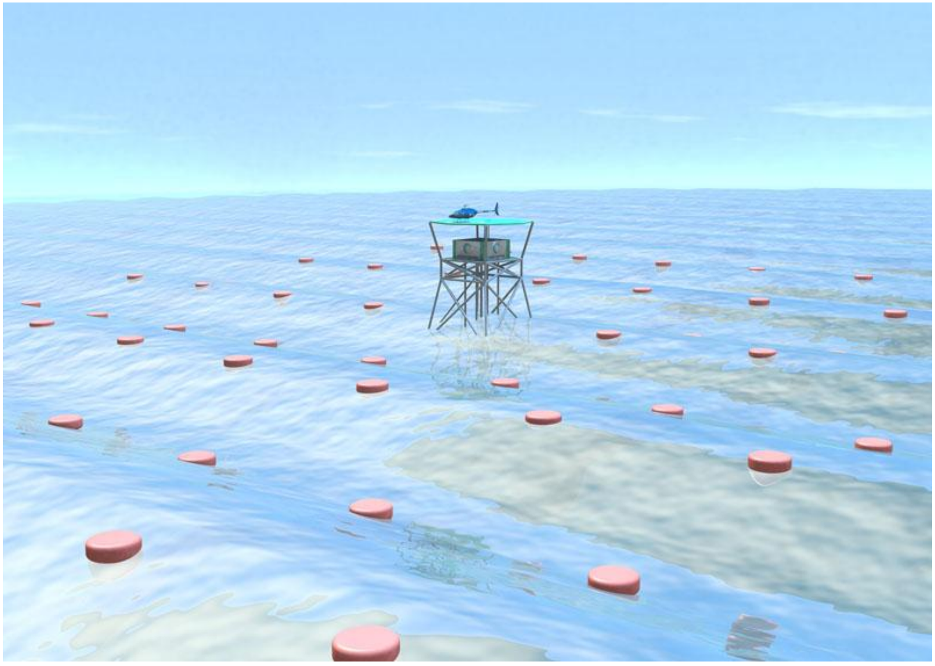


Figure 11 SurgeDrive Schematic [52]

Whilst this system is a free standing wave farm which uses a centralised structure, *AquaGen* have been working on the *RigDrive* system which specifically makes use of an oil rig as the centralised standing source, with the wave farm surrounding. A great benefit of the *SurgeDrive* wave farm is its storm survivability system. As the seas get rougher and waves gain in size, the buoys in the surrounding farm automatically retract below the surface and out of the extreme elements, protecting the wave device as it waits for the weather to pass and generation to resume. *AquaGen Technologies* claim that the limit to the *SurgeDrive's* power output is only limited by the marine environment surrounding, which suggests the ability for consumer expansion to potentially meet all electrical requirements, however pricing and power capacity is still unknown in this patent pending technology, so it cannot be cemented just yet as a potentially viable solution to the carbon emission problem of offshore oil production.

5.4. Solar Power

Much like wind turbines, solar photo voltaic (PV) and solar thermal panels are a well-known and well developed renewable energy technology available to almost anyone looking to retrofit their home or workplace to use less energy from fossil fuels.. Whilst not perfectly suited to northern climates and without ability to function to their full potential, utilisation of this valuable energy source is more effective closer to the equator in places that receive greater sun exposure. Solar thermal panels are something that would be greater utilised in the North Sea where there will be higher hot water and heating demands, however the conditions are more often than not cloudy and there is little sun exposure, letting very little direct radiation through.

Solar PV utilisation in areas nearer the equator such as the Gulf of Mexico could help satisfy a portion of electricity demands on a rig located in these waters. The real benefit of most PV modules is their ability to be added simply and efficiently to the façade of a building and even integrated as part of the cladding materials of a building as solar technology has advanced. This allows older structures the ability to make use of new technology without intrusive and vast retrofitting required to the buildings structure. This is extremely suited to a rig located in sunny waters, where PV solar panels could be rigged onto the living quarters directly to provide a steady and reliable renewable energy contribution towards the energy requirements of that area.

Solar thermal panels in southerly waters as well as colder northern climates can help reduce the energy expelled in hot water heating. Regardless of location, measures have to be taken in hot water storage to prevent legionella disease, and so most water systems are heated to 60° or above. However the levels of sunshine located off the Gulf of Mexico would allow for a lower temperature differential between the pre heated water after it has cycled through the solar thermal system and the temperature of the stored water.

Chapter 3

To effectively assess the demand of an offshore rig, the energy demands of a sample rig were calculated for analysis. The energy demands of the sample rig, referred to as Rig Strath, were split amongst living demands and production requirements, to assess the scale of energy required for each area on the platform. The demands were calculated for two different climates, to assess the effect this had on energy demands. Renewable devices were then reviewed for each climate, and there applicability to successful energy generation questioned.

6. Specifications of Sample Rig for Analysis

Without direct access to an offshore rigs energy demands and demand profiles, the energy data of a functioning hotel was manipulated and presented to match that of a functioning living quarters on an offshore rig. To ensure the data was within appropriate ranges, it was compared with the energy demands of a 140 man FPSO *Table 3*, provided by a PSVM (Plutão, Saturno, Vênus and Marte) Offshore Installation Manager for *BP* working in Angola. The living quarters of Rig Strath were assumed to be on a separate platform. In order to allow for 75 person groups to carry out daily 12 hour shifts, the housing requirement was stated as 150 people. Resultantly, the living quarters undergo two 12 hour working days in one 24 hour period. The working platform reflects this schedule with two 12 hour shifts. Although all processes on the working platform are assumed to be functioning constantly, the living quarters are characterised by energy spikes which coincide with regular events such as the serving of dinner or a demand for hot water for showers after shift.

For all renewable technology possibilities to be considered, and their functionality tested, a comparison will be carried out in two different climates; assessing the effect this has on renewable energy potential and its ability to satisfy energy demand. Firstly Rig Strath's power demand will be calculated for a platform located in the North Sea off the north-east coast of Scotland. Energy demand data will then be calculated for a rig located in the Gulf of Mexico, a much warmer and sun-blessed climate. The difference in demands will be calculated with regards to the climates effect on energy demands, where an initial energy load was calculated for the North Sea climate, and altered accordingly for the more southern Gulf of Mexico climate.

The dimensions of the living quarters are drawn with reference to a living quarter installation available for sale to offshore rigs [53]. An image of the rigs structure is shown in *Figure 12* and depicts one of the 50 man living quarters. *Table 2* lists the dimensions of the structure and the features of the four floors [53]. The main criteria of the living quarters on the majority of offshore rigs are; cabins (bedrooms), recreational area, kitchen, bathroom and showers, offices, and more common than not a gymnasium. All of these areas require lighting, heating and cooling and ventilation systems.

Figure 12 Offshore Rig Module [53]

Table 2 Rig Specifications [53]

	Dimensions (LxBxH)	**Material Used**	**Accommodation Capacity**
Technical Specifications	20.8mx32.4mx20.3m	Complete steel structure of weight 1653 tonnes	150
		Features	
45 2person cabins of 12.4 or 9.25m^2	15 4prson cabins of 13.9 or 10m^2	Aluminium Helicopter Deck designed for Sikorsky S-61N [54]	Male/Female Locker Rooms
36m^2 Tea room	135m^2 Mess room	36m^2 Fitness Area	44.1m^2 Health Office
93m^2 Recreation Day Room	75m^2 Smokers Recreation Day Room	180m^2 Control Room	3 36m^2 Office Areas

7. Energy Demands of a Sample Offshore Rig

The energy demands of the rig were split into North Sea and Gulf of Mexico. The surrounding seas and climate will result in a call for different renewable technologies at each location, and the comparison will show the broadness of devices available for power supply, as well as their suitability to this industry. In order to clarify that the sample energy demands are valid, the following FPSO living quarter energy demands will be used as a base case reference, *Table 3* (Beadie. G, 2014) and *Figure 13*.

Table 3 Average Hourly Energy Demands of FPSO in Angola (Beadie. G, 2014)

	% of Total Energy Use	**kWh Usage**
Galley (Kitchen)	5	20
Laundry	3	12
Heating, Ventilation and Air Conditioning (HVAC)	50	200
Lighting	13	52
Elevators	5	20
Safety Systems	8	32
Chillers	6	24
Sewage System	4	16
Water System	5	20
Radio Communications	1	4
Total	**100**	**400kWh**

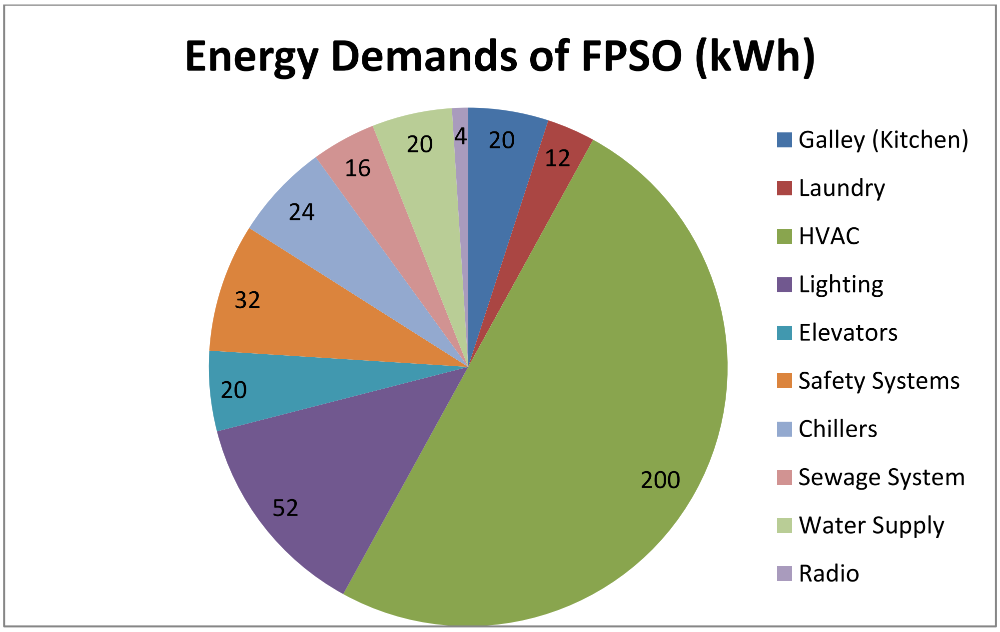


Figure 13 Chart Showing Ratios of Energy Demands in Living Quarters

The energy demands on-board Rig Strath will be split amongst electrical living demands, including heating, and production demands with machinery loads. In order to integrate renewables more effectively, the demand load should be a constant value, as fluctuating demands with intermittent energy production can prove hard to satisfy.

7.1. North Sea

North Sea oil and gas platforms are primarily located off the North East of Scotland's Aberdeenshire coast, but do run further south as shown in *Figure 14* [55]. The conditions in this area are often cold and wet, with mild summers and harsh, dark winters that can affect energy demands and working conditions.

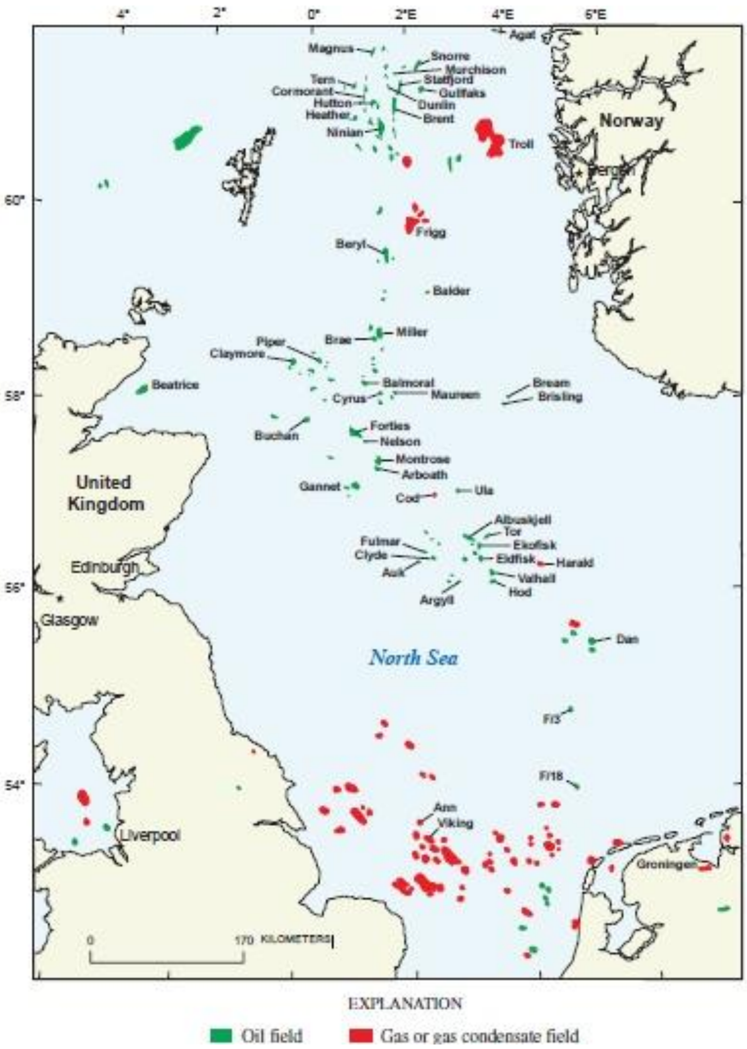


Figure 14 Distribution of Oil and Gas fields in North Sea [55]

7.1.1. Electrical Living Quarters

The ratio of electrical demand in the living quarters of the rig varies relatively evenly, with prevalence given to the heating demands and lighting requirements. Heating, ventilation and air conditioning (HVAC) energy demands are relatively constant throughout the day as temperature has to be maintained for people off shift residing in the living quarters. The overall HVAC demand required on a rig located in the North Sea is heating, with space heating and hot water requirements requiring the majority of energy for the living quarters. Air conditioning (AC) is most likely to occur in the gym area, but it will be a relatively small load in comparison and so will only result in a slight addition to the overall HVAC demand.

Table 4 shows the various electrical demands and the ratio split of each for the living quarters of a North Sea located rig.

Table 4 Average Hourly North Sea Rig Strath Living Quarter Demands

	% of Total Energy Use	kWh Usage
Galley (Kitchen)	7	35
Laundry	2	10
HVAC	45	225
Lighting	15	75
Elevators	2	10
Safety Systems	8	40
Chillers	7	35
Sewage System	4	20
Water System	4	20
Radio Communications	1	5
Recreation Facilities	3	15
Gym Equipment	2	10
Total	**100**	**500kWh**

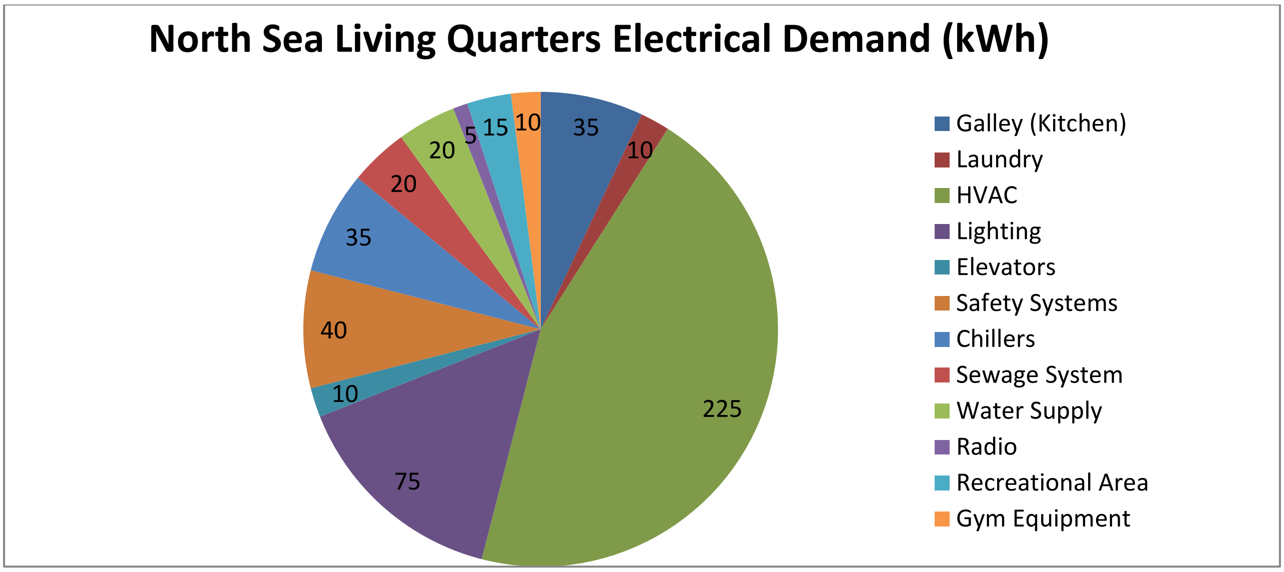


Figure 15 Chart Showing Ratios of Energy Demands in Living Quarters (North Sea)

The energy data of a functioning hotel was manipulated to generate the figure of 500kW for the overall living demand of the sample offshore rig, which was then cross referenced with the known FPSO electrical living quarter demands. A hotel containing 140 rooms was selected from a list of Singapore hotels [56].The data was altered to meet the demands of two 12 hour shifts as opposed to the one day shift experienced in a hotel. Compensation was subtracted for the swimming pool load that was present in the Singapore hotel, with extra taken off for the additional rooms available. The final energy demand of the hotel was 567kW, and so after subtractions from the hotels load the oil rig energy demand was calculated to be 500kW. This gives a yearly energy consumption of 4.38GWh.

7.1.2. Production Demand (Machinery)

The demands of the production platform are by far the most draining energy requirement, with electrical needs for lighting and safety systems adding to the machinery loads of the production area. The machinery and equipment in use on the production platform varies greatly, with machinery required for pumping and lifting objects, in addition to a multitude of various equipment and devices required for the oil extraction and containment process. There are additional loads for the separate facilities and equipment required for offloading on deep-sea rigs. The vast amounts of machinery on-board an offshore rig all require power and this comes from engines and generators running off fossil fuels located on the production platform. The production generators and power sources information supplied by *TransOcean* for their Sovereign Explorer drilling rig is shown in *Table 5* [57], and gives an understanding of the machinery energy usage that might be incurred on a production platform.

Table 5 Power Supply Specifications for Drilling Rig Machinery [57]

Machinery Power Supply	
Main Power	4xWartsila 12-V-25 diesel engines rated 3698 hp each, driving 4x 2640kW ABB AC Generators
Emergency Power	1x Cummins KT-2300 diesel engine rated 650 hp, driving 1 x 650kW ABB Stromberg generator
Power Distribution	Hill Graham SCR system, 7 Units, 1200 amps, 720V output
Deck Cranes	2 x Wolffkran HDK 1100HM electro-hydraulic cranes, 131ft boom, 55mt @ 66ft
Thrusters	2 x 2400kVA Kamewa azimuthing thrusters
Propulsion	As Above

Despite the Sovereign Explorer rig making use of diesel engines and generators for its machinery power, the majority of offshore platforms are fitted with aero derivative gas turbines and dual fuel generators for all energy needs. The energy demands were calculated using the information provided by the *BP* contact. The Angolan FPSO is fitted with four 22MW dual fuel gas turbines, as well as four diesel generators and one emergency diesel generator all on standby for additional or emergency power requirements. The FPSO typically runs two to three of the gas turbines daily, and so the daily output of two 22MW turbines was calculated to give a yearly energy figure. Two 22MW turbines running all day at 40% efficiency produces 422.4MWh per day. The living quarter's power consumption is 4.38GWh yearly and so the yearly average power consumption of the production platform equates to 149.8GWh

7.2. Gulf of Mexico

Oil and gas rigs located in the Gulf of Mexico are located off the southeast coast of Texas, running in parallel with the coast eastwards and down towards Mexico (See *Figure 16*). The climate in this area is often subject to high temperatures and sun exposure, with long dry summers from April till September and fairly mild winters in comparison to northern climates

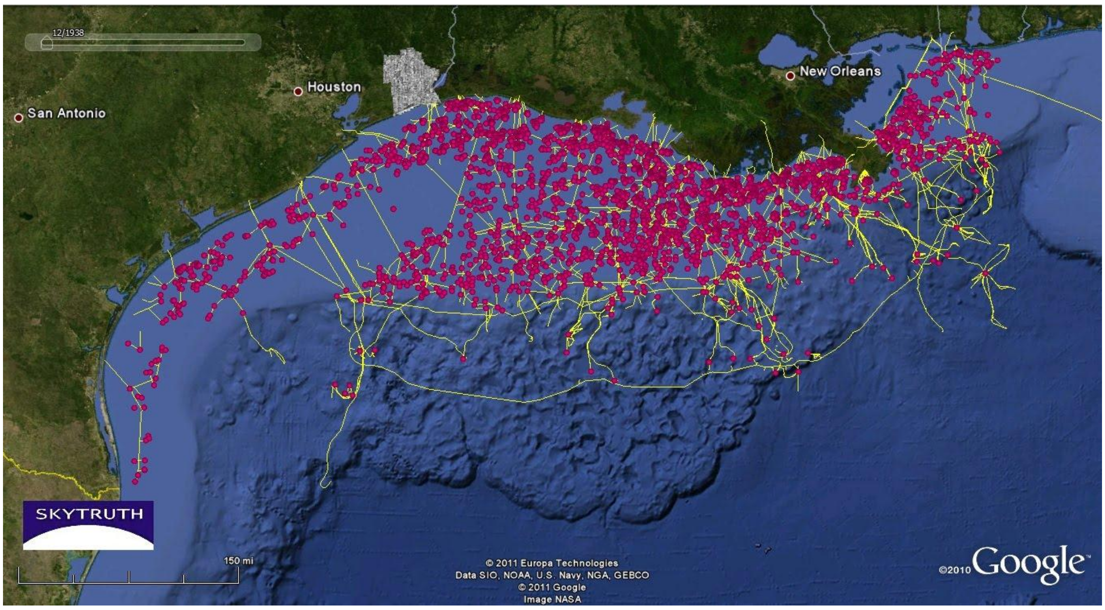


Figure 16 Active Oil and Gas Rig Location in Gulf of Mexico [58]

7.2.1. Electrical Living Quarters

The electrical energy requirements of the living quarters were assumed to be much like that of the North Sea located rig, with the exception of lighting, which was assumed to be a lesser load as there are longer and brighter days nearer the equator. The HVAC demand is assumed to be greater, as AC will be the main heating/cooling demand throughout the day and uses more energy than heating, as it produces waste heat in its process which has to be vented out. *Table 6* shows the living quarter energy demands of the Gulf of Mexico sample rig.

Table 6 Average Hourly Gulf of Mexico Rig Strath Living Quarter Demands

	% of Total Energy Use	**kWh Usage**
Galley (Kitchen)	7	35
Laundry	2	10
HVAC	48	240
Lighting	10	50
Elevators	2	10
Safety Systems	8	40
Chillers	8	0
Sewage System	4	20
Water System	4	20
Radio Communications	1	5
Recreation Facilities	4	20
Gym Equipment	2	10
Total	**100**	**500kWh**

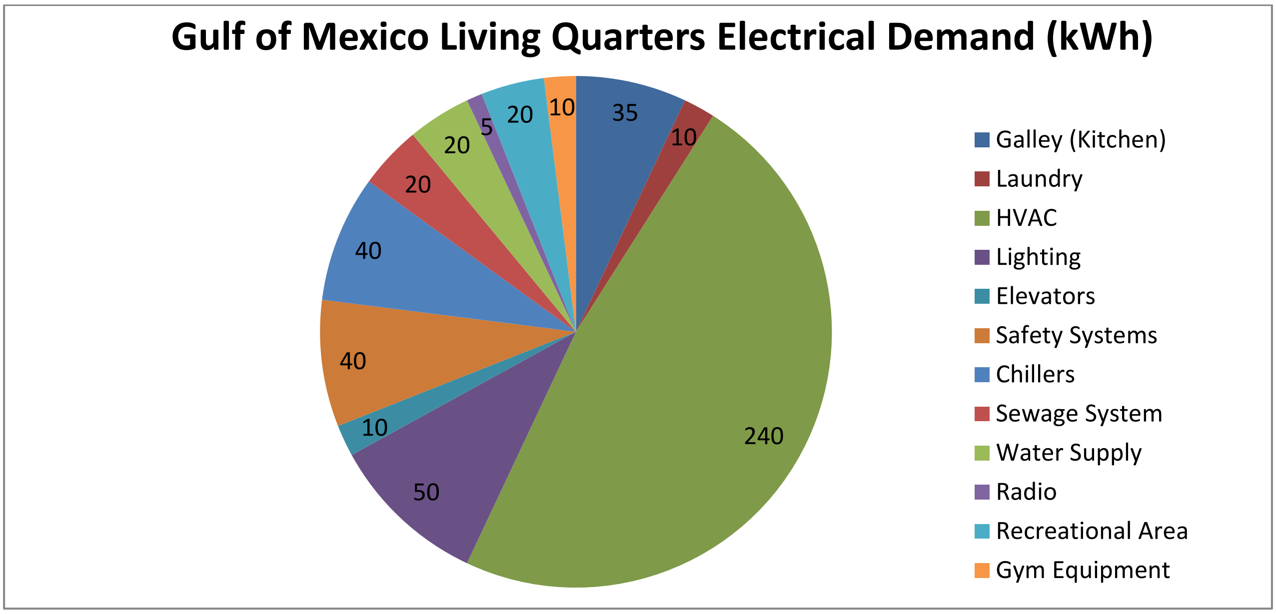


Figure 17 Chart Showing Ratio of Energy Demands in Living Quarters (Gulf of Mexico)

7.2.2. Production Demand (Machinery)

The equipment functioning on-board for extraction is assumed to be identical to that of the North Sea rig as they are both carrying out the same process, and climate was regarded as having little effect on energy consumption. Therefore the Gulf of Mexico rig also incurred 149.8GWh production energy consumption.

8. Conditions Offshore

Aside from financial investment costs and generation capabilities, the conditions experienced in offshore climates is one of the main deciding factors on which renewable device is most suitable for energy generation, if any. With oil fields located all over there world and in every which climate, see *Figure 18*, the renewable devices available for power generation vary greatly.

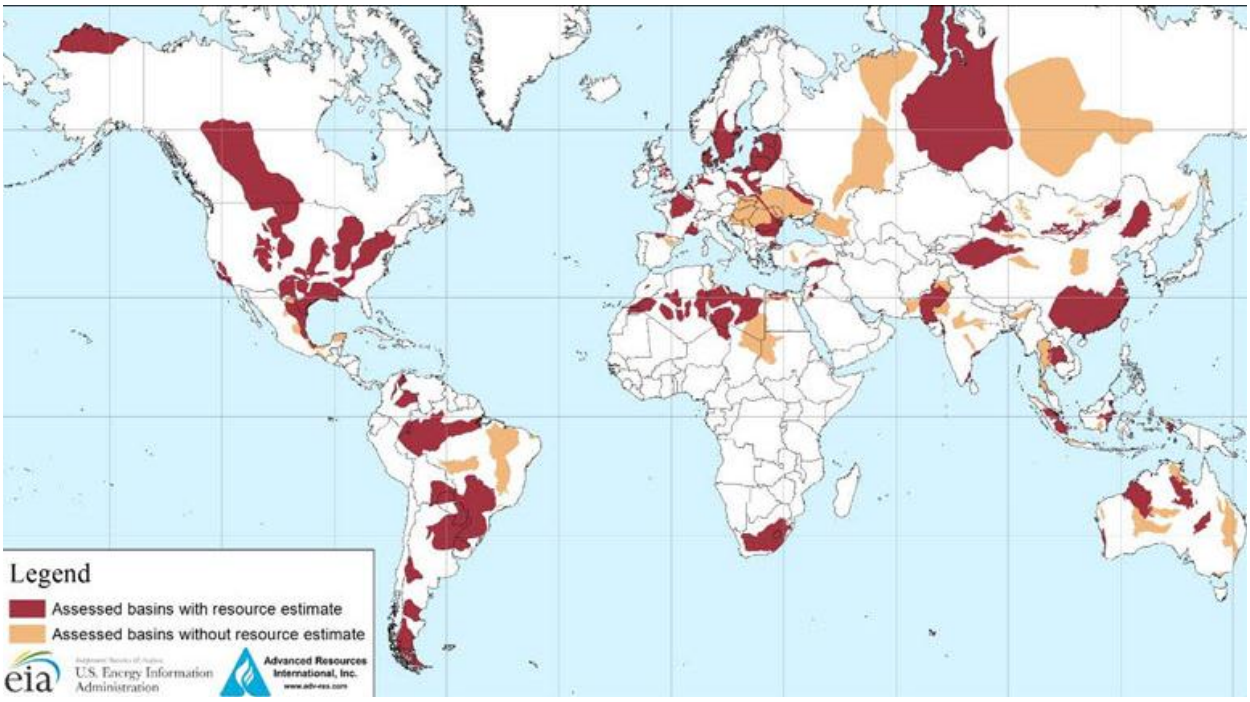


Figure 18 Map of Basins with Assessed Oil and Gas Formations [59]

The conditions in the North Sea give way to cold winters, resulting in snow storms and choppy seas. The harsh winters can make working offshore in the North Sea considerably harder, as workers have to work longs shifts while battling the cold winter elements. Yet this harsh weather can harvest a lot of power, which can be utilised by the renewable resources available. During the winter, waters of the north-east coast of Scotland can generate waves of heights ranging from 2-4m, see *Figure 19*. Whilst this can make sailing in these waters a challenge, the energy harnessed within these waves can be anywhere from 40kW/m of wave crest off the coast of Aberdeen up to 80kW/m in the waters surrounding the Shetland Islands, see *Figure 20*.

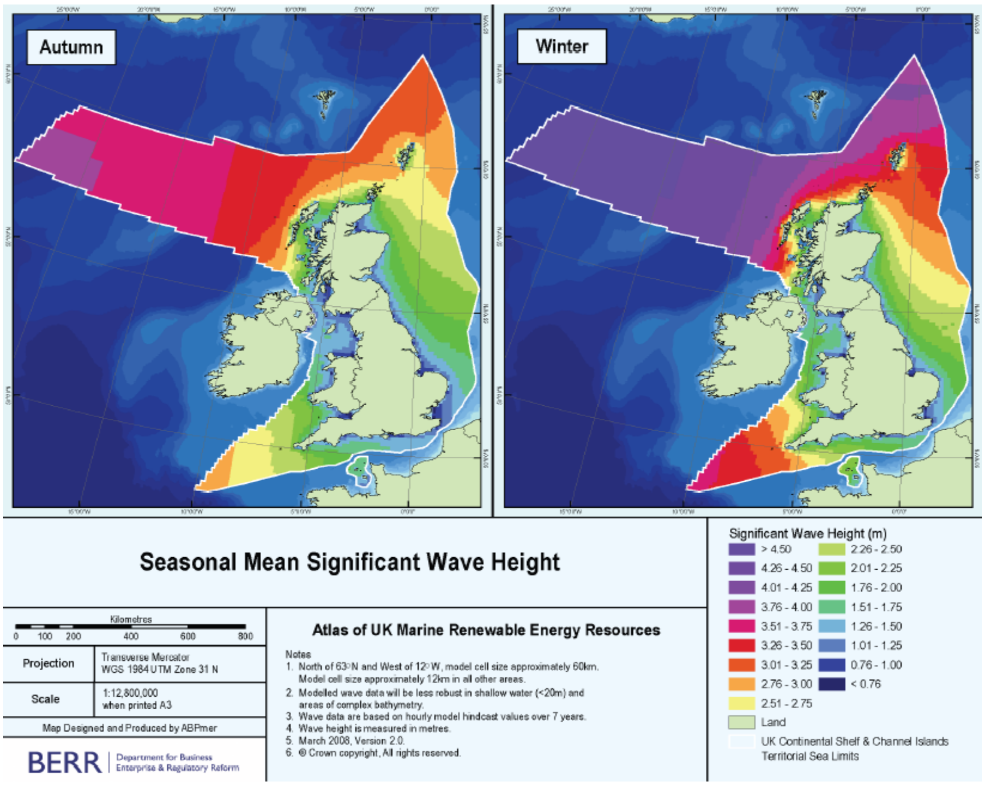


Figure 19 Seasonal Wave Height of UK Waters [60]

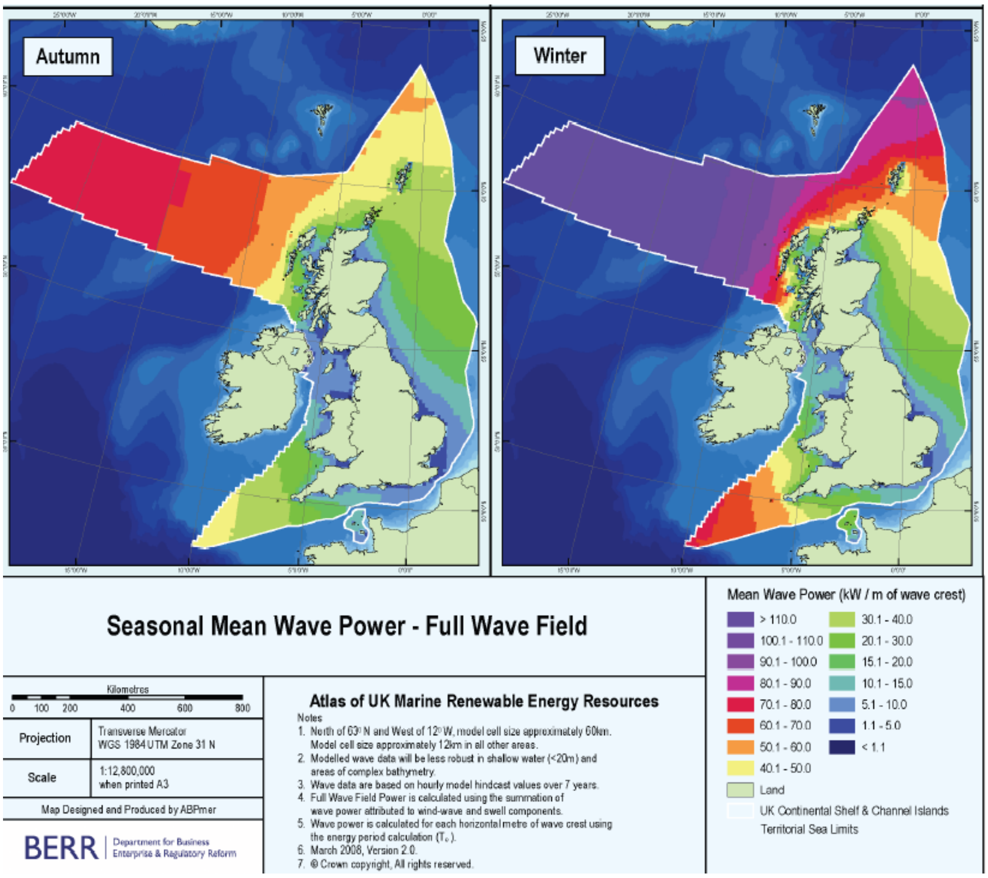


Figure 20 Seasonal Mean Wave Power of UK Waters [60]

The conditions in the North Sea favour wind and wave for power generation as the deeper, and significantly further offshore oil rigs would not suit tidal turbines as the tidal flows often take place closer to shore. Solar PV panels for electricity generation are also less likely to be efficiently utilised because of the lack of direct sunshine experienced in the northern climate as shown in *Figure 21*.

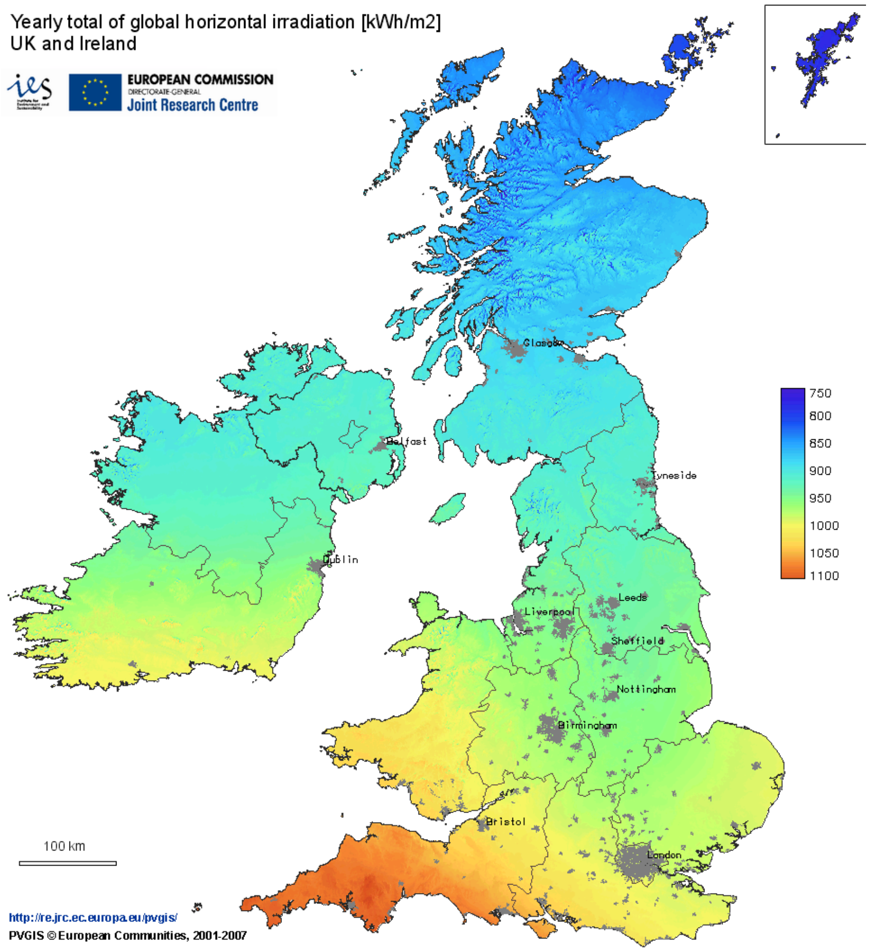


Figure 21 Yearly Mean Global Horizontal Irradiation of UK [61]

In comparison, the waters in the Gulf of Mexico surrounding Americas south-east coast can be relatively tame in the spring and summer months, where temperatures can soar to +35°C [62] and the horizontal irradiation experienced yearly can reach 1900kWh/m^2 [63]. However the waters of the Gulf of Mexico become a different place between the months of June and November, where the surrounding waters of the south-eastern coast of America face hurricane season [64]. The region has previously felt the disastrous effects of hurricanes as they gain power across the ocean on their path towards land. The effect of extreme weather on oil rigs in this region was seen in 2005 when hurricane Katrina made its way across the Gulf towards the American coast [65]. The Minerals Management Service (MMS) reported that 12 rigs were damaged in the storm, with at least 5 rendered unusable after severe damages. Nonetheless, a hot climate gives way to different energy demands than that of the North Sea rig, and could potentially allow for the introduction of a variant of different renewable devices from that of the north east climate.

9. Renewables Reviewed that can Satisfy Energy Requirements

The applicability of certain renewables and their ability to satisfy demand primarily depends on the portion of energy demands that they have to supply. If a renewable device was installed to satisfy 5% of the required energy demand of a building when working at full potential, then this device could be installed with relatively no intrusion as there would be sufficient supply from other sources to cover any losses in renewable energy production. It would also mean that any excess would not be of a significant loss to require storage. When the dependency of renewables for power supply increases, the intermittency of the technologies installed becomes a problem, as storage options for excess demand become a necessity. The reliance on the renewable device for power supply must also be questioned when the device is not producing enough power, and the building will have to rely on an external power source on standby as to not halt proceedings.

9.1. Renewables in the North Sea

Of the wave devices reviewed in Chapter 2, deep-sea initiatives such as *Wave Dragon* and *SurgeDrive* are most suited to the North Sea conditions. The process of the *Wave Dragon* which revolves around overtopping makes it particularly suited to the choppy conditions of the North Sea, however the storm survivability of this system is not defined in any literature, and so there is the possibility that large waves could destabilise the large floating structure. Thus the *SurgeDrive* would be the recommended device as production is increased with greater movement in the seas and it already integrates a storm safety system. The *Wave Dragon* could increase its suitability to offshore power supply by incorporating such a safety system as the *SurgeDrive*, which retracts under water in rough seas. The *Wave Dragon's* remote controlled flotation devices could be emptied of air bringing it below the surface and thus out of the harsh elements experienced in a North Sea storm, after which it could be remotely re-inflated and resume power generation.

Wind power in the North Sea is a well-developed technology and is implemented along the coast of the United Kingdom; however interconnection with oil rigs as discussed in Wei et al [1] is something that would require a large financial investment and time to do so, with the average cost of a wind turbine alone ranging from £1.5-3million per MW [66]. Regardless of the financial barriers, wind power is still one of the most probable renewable solutions for lowering the carbon emissions associated with rigs found in the North Sea. Although a sustained partnership between renewable energy companies and oil companies has not yet been practiced, many oil and gas companies have investigated renewables in the past, such as *BP* and *Shell* [67] [68]. However these investigations have been regarding small scale renewables, and so for effective action to ensue, the need for carbon reduction has to be stressed.

9.2. Renewables in the Gulf Mexico

The oceanic conditions in the Gulf of Mexico favour Wind, Wave and Solar power. There is a much higher direct sunshine intensity in this region of the world, with an average direct horizontal irradiation of 1900kWh/m^2. Rigs in the gulf could prosper with utilisation of solar PV panels, yet some high power solar devices such as the *Seldon Energy* device could prove too 'delicate' for such conditions when the storm season begins. Despite the potential for damage, oil rigs located in these threatened waters are developed and equipped to deal with stormy, rough conditions, and so utilisation of the high irradiation levels for power generation or hot water needs would help in the direction of carbon reduction in the Gulf of Mexico.

The threat of hurricanes during storm season rule's out the use of floating wind turbines near deep-water rigs as a permanent energy source, due to the risk of damage and potential loss of these multi million pound devices. However solid structure wind turbines exist offshore in the Gulf of Mexico [69] and so interconnection of wind power for rig power requirements is still a feasible option in the Gulf.

From the wave devices reviewed the *SurgeDrive* again proves most feasible because of its storm control measures. Whilst the climates of each location are so far apart, the forces of nature felt by each environment prove to be similar at times during the year. Resultantly the two technologies best suited for renewable power supply to offshore rigs in both environments are the well-developed offshore wind turbines and the *SurgeDrive* wave energy converter (WEC).

Chapter 4

ExxonMobil and *GE* rank amongst the top 10 companies in the world in measures of revenue and profit margins [70]. Resultantly, these firms have little financial justification for avoiding action to reduce carbon emissions of oil and gas rigs, especially where the technology is available. This chapter initially analyses the current price of fossil fuel energy production before assessing the cost of energy from a range of renewable energy devices which would be suited to offshore energy production for oil platforms. Subsequently, the cost of energy for the renewable devices is compared and contrasted against the cost of energy for the fossil fuels currently used by oil production companies, like *ExxonMobil* and *GE*.

10. Current Production Pricing

Every rig built is different, and so each rig operates with different machinery and makes use of different technologies for their energy production. Despite this, the majority of operating rigs make use of natural gas and diesel for generation. Whilst the fuel that rigs are receiving is either subsidised or produced ‘in house’, western fuel prices are used here to put the fuel usage into perspective. The fuel requirements for producing electricity for the living quarters, and the fuel consumption of the production platform, were calculated for analysis.

10.1. Living Quarters

The total demand of the living quarters is solely electrical and is provided from an aero-derivative gas turbine. The turbines efficiency and power output, as well as the cost of natural gas, were used to estimate the cost of fuel in powering the living quarters of the sample offshore rig. A daily fuel usage was calculated and a yearly average approximated.

The turbines run on the Angolan FPSO used 22MW dual fuelled gas turbines. Assuming there are no re-heat cycles or CHP recovery in place, the efficiency of such a turbine exclusively generating electricity would be around 40% [71]. With the load of Rig Strath’s living quarters estimated around 500kW, the consumption of the living quarters in one day is 12MWh. The price of natural gas to consumers is 4.9p per kWh [72] and the price of diesel is 13p per kWh, taking the price per litre of diesel to be £1.38 [73] and using the ratio of 11kWh/litre of diesel [74]. Using the estimated efficiency of the turbine, it would require 2.5 times of each fuel to satisfy the 12MWh daily demand. Assuming the dual fuel gas turbine produces half of the 12MWh energy demand equally from each fuel suggests that 6MWh of the energy is produced from natural gas and 6MWh is derived from diesel. The cost of the natural gas in generating 6MWh would equate to £735, and the cost of diesel would be £1950, with a total cost of £2685 in fuel charges per day.

For the purpose of this investigation it can be estimated that the fuel charge in generating electricity for the living quarters is £980,025 per year, omitting any subsidies that might occur in the process.

10.2. Production Platform

In order to calculate the fuel usage of the production area on Rig Strath, the energy information supplied by an offshore plant manager at *BP* for an Angolan FPSO was used to produce a figure for use in analysis. There are 4 22MW gas turbines on-board the FPSO with 2-3 running each day, as well as 3 auxiliary diesel generators on standby and 1 emergency diesel generator on standby. Using the fuel pricing figures above and subtracting the overall living quarter energy demands, the rest of the rigs power demands were calculated in terms of fuel use.

Two 22MW turbines running all day at 40% efficiency produces 422.4MWh per day.

Assuming each fuel generates half of the power required evenly, 211.2MWh comes from each fuel type.

The price of natural gas is 4.9p/kWh and so the cost of natural gas per day is

$$211200 \times 0.049 = £10{,}349$$

The price of diesel fuel is 13p/kWh and so the cost of diesel fuel per day is

$$211200 \times 0.049 = £27{,}456$$

Therefore total production fuel costs per year would equate to

$$((10349 + 27456) \times 365) - 980025 = £12.8 million.$$

11. Economic Analysis

The overarching aim of oil and gas companies is profit output; consequently any large cost which can be avoided such as the installation of a large renewable energy device will often be overruled if a cheaper option is viable. In order to compare renewable devices against the industry preferred fossil fuel counterpart, the cost of energy for each device must be calculated and compared to fossil fuel devices on-board the Angolan FPSO. The equation for the cost of energy was obtained from *Entec UK LTD's* report for the *Carbon Trust* [75]:

$$Cost\ of\ energy[\frac{£}{kWh}] = \frac{PV(Capital\ Cost) + PV(O + M\ Costs) + PV\ (Decommissioning\ Costs)}{PV(Energy\ Production)}[\frac{£}{kWh}]$$

Equation 1 Cost of Energy

where PV indicates the present value over the service life.

This simple equation allows estimation of the cost of energy produced from installation of a renewable energy device. However, other factors entailed in each of the three device costs are more complicated. The capital costs of the project would require an initially vast investment, followed by operation and maintenance (O&M) costs throughout the lifespan of the device. A final, immediate and pre-planned investment is also required at the end of the device's lifespan for decommissioning. *Table 7* shows the costs associated with the capital investment, and *Table 8* shows the costs associated with operation and maintenance of the renewable device.

Table 7 Capital Costs Associated with Renewable Energy Project [75]

Capital Costs	
Costs Incurred	**Components Involved**
Structure	Material Costs, Power Devices, Assembly
Mechanical & Electrical	Energy Conversion Devices, Generators
Project Management	Project Planning and Implementation
Mooring	Steel structures, Weighted Anchors, Water Depth
Installation	Ships to transport, Jack-ups, Lifting Devices
Grid Connection	Cables, Transformers, Switchgear

Table 8 Operational & Maintenance Costs Associated with Renewable Energy [75]

Operation & Maintenance Costs	
Costs Incurred	**Components Involved**
Planned Maintenance	Cost of replacement parts
	Cost of servicing vessels and personnel
	Shutdown cost due to weather conditions on ability to service device
Unplanned Maintenance	Cost of spares in case of failure
	Cost of emergency replacement parts if not available
	Cost of stand-by service equipment and personnel in case of failure
	Cost of emergency servicing and personnel
	Shutdown costs incurred while waiting for repairs

The costs incurred at each stage vary from project to project, but it is often the case that the structure and its mechanical and electrical components are often very costly in the production process of the device. *Figures 22* and *23* show an example cost breakdown for a sample wave device given by *Carbon Trust*.

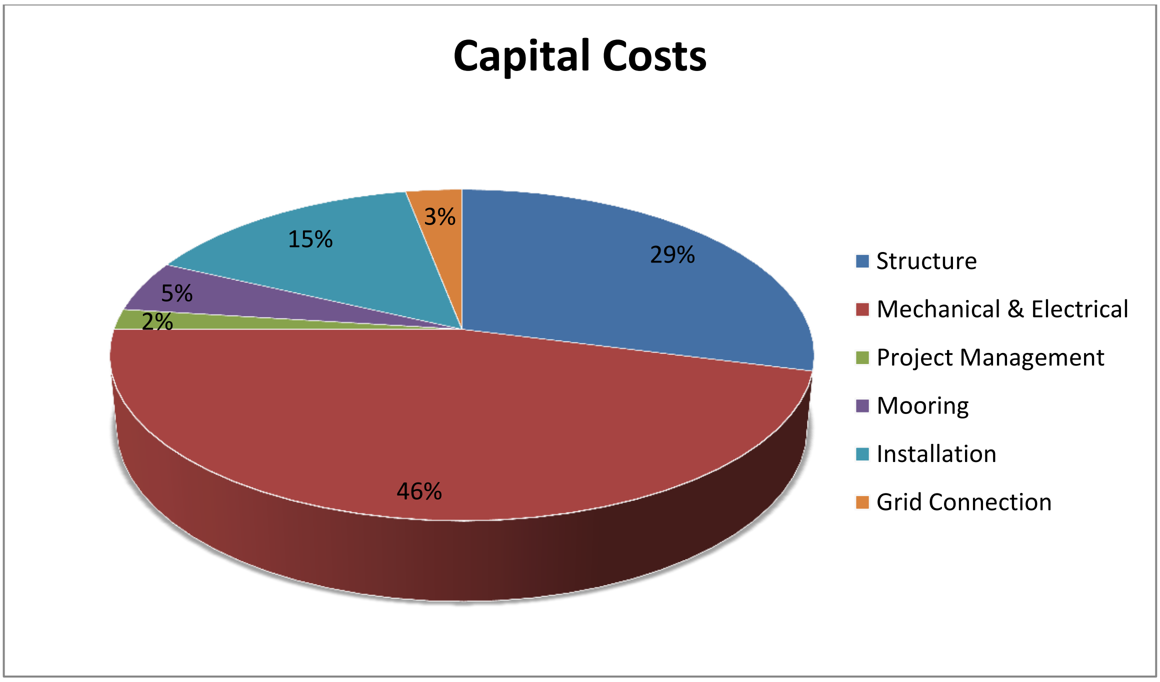


Figure 22 Capital Costs Associated with Installation of a Renewable Device [75]

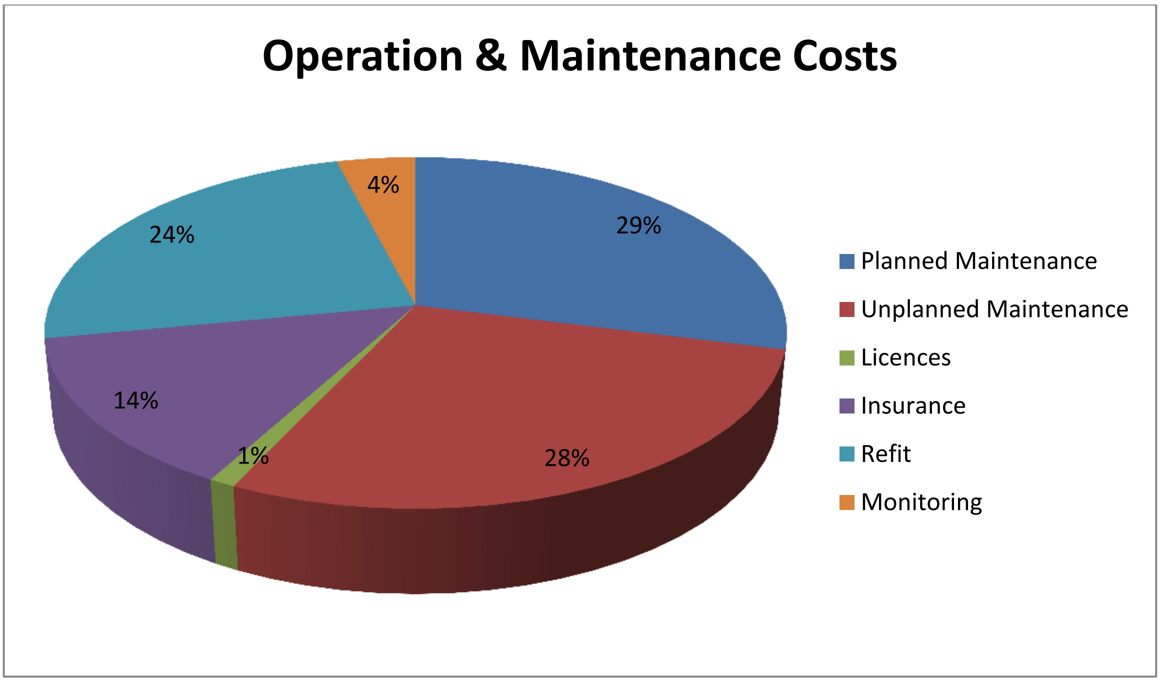


Figure 23 O&M Costs Associated with Installation of a Renewable Device [75]

To calculate the energy production required for the cost of energy equation, the capacity factor of each device was applied to the rated power to obtain a yearly average power output. For a more in depth analysis, weather data could be analysed and an average production figure calculated for each device, after efficiencies and days without production were taken into consideration. The most suitable energy devices were analysed and so the cost of energy for the *Wave Dragon* and *SurgeDrive* wave devices were calculated, as well as an offshore wind turbine of comparable size.

For analytical purposes, a generic O&M cost was applied to both wave devices, and a separate O&M cost applied to the offshore wind turbine, although this would differ in actual operation and currently these figures are not published. Operational and maintenance costs for wave devices are expected to be substantial due to the conditions experienced in the ocean environment. The forces experienced by wave devices during power generation coupled with the corrosive nature of the ocean's seas points towards high levels of maintenance. These stressors could lead to device failures, requiring substantial funds for emergency repair and personnel expenses. Although O&M stats for wave devices are not publicly available, offshore oil platforms tend to have higher O&M costs than their onshore counterparts. At the outset this means that wave devices are likely to be more costly due to their offshore nature. The capital costs of each renewable device were estimated per kW, and so an energy cost calculation could be carried out and a comparison made with that of the current production costs utilising fossil fuels. In each case the lifespan of the renewable device has been estimated at 20 years' service life, to allow a breakdown of cost requirements on a yearly basis.

In all cases, estimations have been made with reference to average energy figures and the calculated energy prediction is of efficient and constant energy production year round. Real time analysis is expected to show fluctuation of the figures produced. The costs are likely to be more than suggested, with investment in storage for un-interrupted energy supply to the living quarters, or adding cables and transformers for connection to the main grid.

11.1. Wind Turbine Analysis

Wind turbines which are based onshore and those which are offshore are a well-developed technology. Resultantly technical figures are readily available online for their energy production. Using the *European Wind Energy Associations* (*EWEA*) electricity cost calculator [76], the data for a 2MW offshore wind turbine was derived from the results of a 10MW turbine analysis. *Table 9* shows the parameters for the turbine and the cost of energy results.

Table 9 Parameters and Cost of Energy of an Offshore Wind Turbine

Category	**Cost Component**	**Data**
Energy Calculations	Installed Capacity (MW)	2
	Capacity Factor (%)	35
	Energy Produced in Year (MWh)	6,132
	Inflation (%)	2
	Discount Rate[1] (%)	5.39
	Years of Operation (Lifetime)	20
Technology Cost	Learning Rate[2] (%)	5
	Capital Cost (£/kW)	1,990
	Percentage of Total Cost (%)	62.34
O&M	O&M (£/kWh)	0.02
	Percentage of Total Cost (%)	37.66
Result	Cost of Electricity (£/kWh)	0.05

To confirm the results of the *EWEA* calculator's results, the cost of energy was also calculated using Equation 1 from the *Carbon Trust*.

$$Cost\ of\ energy = \frac{£3,980,000 + £2,452,800 + £80,000^{A}}{122,640,000} = 0.053[\frac{£}{kWh}]$$

A* - Average decommissioning costs of offshore wind turbine £40,000/MW, obtained from [77]

With reference to the current production pricing, the cost per kWh of energy from the dual fuelled gas turbines is £0.223/kWh, 4 times more than the cost of energy from a 2MW wind turbine. The average energy production of the wind turbine per year is more than enough to satisfy the energy demand of the living quarters, with an excess of approximately 2GWh per annum (p.a.). However, these figures are calculated with the assumption that the wind conditions are always suitable for generation, which is not the case in operation, and so the excess is more likely to be significantly less. Despite the actual energy produced totalling at a lower amount, there will still be some excess. Consequently, storage options would have to be investigated if the energy was to be utilised on-board, enabling constant power of the living quarters during energy production troughs from the wind turbine.

The fuel costs of the living quarters is estimated at £980,025 p.a. Combining this figure with the O&M costs for 20 years and its final decommissioning expenses gives a total figure of £6,500,000 approximately. If the wind turbines function was solely to power the living quarters of Rig Strath, the payback period of the wind turbine at the rate of fuel savings from the renewable's installation would be 6.6years, allowing for 13 years of potentially free clean renewable energy production.

11.2. Wave Dragon Analysis

The size requirement of the *Wave Dragon* is dependent on the wave power per metre of waves generated, and ranges from 4MW-15MW. The North Sea conditions yield a wave power of 38kW/m on average, as depicted in *Figure 24*, and so the 7MW *Wave Dragon* is best suited to these waters. Previous research conducted by Ian Fairley has demonstrated that the capacity factor of the *Wave Dragon* device after testing was between 14-18% [78], in comparison to the 35% capacity factor stated by Hans Soerenson [79], and so a capacity factor of 16% was applied for calculation purposes, giving a yearly power output of 9.8GWh for the *Wave Dragon*. *Table10* shows the parameters of the *Wave Dragon* device and the cost of energy results, calculated using *Equation 1* (see page 49). Assuming capital costs from the information available via the *Wave Dragon* developers, the capital cost of the W*ave Dragon* is approximately £2.5Million/MW.

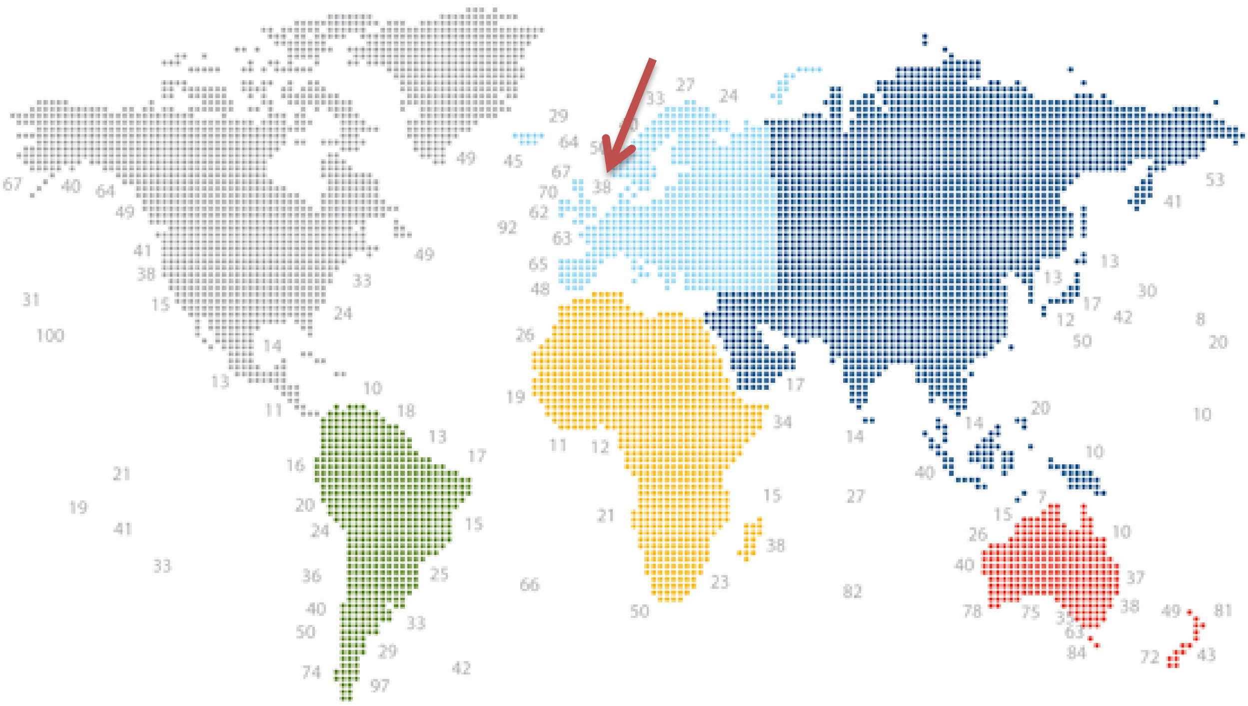


Figure 24 Average Global Wave Energy Flux Estimates in kW/m [80]

The maintenance costs of the wind turbine predicted by the *EWEA* calculator presented a value of £0.02/kWh for an offshore wind turbine, equating to approximately £125,000 per year of service life. The maintenance costs of WEC's is assumed to be higher as the devices function in the water and so are heavily exposed to corrosive salt water. In addition to this, the wave Dragon will be subject to large forces from colliding waves and so a generic maintenance cost for each wave device was set at approximately £300,000 p.a.

Table 10 Parameters and Cost of Energy of Wave Dragon

Category	**Cost Component**	**Data**
Energy Calculations	Installed Capacity (MW)	7
	Capacity Factor (%)	16
	Energy Produced in Year (MWh)	9,811
	Years of Operation (Lifetime)	20
Technology Cost	Capital Cost (£/kW)	2,500[1]
	Percentage of Total Cost (%)	74.51
O&M	O&M (£/kWh)	0.031
	Percentage of Total Cost (%)	25.49
Result	Cost of Electricity (£/kWh)	0.12

[1] Capital Cost obtained from *Wave Dragon* Presentation [79]

$$Cost\ of\ energy = \frac{£17{,}500{,}000 + £6{,}082{,}944 + £280{,}000}{196{,}224{,}000} = 0.122[\frac{£}{kWh}]$$

The cost of energy for the dual fuel turbines is 1.8 times that of an installed 7MW *Wave Dragon* energy converter system. The average calculated energy production of the *Wave Dragon*, if conditions were suitable every day, would produce over and above the energy requirements of the living quarters. However, this estimation is based the assumption that the *Wave Dragon* is constantly producing energy. The intermittency of the energy demand along with the intermittency of wave energy generation would require storage for autonomous energy supply to the living quarters. The daily load of the living quarters is 12MWh per day, and the potential generation of the 7MW Wave Dragon is 26MWh per day. With constant production in ideal conditions, there would be an excess load of 5GWh per year, and so considerations for this excess would be required, adding to the final cost of the WEC. The steady energy load of the production platform could utilise the excess energy supply of the WEC, however the dips in power production would not be sufficient to allow the platform to rely on the WEC for part of the production platforms energy supply, and so turbines of suitable capacity would still have to be present on-board to supplement power dips.

With the fuel costs of the living quarters estimated at £980,025 yearly, the total cost of the *Wave Dragon* over its 20 year life including O&M and decommissioning costs is approximately £23,860,000. If the *Wave Dragon's* function was solely to power the living quarters of Rig Strath, the payback period of the WEC at the rate of fuel savings from the renewable's installation would be 24years, resulting in a debt period of 4 years after decommissioning. Yet with a renewable technology of this size, there are various options for the excess energy generated, thus reducing the payback period of the Wave Dragon over its 20 year service life.

11.3. SurgeDrive Analysis

The size requirement of the *SurgeDrive* system is only dependent on the consumer's needs. The *SurgeDrive* system is deployed as a wave farm and is expandable, so the system can theoretically be retrofitted for power generation of any size.

AquaGen Technologies employed the help of *Worley Parsons* to perform a technical review of their system, showing a cost of energy at 8-24cents/kWh (AUD) [81]. Manipulation of this data against the 70MW wave farm to be deployed in Europe [82]gives a capital cost of £2,665/kW. Fairley's research found that the capacity factor of the *SurgeDrive* device after testing was between 9-17% [78] and so a capacity factor of 15% was applied for calculation purposes. Analysis of a 4MW wave farm using *AquaGens SurgeDrive* technology would yield a yearly power output of 5.26GWh. *Table 11* shows the parameters of the *SurgeDrive* device and the cost of energy results, calculated using *Equation 1*.

As with the *Wave Dragon*, the maintenance costs of the SurgeDrive are likely to be higher than the wind turbine as the device operates underwater and is heavily exposed to corrosive salt water and stressful forces. Resultantly, the O&M costs of the *SurgeDrive* were estimated at £300,000 per year.

Table 11 Parameters and Cost of Energy of SurgeDrive

Category	Cost Component	Data
Energy Calculations	Installed Capacity (MW)	4
	Capacity Factor (%)	15
	Energy Produced in Year (MWh)	5,256
	Years of Operation (Lifetime)	20
Technology Cost	Capital Cost (£/kW)	2,665
	Percentage of Total Cost (%)	64.36
O&M	O&M (£/kWh)	0.057
	Percentage of Total Cost (%)	35.64
Result	Cost of Electricity (£/kWh)	0.16

$$Cost\ of\ energy = \frac{£10{,}660{,}000 + £5{,}991{,}840 + £160{,}000}{105{,}120{,}000} = 0.16[\frac{£}{kWh}]$$

The cost of energy from the dual fuel gas turbines is 1.4 times that of an installed 4MW *SurgeDrive* wave farm. The average calculated energy production of the *SurgeDrive*, assuming operational conditions occur year long, would more than satisfy the daily energy demand of the living quarters. Again this is based on the assumption that there is constant energy production from the *SurgeDrive* device, and the peaks in energy demand can be satisfied with standard energy production from the wave farm. Like all renewable devices, the issues associated with intermittent power production brings into question the reliability of the *SurgeDrive* device as an autonomous energy system for the living quarters of Rig Strath. Incorporation of the *SurgeDrive*'s output into the overall demands of the production platform would allow for reasonable fossil fuel reduction, and with the 22MW gas turbines on-board, there will be enough back power available if the WEC is not producing energy when required. This would allow for the gas turbines to run at a lower capacity, with the option for upping power output if necessary.

The total estimated cost of the *SurgeDrive* wave farm over its 20 year life including O&M and decommissioning costs is approximately £16,800,000. If the *SurgeDrive's* sole function was to power the living quarters of Rig Strath the payback period of the *SurgeDrive* wave farm at the rate of fuel consumption, i.e. £980,025 a year, would be 17.1years, allowing for 2.9 years of potentially free clean renewable energy production.

12. Discussion

The cost of energy of the renewable systems in each case is significantly less than that of the fossil fuel systems currently in use, as depicted in *Figure 25*.

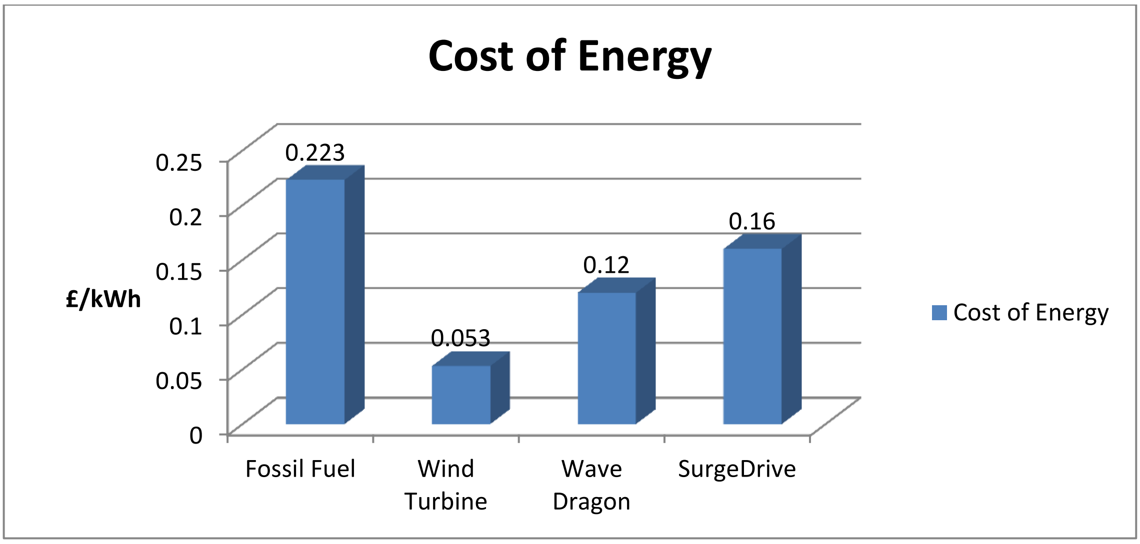


Figure 25 Comparison of Cost of Energy of Renewables and Fossil Fuel

While it is important to note that the energy figures are calculated on a best case scenario, assuming constant generation at the capacity factor, the size of the renewable devices reviewed have sufficient power to cover the living quarter load, but only with addition of storage systems, see *Figure 26*. As shown in *Figure 26*, the instantaneous energy requirements experienced do not often follow the peak energy production.

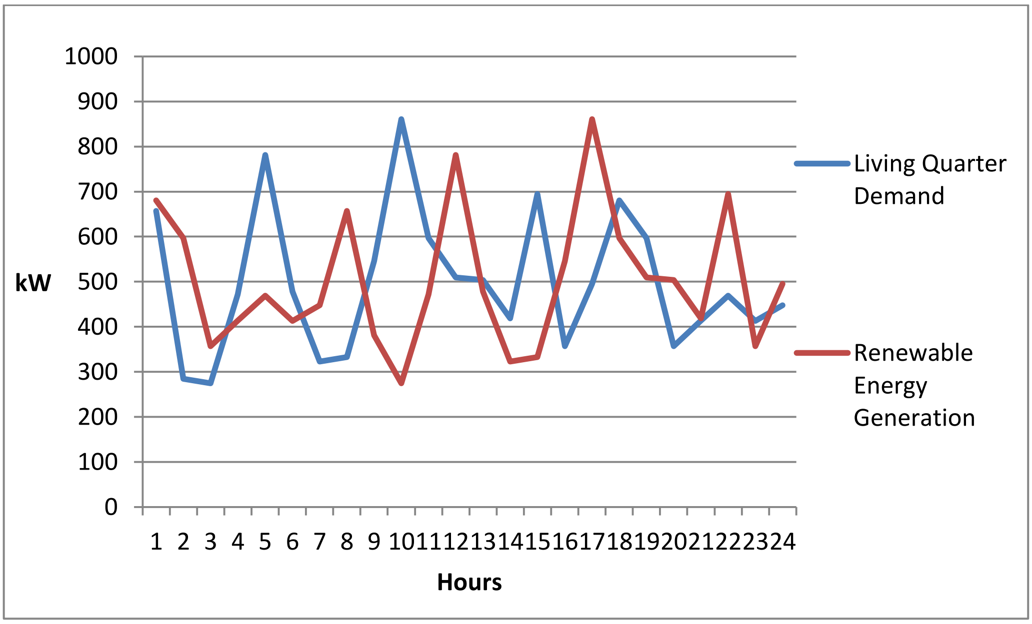


Figure 26 Sample Realistic Energy Demand and Renewable Supply

The majority of the electrical load is heating, and so hot water storage options could be utilised as a simple and cheap storage system for the living deck. This is on the basis that the heating system on-board the rig is a hot water system. For hot water storage tanks, the useful energy storage is dependent on the temperature the tank is maintained at. The useful energy storage potential of a 500L tank with an average temperature of 60°C is approximately 11.3kWh, whereas the same tank with an average temperature of 80°C is 23kWh [83]. Each floor of Rig Strath could accommodate one of these storage tanks, or alternatively a larger tank could be used as storage for the entire living quarters giving sufficient heat capacity when required.

Electrical storage options for use offshore are restricted. Onshore there are many environmentally friendly storage options like pumped hydro, or compressed hydrogen, but offshore space limitations are very strict, and so if storage options are going to be utilised sacrifices have to be made. Higher efficiency batteries utilise precious metals and as a result are considerably more costly [84], so it is more common that lead acid batteries are used. Lead Acid batteries are the oldest form of rechargeable battery, and despite advances in the technology making use of different metals, the lead acid battery is still an efficient and cheap storage option. However making use of batteries for storage only exacerbates the environmental issues associated with offshore rigs.

In situations where the power produced far surpasses the requirements of the living quarters, it has to be assessed whether this excess energy will be utilised on the production deck of the rig or if it is better to transport the energy produced back on land for integration into the national grid. With the cabling in place for transferring the renewable energy generated to the living quarters, it would be financially viable to make use of this excess energy on-board the rig. However the intermittency of power generation experienced with all renewables and the importance of consistent power supply on the production platform means that this is not a suitable option for offshore rigs. Transportation of the excess energy generated on land for integration into the national grid would be the financially viable option if required.

If an offshore rig was to integrate a renewable energy system, the carbon emissions of that rig would decrease as less fossil fuel would be required. The CO_2 reduction in substituting fossil fuels for renewable energies can be vast. If the renewables were to take over supply of the living decks energy needs, the energy savings from fossil fuels would be 12MWh daily, and 4.28GWh per year. The amount of CO_2 produced per kWh can be calculated by multiplying the CO_2 emissions factor of that fuel by the efficiency of the generator, and dividing the result by 1,000,000 [85]. 0.55 kilograms (kg) of CO_2 is produced for every kWh of natural gas combusted, and 0.76kg of CO_2 is produced when consuming 1kWh of diesel. The efficiency of the turbine means that more fuel has to be combusted to achieve the required energy, and so 1.375kg of CO_2 is produced for every kWh of useful energy from natural gas and 1.9kg of CO_2 is created from 1kWh of useful energy from diesel. This results in addition of 0.0029 metric tonnes (Mt) of CO_2 to the atmosphere every year. This may seem to be an extremely small amount, but the living quarter demands only account for 2.7% of the total energy demands of the sample rig, which would produce approximately 0.107Mt of CO_2 per year in its operations. When considered that the total CO_2 emission allocation for offshore Oil and Gas in the UK is 18.1Mt/year [86], the benefits of this reduction can be understood. This is just a small portion of the carbon emissions of offshore oil rigs, but if this amount can be reduced by addition of renewables to one rig, it shows the benefit and importance of renewables for power generation.

13. Conclusion

On reviewing the renewable modification's which exist in the oil and gas industry, it was found that very few of these solutions are deployed in practice. After analysing various renewable devices and conducting an economic analysis for their suitability in the oil industry, it was found that renewables can be integrated as a sufficient source of power for offshore oil platforms. However, the renewable devices alone cannot be relied upon for power generation and so storage devices would be required to ensure constant power, or the availability of substantial backup power on standby.

Whilst it is apparent that there are factors which restrict the use of renewables as a power supply for offshore oil platforms, cost is not one of them, with the cost of energy from the renewables analysed less than the current fossil fuel systems. The variety of climates around the world which harbour oil enables a variety of renewables to be utilised for power generation in the most remote of locations. Whilst some of these technologies might not be the most efficient source of generation at present, technology is continually advancing, and the benefits that can be reaped from renewable devices can be plentiful. The oil and gas industry is not disappearing anytime soon, however these industries should work to ease their environmental impact on the world by reducing carbon emissions, a goal that is achievable through adaptation and integration of renewables.

References

[1] W. He, K. Uhlen, M. Hadiya, Z. Chen, G. Shi and E. d. Rio, "Case Study of Integrating an Offshore Wind Farm with Offshore Oil and Gas Platforms and with an Onshore Electrical Grid," *Journal of Renewable Energy,* vol. 2013, 2013.

[2] M. L. Kolstad, A. R. Ardal, D. I. K. Sharifabadi and P. T. M. Undeland, "Grid Integration of Offshore Wind Power and Multiple Oil and Gas Platforms," Trondheim.

[3] "Riding the North Sea price waves: turbulent times for Brent crude," 2012. [Online]. Available: www.offshore-technology.com/features/featurenorth-sea-price-turbulent-times-brent-crude/featurenorth-sea-price-turbulent-times-brent-crude-3.html. [Accessed 2014].

[4] "Cruise Ship Fuel Consumption," [Online]. Available: http://www.shipcruise.org/cruise-ship-engine-propulsion-fuel/.

[5] "Cummins dual fuel engines," [Online]. Available: http://cumminsengines.com/dual-fuel.

[6] Dual Fuel Orginization, "Converting Diesel Engines to Bi_Fuel," [Online]. Available: http://www.dualfuel.org/technology/converting-diesel-engines-to-dual-fuel/.

[7] Offshore technology, "Sanha / Bomboco Development, Angola," 2011. [Online]. Available: http://www.offshore-technology.com/projects/sanha/.

[8] Capstone, "10 Things You Didn't Know About Microturbines," [Online]. Available: http://www.cogeneration.org/111011Conf/Presentations/McAvoy.pdf.

[9] C. T. Corporation, "Turning Waste into Power," [Online]. Available: http://www.capstoneturbine.com/prodsol/solutions/rrbiogas.asp.

[10] U.S. Energy Information Administration , "International Energy Statistics," [Online]. Available: http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=53&aid=1&cid=ww,&syid=2013&eyid=2013&unit=TBPD.

[11] Oil & Gas UK, "Environment Report 2013," London, 2013.

[12] Beacon, "What is a Greenhouse Gas?," [Online]. Available: http://beacon.berkeley.edu/GHGs.aspx.

[13] J. Palsson, A. Selimovic and L. Sjunnesson, "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, 2000.

[14] Ocean Portal and Smithsonian National Museum of Natural History, "Gulf Oil Spill," http://ocean.si.edu/gulf-oil-spill.

[15] The Telegraph and E. Gosden, "BP warns Gulf spill costs will exceed $42.4bn as compensation costs rise," 2013.

[16] The Financial Times and E. Crooks, "BP warns of ‘staggering’ oil spill compensation costs," New York, 2014.

[17] Clarke Energy and GE, "Associated Petroleum Gas/ Flare Gas," [Online]. Available: http://www.clarke-energy.com/gas-type/associated/.

[18] [Online]. Available: http://www.thecyberhawk.com/inspections/offshore-oil-gas/.

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

[20] J. Z. C. LLC, "Refining & Petrochemical Flares," 2004.

[21] ChemEngineering, "Gas Flares," [Online]. Available: http://chemengineering.wikispaces.com/Gas+flares.

[22] "Flare Stack System," 2012. [Online]. Available: http://en.wikipedia.org/wiki/Gas_flare#mediaviewer/File:FlareStack_System.png.

[23] Oil and Gas Industries, "Flaring and Venting," [Online]. Available: http://oilandgas.livingearth.org.uk/key-challenges/flaring-and-venting/.

[24] Gazprom Informatorium, "What is associated petroleum gas," [Online]. Available: http://www.gazprominfo.com/articles/associated-gas/.

[25] [Online]. Available: http://www.gazprominfo.com/f/ru/global/i/articles/article_17/lens2b.png.

[26] O. S. Ismail and G. E. Umukoro, "Global Impact of Gas Flaring," *Energy and Power Engineering,* no. 4, pp. 290-302, 2012.

[27] T. J. Blasing, "Recent Greenhouse Gas Concetrations," Cardon Dioxide Information Analysis Center, 2014.

[28] TEEIC and Tribal Energy and Environmental Information, "Potential Impacts of Oil and Gas Production".

[29] Defender of Wildlife, "Outer Continental Shelf Drilling".

[30] H. G. Svendsen, E. V. Oyslebo, M. Hadiya and K. Uhlen, "Integration of offshore wind farm with multiple oil and gas platforms".

[31] Global Hunter Securities and Mike Kelly, "Thought of the Day: Converting diesel powered drilling rigs to natural gas," 2012.

[32] renewableUK, "UK Wind Energy Database (UKWED)," [Online]. Available: http://www.renewableuk.com/en/renewable-energy/wind-energy/uk-wind-energy-database/.

[33] Miller Dome, "About the Miller Platform," [Online]. Available: http://www.millerdome.co.uk/.

[34] G. Hassan, "Cost of energy of floating wind," [Online]. Available: http://www.gl-garradhassan.com/assets/downloads/Cost_of_energy_of_floating_wind.pdf.

[35] S. Energy, "Off-Grid Power," 2011. [Online]. Available: http://www.seldonenergy.com/.

[36] WhisperPower. [Online]. Available: http://www.whisperpower.com/1/home.html.

[37] NAM, "Our History," 2013. [Online]. Available: http://www.nam.nl/en/about-nam/our-history.html.

[38] British Petroleum, "Liquefied Natural Gas," [Online]. Available: http://www.bp.com/en/global/corporate/products-and-services/liquified-natural-gas.html.

[39] Capstone Turbine Corporation, "C65 Microturbine," [Online]. Available: http://www.capstoneturbine.com/_docs/datasheets/C65%20Oil%20&%20Gas_331040F_lowres.pdf.

[40] "Combined Heat and Power Using Turbines," [Online]. Available: http://i-dacta.digibel.be/pages/turbines.php?param=en.

[41] J. R. Koren, "Gas, Oil PowerTurbine Maker," *Los Angeles Business Journal,* vol. 34, no. 32, p. 41, 2012.

[42] T. J. Price, "Jamies Blyth - Britain's first modern wind power pioneer," *Wind Engineering,* vol. 29, pp. 191-200, 2005.

[43] Enercon, "E-126 / 7,580 kW," [Online]. Available: http://www.enercon.de/en-en/66.htm.

[44] AMSC, "SeaTitan 10MW Wind Turbine," Massachusetts.

[45] U.S. Energy Information Administration, "International Energy Statistics," 2013. [Online]. Available: http://www.eia.gov/countries/data.cfm.

[46] Marine Current Turbines, "Tidal Energy," [Online]. Available: http://www.marineturbines.com/Tidal-Energy.

[47] Ocean Explorer, "Predicting the Tides," 2013. [Online]. Available: http://oceanexplorer.noaa.gov/edu/learning/10_tides/activities/predicting_tides.html.

[48] Yachting Monthly, "How to Work out the Tidal Stream," 2012.

[49] Pelamis, "Pelamis P2," [Online]. Available: http://www.pelamiswave.com/image-library.

[50] Wave Dragon, "Principles," [Online]. Available: http://www.wavedragon.net/index.php?option=com_content&task=view&id=6&Itemid=5.

[51] "Ocean Energy Classification," [Online]. Available: http://ikionrenewableenergy.files.wordpress.com/2010/02/6.jpg.

[52] AquaGen Technologies, "SurgeDrive," [Online]. Available: http://www.aquagen.com.au/technologies/surgedrive.

[53] "Offshore Accomodation Module," [Online]. Available: http://www.worldoils.com/marketplace/equipdetails.php?id=486.

[54] "Sikorsky S-61N," [Online]. Available: http://en.wikipedia.org/wiki/Sikorsky_S-61.

[55] D. L. Gautier, "Kimmeridgian Shales Total Petroleum System of the North Sea Graben Province," Reston, VA, 2005.

[56] R. Priyadarsini, W. Xuchao and L. S. Eang, "A study on energy performance of hotel buildings in Singapore," *Energy and Buildings,* no. 41, pp. 1319-1324, 2009.

[57] TransOcean, "Sovereign Explorer Specifications," [Online]. Available: http://www.deepwater.com/Documents/RigSpecs/Sovereign%20Explorer.pdf.

[58] Skytruth. [Online]. Available: http://blog.skytruth.org/2011_04_01_archive.html.

[59] EIA, "World Maps," May 2013. [Online]. Available: http://www.eia.gov/analysis/studies/worldshalegas/images/fig1map_large.jpg.

[60] BERR, "Atlas of UK Marine Renewable Energy Resources," Crown Copyright, 2008.

[61] Contemporary Energy, "Yearly total of global horizontal irradiation [kWh/m2]," 9 Jun 2010. [Online]. Available: http://www.contemporaryenergy.co.uk/picts/solarMap2.png.

[62] The Weather Channel, "Monthly Averages for Gulf of Mexico," 2014. [Online]. Available: http://www.weather.com/weather/wxclimatology/monthly/graph/26894:21.

[63] SolarGIS, "Global Horizontal Irradiation USA Mainlands," GeoModel Solar, 2013.

[64] Oil & Gas Journal, "Hurricane Preparedness," 29 July 2013. [Online]. Available: http://www.ogj.com/articles/print/volume-111/issue-7d/regular-features/journally-speaking/hurricane-preparedness.html.

[65] Rigzone, "Special Report: Hurricane Katrina Damage Assessment," 02 September 2005.

[66] P. Greenacre, R. Gross and P. Heptonstall, "Great Expectations: The cost of offshore wind in UK waters - understanding the past and projecting the future," UK Energy Research Centre, 2010.

[67] Shell, "Wind and sum power one-legged platform," [Online]. Available: http://www.shell.com/global/future-energy/innovation/inspiring-stories/monotower.html.

[68] Renewable Energy World, "When Renewables Meet the Oil and Gas Industry, Opposites Attract," 2014. [Online]. Available: http://www.renewableenergyworld.com/rea/news/article/2014/04/when-renewables-meet-the-oil-and-gas-industry-opposites-attract.

[69] Bureau of Ocean Management, "Offshore Wind Energy," 2014. [Online]. Available: http://www.boem.gov/renewable-energy-program/renewable-energy-guide/offshore-wind-energy.aspx.

[70] Forbes, "The World's Biggest Public Companies," July 2014. [Online]. Available: http://www.forbes.com/global2000/.

[71] General Electric Company, "LM2500 Gas Turbine Fact Sheet," 2013.

[72] Biomass Energy Centre, "Fuel Cost per kWh," [Online]. Available: http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,59188&_dad=portal.

[73] "The Price of Fuel," 2013. [Online]. Available: http://www.petrolprices.com/the-price-of-fuel.html.

[74] Carbon Trust, "Conversion Factors," 2013.

[75] Entec UK Ltd, "Cost Estimation Methodology: The Marine Energy Challange approach to estimating the cost of energy produced by marine energy systems," 2006.

[76] EWEA, "European Wind Energy Association Cost Calculator," 2013. [Online]. Available: http://www.ewea.org/policy-issues/economics/.

[77] Climate Change Capital, "Offshore Renewable Energy Installation Decommissioning Study".

[78] I. Fairley, "Wave Resources in South Wales and a Comparison with Wave Climate at the Wave Hub," Marine

] Energy Research Group, Swansea, 2012.

[79] H. C. Soerensen, "Wave Dragon," 2006. [Online]. Available: http://ec.europa.eu/research/energy/pdf/gp/gp_events/ocean_energy/1010_wave_dragon_en.pdf.

[80] Renewable Energy Holdings plc, "Wave Energy," 2013. [Online]. Available: http://www.reh-plc.com/technology_wave_energy.asp.

[81] AquaGen Technologies, "Worley study reports that SurgeDrive will be competitive with wind and solar," 2012. [Online]. Available: http://www.aquagen.com.au/press/latest-news/51-worley-report-indicates-that-surgedrive-will-be-competitive-with-wind-and-solar.

[82] AquaGen Technologies, "Agreement signed for 70Mw wave farm in Southern Europe," 2014. [Online]. Available: http://www.aquagen.com.au/press/latest-news/43-agreement-signed-for-70mw-wave-farm-in-southern-europe.

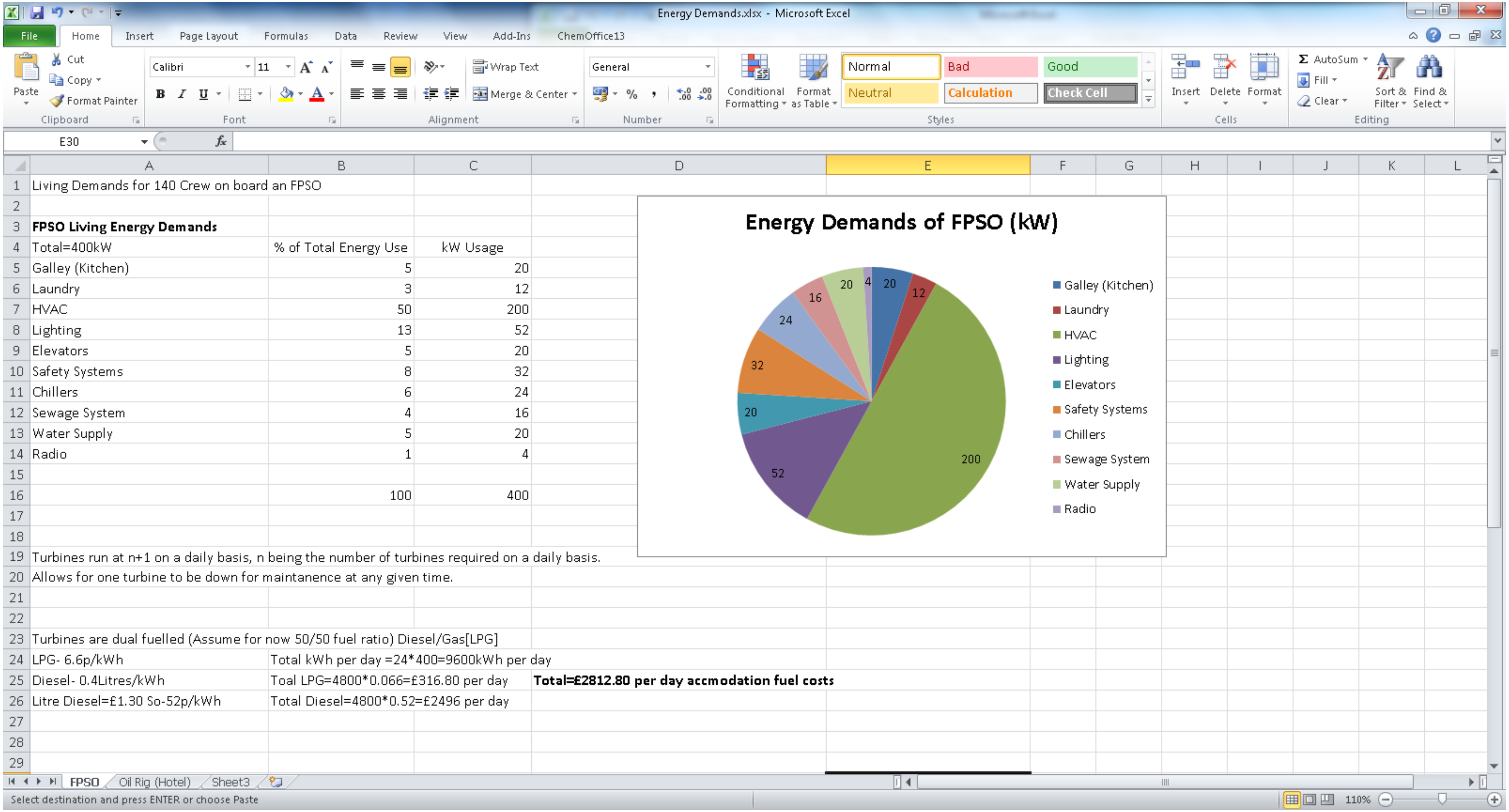
[83] L. R. Perez, J. B. Copeland, J. S. MacDonald, S. Vivaudou and A. Girona, "Load Shifting Utilising Thermal Storage," 2014. [Online]. Available: http://www.esru.strath.ac.uk/EandE/Web_sites/13-14/Findhorn/heatingsystems.html#LoadShiftingUtilisingThermalStorage.

[84] Battery University, "Cost of Power," [Online]. Available: http://batteryuniversity.com/learn/article/cost_of_power.

[85] U.S. Energy Information Administration, "How much carbon dioxide is produced per kilowatthour when generating electricity with fossil fuels?," April 2014. [Online]. Available: http://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11.

[86] S. Gomersall and A. James, "Oil and Gas Emissions: A Carbon and Storage Perspective," 2009.

Appendix A – Energy Demands of FPSO and Sample Rig



Living Demands for 140 Crew on board an FPSO

FPSO Living Energy Demands		
Total=400kW	% of Total Energy Use	kW Usage
Galley (Kitchen)	5	20
Laundry	3	12
HVAC	50	200
Lighting	13	52
Elevators	5	20
Safety Systems	8	32
Chillers	6	24
Sewage System	4	16
Water Supply	5	20
Radio	1	4
	100	400

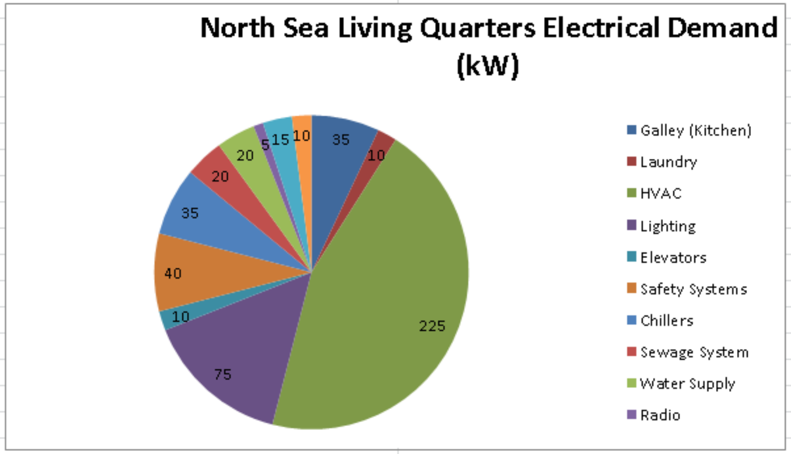
Turbines run at n+1 on a daily basis, n being the number of turbines required on a daily basis.
Allows for one turbine to be down for maintanence at any given time.

Turbines are dual fuelled (Assume for now 50/50 fuel ratio) Diesel/Gas[LPG]

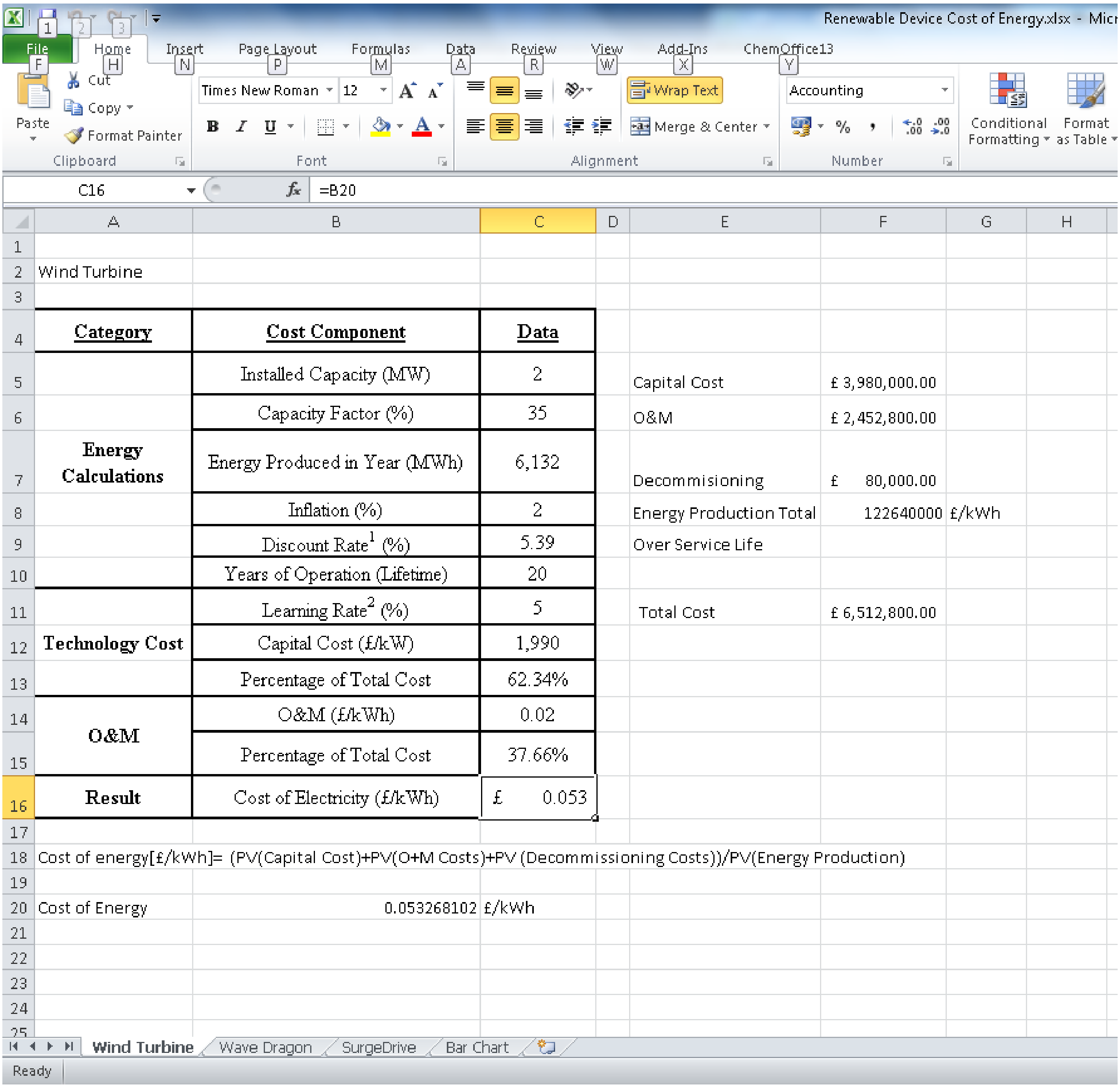
LPG- 6.6p/kWh	Total kWh per day =24*400=9600kWh per day	
Diesel- 0.4Litres/kWh	Toal LPG=4800*0.066=£316.80 per day	**Total=£2812.80 per day accmodation fuel costs**
Litre Diesel=£1.30 So-52p/kWh	Total Diesel=4800*0.52=£2496 per day	

Assuming 150 person living quarters required, 2 12 hour shifts of 75 at a time

A	B	C	D	E
Oil Rig/Hotel Energy Demands	North Sea			
Total=??kW	% of Total Energy Use	kW Usage		
Galley (Kitchen)	7	35		
Laundry	2	10		
HVAC	45	225		
Lighting	15	75		
Elevators	2	10		
Safety Systems	8	40		
Chillers	7	35		
Sewage System	4	20		
Water Supply	4	20		
Radio	1	5		
Recreational Area	3	15		
Gym Equipment	2	10		
	100	500		
	Equipment	Rating	12h - no. on board/hours use/total kWh for period	24h - no. on board/hours use/total kWh for period
Gym Equipment Rating	Treadmill	2400w	10/18/43.2kWh	10/36/86.4kWh per day
	Bike	1725w	10/25/43.125kWh	10/50/86.25kWh per day
	Crosstrainer	1725w	8/10/17.25kWh	8/20/34.5kWh per day
	Total	5.85kW	87.75kWh	175.5kWh



Appendix B – Cost of Energy of Renewables



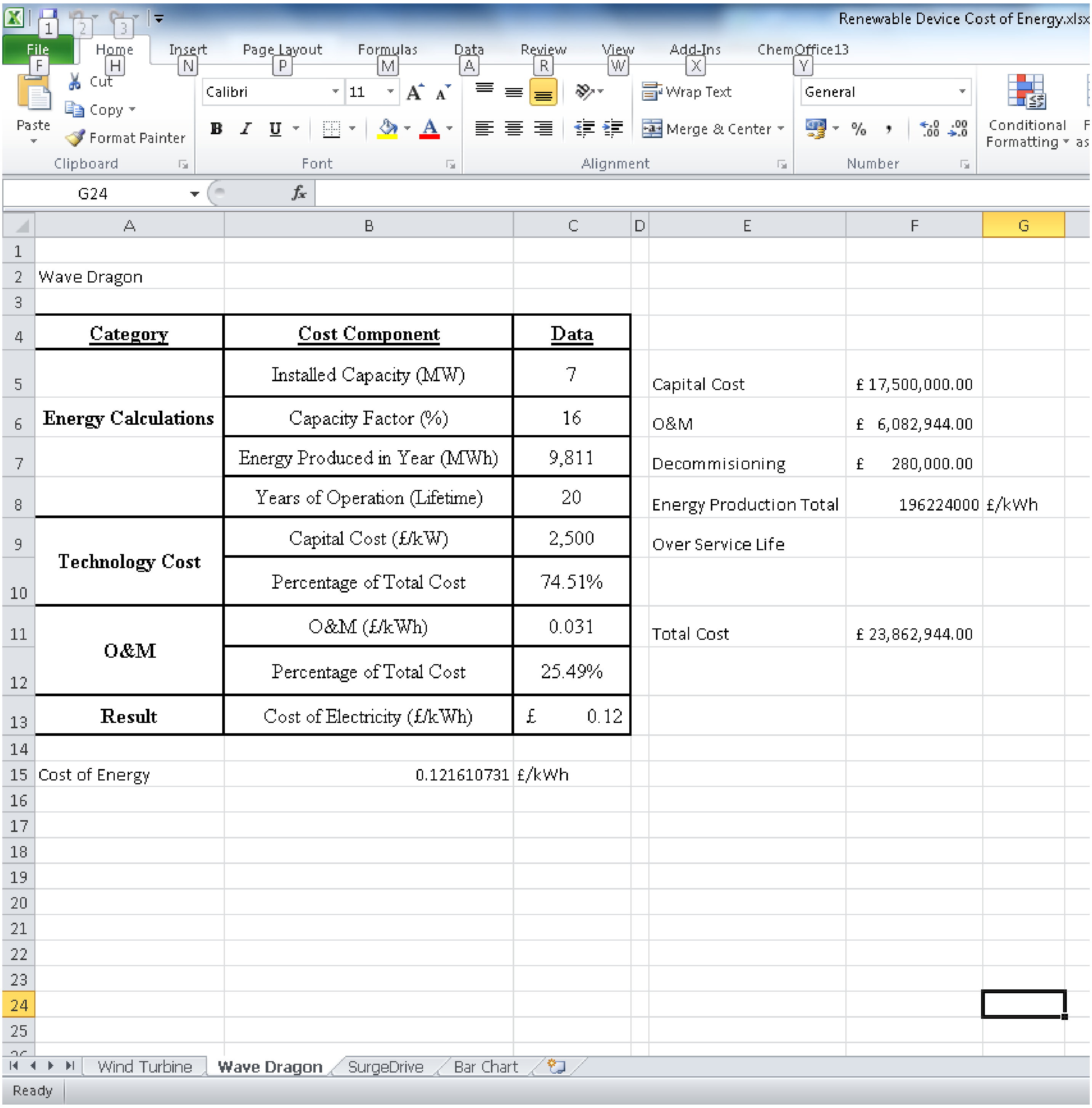
Wind Turbine

Category	Cost Component	Data
Energy Calculations	Installed Capacity (MW)	2
	Capacity Factor (%)	35
	Energy Produced in Year (MWh)	6,132
	Inflation (%)	2
	Discount Rate[1] (%)	5.39
	Years of Operation (Lifetime)	20
Technology Cost	Learning Rate[2] (%)	5
	Capital Cost (£/kW)	1,990
	Percentage of Total Cost	62.34%
O&M	O&M (£/kWh)	0.02
	Percentage of Total Cost	37.66%
Result	Cost of Electricity (£/kWh)	£ 0.053

Capital Cost	£ 3,980,000.00	
O&M	£ 2,452,800.00	
Decommisioning	£ 80,000.00	
Energy Production Total Over Service Life	122640000	£/kWh
Total Cost	£ 6,512,800.00	

Cost of energy[£/kWh]= (PV(Capital Cost)+PV(O+M Costs)+PV (Decommissioning Costs))/PV(Energy Production)

Cost of Energy 0.053268102 £/kWh

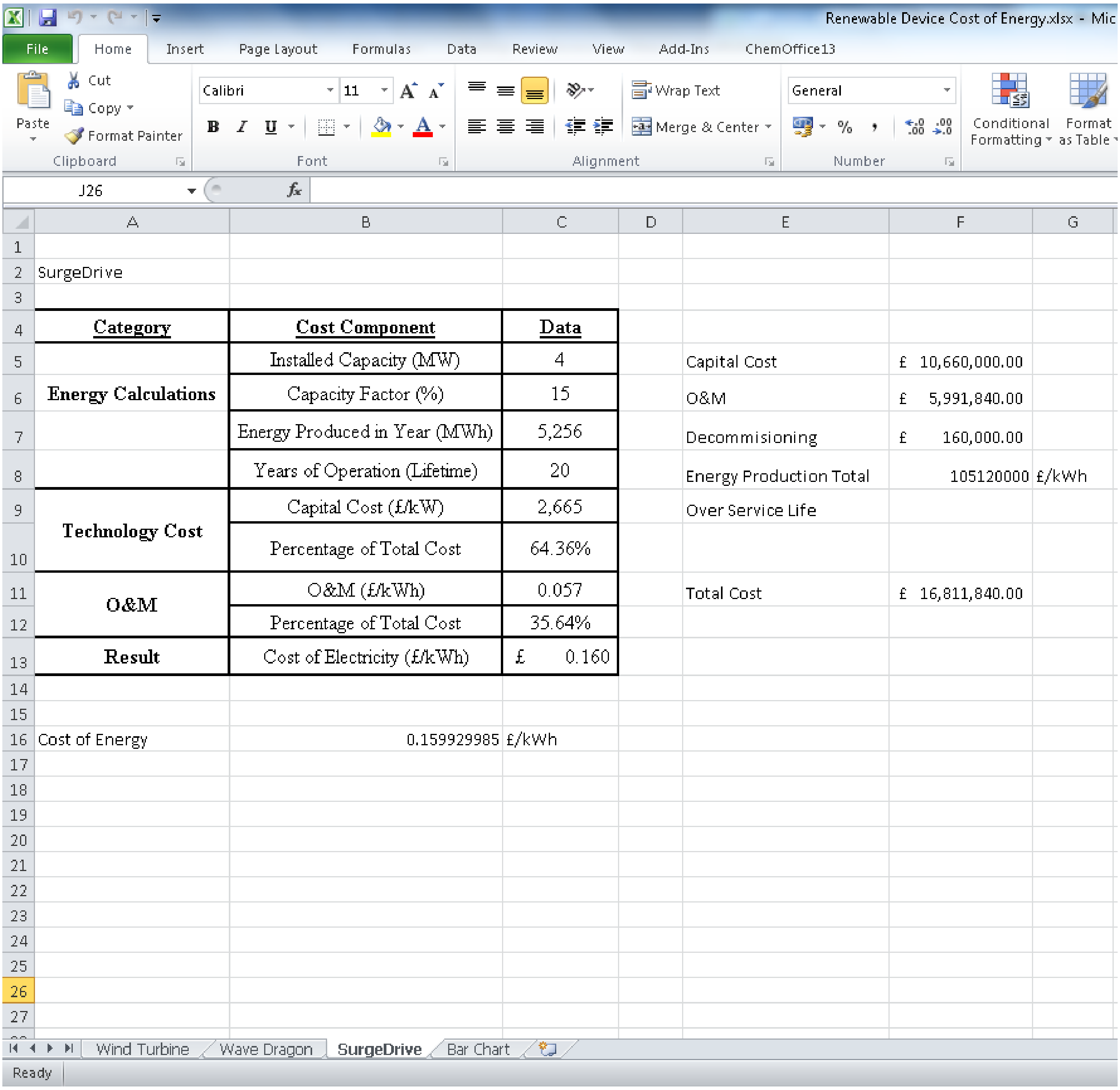


Wave Dragon

Category	Cost Component	Data
Energy Calculations	Installed Capacity (MW)	7
	Capacity Factor (%)	16
	Energy Produced in Year (MWh)	9,811
	Years of Operation (Lifetime)	20
Technology Cost	Capital Cost (£/kW)	2,500
	Percentage of Total Cost	74.51%
O&M	O&M (£/kWh)	0.031
	Percentage of Total Cost	25.49%
Result	Cost of Electricity (£/kWh)	£ 0.12

Capital Cost	£ 17,500,000.00	
O&M	£ 6,082,944.00	
Decommisioning	£ 280,000.00	
Energy Production Total	196224000	£/kWh
Over Service Life		
Total Cost	£ 23,862,944.00	

Cost of Energy 0.121610731 £/kWh



	A	B	C	D	E	F	G
1							
2	SurgeDrive						
3							
4	**Category**	**Cost Component**	**Data**				
5	**Energy Calculations**	Installed Capacity (MW)	4		Capital Cost	£ 10,660,000.00	
6		Capacity Factor (%)	15		O&M	£ 5,991,840.00	
7		Energy Produced in Year (MWh)	5,256		Decommisioning	£ 160,000.00	
8		Years of Operation (Lifetime)	20		Energy Production Total	105120000	£/kWh
9	**Technology Cost**	Capital Cost (£/kW)	2,665		Over Service Life		
10		Percentage of Total Cost	64.36%				
11	**O&M**	O&M (£/kWh)	0.057		Total Cost	£ 16,811,840.00	
12		Percentage of Total Cost	35.64%				
13	**Result**	Cost of Electricity (£/kWh)	£ 0.160				
16	Cost of Energy	0.159929985	£/kWh				