Feasibility analysis of year-round use of marine renewable energy in the UK

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Abstract

With an ever-increasing population and the necessity for copious quantities of energy, the way by which this is generated shall ultimately shape the future state of the world. Historically the use of fossil fuels powered our industries and coals ignited our fires, but the effects caused by these fossil fuels has had a detrimental impact on the atmosphere, with incredible amounts of carbon dioxide (CO_2) as a by-product being released. According to NASA (2018), the total level of CO_2 has risen from 300ppm in 1950 to over 400ppm in 2013, we are now at a crisis point. This has been emphasised across the world, with major cities aiming to reduce emissions through the prohibition of petrol vehicles in the next 20 years. Paris recently stated this in an environmental plan to cut emissions. These approaches may seem impulsive, but for a planet that has exploited fossil fuels and their lucrative powers for decades, significant change is necessary. The effect of extensive fossil fuel usage has driven our atmosphere into turmoil, the world consumes a total of 12,500 Million tonnes of oil equivalent (Mtoe) per year, and the UK covers 196 Mtoe of that (Focus Market, 2012). In 400 years, the average temperature of the planet has risen by a staggering 1.4°C (National Geographic, 2007) and this is increasing at an alarming rate. This value may seem inconsequential to some, but the effects are catastrophic. To list a few: loss of artic ice, damage to coral reefs, terrifying storms and wide spread forest fires, all of which are a direct consequence of our actions. These terrifying events result in loss of life, poverty and a continual cycle which is perpetually never broken through (National Geographic, 2007). As these catastrophes unfold, emphasis on the use of renewable energy is paramount and by the year 2020 we are required to provide 15% of our energy from renewable sources (Focus Market, 2012). This is only one of many approaches, and we must adapt to ensure the protection for future generations. This project shall focus on this issue by utilising offshore renewable devices. This approach will allow for better understanding of year-round use of renewable energy.

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Chapter 1. Background & Objectives

Renewable energy has been developing for many years and as commercialisation has occurred, it has been implemented into our society. The stigma surrounding the use of renewable energy is rapidly decreasing and it now greatly contributes to the generation of electrical energy. As consumers have realised the benefits, the oil sector's domination has subsided. Promisingly, the UK has decreased its energy consumption since the millennium, from 1951 kWh/per year per person in 2008 to 1766kWh/per year per person in 2013 (Harrabin, 2014). The research of this project will be undertaken in the UK, to gain a greater understanding of the potential resources available to us as an Island. This project will primarily consider offshore renewable energy and the combination of multiple devices, to utilise various sources of energy. In doing this, the potential to supply electricity from offshore devices year-round may be more favourable and feasible than other methods of energy generation.

1.1) Aims and Objectives

Primarily, this project will focus on offshore renewables and the motivations driving this sustainable approach. With a deeper understanding of why they must be implemented and how to approach the problem. Focus on site and device selection are vital, and likely combinations will be established through reviewing renewable methods. This will involve using a strength and weaknesses analysis on likely devices and progression will be possible where an understanding of the systems is established. Device characteristics will be determined through manufacturer brochures, allowing for determination of power output. These characteristics are often displayed in the form of power matrices and shall be established later. *Sections 1.2 to 1.8* provide the steps of this project and how they shall be undertaken. The overall objective of this project is to determine the feasibility of year-round use of renewable energy in the UK.

1.2) Literature Review: Motivations

To gather a greater understanding of renewable energy, key motivations for its use shall be determined. Including primary factors which influence the progression of renewable energy development, such as environmental and social factors.

1.3) Literature Review: Renewable Methods

Through developing knowledge of each renewable energy form achievable offshore, a deeper understanding and appreciation of the subject shall become established. This review shall be crucial when determining sites and understanding how certain systems may work following integration to the site. This will be achieved through undertaking a literature review and considering companies which have ventured into the renewable energy sector, both at research and commercial stages. Furthermore, an understanding of the origins of methods will be found, entailing both historical and current uses.

1.4) Site Selection Process

Upon completion of the previous outlined objectives, it will be vital to determine specific and suitable sites around the UK for which singular or combined devices can be integrated. Sites will be considered following a thorough review and their suitability will be paired with *section 1.5*. Hypothetically, the site location will be expected to generate energy for a town based upon the total number of houses it contains. During site selection, the total required consumption of the area will be outlined, and shall be expressed in Megawatt-hours (MWhrs).

1.5) Device Selection

As part of the feasibility analysis, device scrutiny will be undertaken for greater understanding. This will ensure the establishment of suitable devices, which shall facilitate determination of power outputs and effectiveness when situated in the selected sites. As a result, this shall allow for thorough analysis of the feasibility of renewable energy in the UK and enables the provision of a more innovative approach towards addressing the inherently challenging nature of energy generation.

1.6) Data Resources and Power Output

To determine device output, implementation and use of power matrices and other device specific information will be necessary. As previously mentioned, this information will be sourced from manufacturers and will be crucial in understanding the potential of each system. Similarly, it will also allow for interpretation of short-comings which may occur as a result of poorly situated systems. Power outputs will be determined once site evaluation has taken place. This will be achieved by gathering site characteristics and site data, such as (but not exhaustively) wind speeds, wave heights and periods. Due to the difficulties associated with obtaining site data, this may be estimated. Ideally, data will be utilised from the previous ten years and contact with the METoffice in addition to other meteorological services may prove vital to the progression of this project.

1.7) Economic Analysis

Offshore renewables are an expensive commodity and costing is a crucial aspect of the feasibility analysis. Current statistics state that the feasibility of these approaches may be limited due to their large cost involvement and in many cases these projects do not have a pay-off period, with renewable projects unable to break-even at the stage of decommissioning. Another problem which is a detrimental factor to the high costs is the level of down-time and inefficiencies of certain offshore devices, which are largely amplified by the variations in energy available throughout the year. Consequently, energy generation from devices is limited and they are therefore unable to generate income for the project. As a result of costing issues, a life cycle costing analysis will take place, encompassing ‘cradle to grave’ operations. Cradle to grave suggests planning and construction, service, maintenance and decommissioning costs. Understanding these operations will allow for the production of relatively accurate cost breakdowns. These can be utilised to establish primary economic indicators such as IRR, NPV and break-even values.

1.8) Feasibility Analysis and Conclusions

Upon completion of the objectives outlined above, conclusions are expected to be drawn with a greater understanding of the feasibility of year-round renewable energy use within the UK. The conclusions shall highlight attention to expected areas of concern, the reader will achieve a greater knowledge and understanding of renewable energy, and how it can be utilised further within the UK. The goal of this project is not necessarily to prove that renewable energy can be used offshore all year-round, but highlight issues and establish what may make a more viable venture. After this objective is undertaken, some clarification of further work will be outlined. It is expected that time limitations will restrict the studies reliability, with numerous assumptions being made where information is scarce.

1.9) Additional Objective: Coastal Protection from WECs

Offshore methods of renewable energy pose multiple tangible benefits. If time permits, consideration of these additional positive factors will be made. Primarily, the way by which certain systems may protect coastal lines from erosion. Numerous studies have been undertaken, suggesting the use of wave energy convertors (WEC) may act as a dynamic barrier for changing coastal conditions. This brief additional objective will be undertaken at the end of the feasibility study by reviewing literature which has previously investigated this subject.

Chapter 2. Literature Review: Motivations

Chapter 2 considers the primary motivations urging the development of renewable energy in the UK. The findings from relevant literature are outlined and shall support the progression of this project.

As the use of renewable energy increases, emphasis should be placed on the underlying motivations in terms of its future benefits or with reference to early stages of renewable development. Keys motivations, which have spurred development within the renewable sector, are outlined below in *sections 2.1-2.3*.

2.1) Environmental and Social Factors

Environmental damage caused by the continual use of fossil fuels and the toxic pollutants released during combustion stages, are primary motivations propelling the development of renewable energy. Implementation of renewable methods shall lead to a reduction in fossil fuel usage, and subsequently less harmful gases shall be released into the atmosphere. Thus allowing for greater protection and a halt in damage to the earth. Further key motivations as portrayed by Morley (2015), include the costing of energy. Which is generally found to be increasing and this may be a direct link to the use of finite sources. By using renewable energy methods, emissions will decrease and amenities will be cleaner, resulting in less polluted environments and slowing of global warming. Furthermore, health is likely to improve, with fewer cases of 'respiratory disease'. Morley (2015) also outlines that the resultant is a likelihood of reduced industrial activity, thus allowing for land 'regeneration', particularly in locations where offshore renewable energy is utilised. As a result, countries shall be more self-sufficient and less influenced by political agendas.

2.2) Acceptance and Driving Factors

Another important element which must be considered, is the acceptance of renewable energy approaches. Several areas of acceptance, including social, market and community, social-political and social-economic factors, influence motivations. In a comprehensive report which discusses combined renewable cases by Mohammed et al. (2014), emphasis is placed upon the factors which encourage the development of combined renewable approaches. From a political viewpoint, the report discusses the way by which political leaders could further explore renewable energy, which is expected to reduce the infrastructure gap between urban and rural areas. As stated by Mohammed et al. (2014), one of the goals is to provide 'economically affordable and environmentally friendly energy to their citizens'.

Also, considered in this report are the economic factors contributing to the development of hybrid renewable energy systems. It has been established that it is unconventional and potentially expensive to create a system which only utilises one form of energy. For example, as suggested by Mohammed et al. (2014), the use of only photovoltaics (PV) from solar power limits the power output potential and it is likely using a fossil fuel power source, is more economically viable. However, by combining PV with wind power, it is probable that the device would be more cost effective and able to generate energy on less variable scale. With higher outputs the system would generate more money and subsequently become more cost effective, or at the very least, equally comparable to a traditional fossil fuel method.

Most importantly are the environmental factors which encourage the development of renewable energy, and which were also considered by Mohammed et al. (2014). Mention of pushing all countries towards focussing on renewable energy and working together due to the 'centrality of the global atmosphere', will facilitate the commercialisation of renewable energy. Another important driving factor is how readily available renewable energy is, and the fact that any site can sustain at least one source of energy which can be utilised through a renewable energy device, is truly enlightening.

2.3) Country Policies

Country policies are another driver in the development of renewable energy. These policies are being set by countries which strive to be self-sufficient and fully renewable within the next decade. A shift to the use of renewable energy provides social, economic and environmental benefits such as: the provision of hundreds of jobs, improvement in the economy and a reduction in global warming. One country which has set such example is France, they have recently set new targets for renewable energy, aiming for between 17-18% of energy generated to be renewable by 2020. However, they have also stated that if this target is not met by 2020, further work could see its achievement in 2023. Scotland aims to generate 50% of electricity using renewable methods within a similar time frame. Offshore generation from wind is expected to rise from 1.3 GW seen during 2010 to 18 GW by 2020, and as both wave and tidal generation approaches are deployed commercially, up to 300MW of energy is expected to be gathered per year (Department of Energy & Climate Change, 2011).

Chapter 3. Literature Review: Renewable Methods

This project will primarily consider offshore methods with focus upon wind, wave and tidal power. This comprehensive review shall provide insight and an understanding of these methods, their history and current utilisation. Following this, analysis will be undertaken on various devices deemed most suitable for use. In undertaking this analysis, multiple devices shall be established and will prove fundamental in determination of site selection.

3.1) Wind Power

Offshore wind power is an industry which is currently thriving, providing 11% of the total electricity generated in the UK (2015). This is a lucrative market, with the total value of offshore wind power expected to be more than £2.9 billion by 2030. Whilst currently, it is considerably less at £1.8bn, as mentioned by Catapult (2016). Wind is a feasible offshore harnessing method, with the potential to utilise available energy 90% of the time. However, wind power is subject to large variability issues, such as changing wind speeds and direction. This shall be considered when determining sites and devices, particularly in cases whereby implementation of additional devices utilising alternative renewable energies may reduce the likelihood of variability.

3.1.1) History

Wind energy has been a process of utilising natural resources for thousands of years. According to Tong et al. (2010), time periods as early as 4000BC saw the Chinese use wind energy to power their rafts by attaching sails. Similarly, the Ancient Egyptians used sails to propel their boats along the river Nile. As time has progressed, wind energy has been exploited in several ways. Around 300BC, Ancient Sinhalese used wind power to moderate temperatures during smelting processes. Wind mills began making appearances as early as 25-220AD, and have been used in China for more than 1800 years. Particularly relevant are the uses of windmills in the Netherlands which were used in the form of horizontal axis windmills as portrayed by Tong et al. (2010). This type of device played an instrumental role in water pumping and milling, as opposed to energy generation.

The first wind turbine was built by Charles Brush in 1888. It could generate up to 12kW of power, which allowed for the charging of batteries used to operate devices, such as lights and basic electric motors. By the 20th Century, Denmark were producing turbines and an important type was the ‘Gedser Wind Turbine’ developed in the 1950s it showed great potential and innovation within wind energy sector (Tong et al., 2010). Many studies conducted between 1970 and 1990, which aimed to investigate the use of offshore wind energy, drew encouraging conclusions regarding its potential. However, preliminary designs which surfaced in the 1970s admitted to being very bulky and un-manageable. The performance of these devices was criticisable and did not consider all eventualities, for example variabilities such as wind and wave loading. Therefore, the devices were over-engineered and extremely difficult to work with. The passage of time has proven a great attribute to the development of wind energy, with construction of large wind farms both on and offshore, providing considerable levels of energy.

3.1.2) Current Devices

Offshore wind turbines can be categorised into two parts, floating and fixed. Generally, fixed wind-turbines are located closer to the shore at depths of less than 30 metres, and can be fixed through various foundations types. These include jacket structures, mono-piles and, potentially, suction caissons. And a research programme is currently being undertaken at the University of Dundee by the Geotechnical Engineering department on the usability of suction caissons. Variations of foundation types can be established in *figure 1*. In recent years, the development of floating devices has been initiated with many studies and prototypes being developed. The benefits of the use of floating devices are considerable, these devices can be situated further out at sea with depths of more than 30 metres. Furthermore, floating devices can utilise energy that previously could not be obtained by non-floating turbines, due to the limitation of depth and rough environments. Other benefits include lower construction costs, easier maintenance and the positioning of the turbines, which is very flexible. The devices can be moved around and anchored to the sea bed using mooring lines. The world’s first floating wind farm is located off the coast of Scotland, the ‘Hywind Plant’ is situated 30km from the coast and the development has been undertaken through a combined investment of various companies and the Scottish Government. The farm was officially opened by Nicola Sturgen, as of the 18th of October 2017. These floating wind turbines are 175m from sea level to the turbine blade tips, and it has been stated by the first minister that they will ‘generate enough power for about 20,000 homes’ (BBC News, 2017). A common theme emerging, is for traditional oil companies to delve into this market, and this case is no exception.

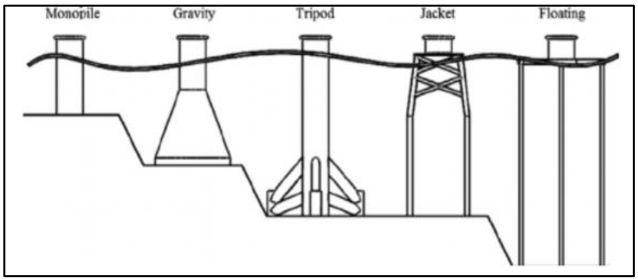


Figure 1: Foundation types (Higgins, 2013)

It is known the Norwegian company, Statoil has been involved in the development and are known in the renewable sector as Hywind.

3.1.3) Cost

Wind energy is now a well-developed and robust sector and as a result construction and energy generation costs have drastically decreased due to the advancement of technology. The cost of offshore wind turbines is expected to fall 25% by 2025. According to Vaughan (2010), the cost reduction is likely to be influenced by increased competition and the development of standardised approaches to the energy generation method. This makes it a very plausible method to source energy, whilst other methods remain in research stages. Wind energy is developing rapidly and it could be said that the market for wind turbines is at saturation level.

3.) Wave Power

Pelc & Fujita (2002) outline clear points as to the way by which wave energy has developed over several years, and is considered a ‘promising’ solution. The method of wave energy generation involves converting the energy present in waves into electrical power, of which can be done in a series of ways. There are a variety of devices which can utilise the energy available, and these will be outlined in *section 3.2.2*. As wave energy is available to be farmed almost continuously, it shall be considered when determining devices.

3.2.1) History

The use of wave energy has evolved over many years. It was first established as a method to harness energy in 1799 and these were recorded in patents. These patents were related to the work of Girard, an inventor in Napoleonic Paris. Unfortunately, they were left in the archives due to the rapid realisation of the energy potential fossil fuels had, and in addition crude oil could be used as an effective source of energy. However, like wind power, the focus on this type of energy conversion increased in the 1970s. As this method of sourcing has developed, the energy conversion method has been catapulted into our industries. There are several devices which are now fully functional and considered capable for use on a greater scale.

3.2.2) Current Devices

At present, there are a vast number of devices which can convert wave energy into useful electrical power for our consumption. They vary slightly, however, all reach the same outcome of converting energy to useable electrical power. According to the Engineering Committee on Oceanic Resources, in 2003 there were over 40 devices which had reached a relatively advanced state of development. Key devices include wave capturing systems such as oscillating water columns and wave profile devices (Twindell & Weir, 2006).

Oscillating Water Column

This method utilises the oscillation of waves, and is ideally located upon a coastline and 'preferably on rocky shores' (Lemay, 2010). This is presumably to aid integration of devices and improve the process by which power is transferred to the national grid. The device traps air through use of a 'piston-type system' which forces air up towards a turbine. The pressure causes the turbine to operate and subsequently allows for the generation of power. When the wave retreats, extra air is inserted into the system, allowing for the continuation of this process. Lemay (2010) highlights two main groups of turbines which can be used in this system: fixed-pitch and variable pitch angle blade turbines. As the turbine is not limited and will rotate regardless of airflow direction, it is praised for its 'simplicity and robustness' (Drew et al., 2009). An example of this method is the LIMPET device, produced by Wavegen. It was installed in Scotland during 2000 and has been operating since construction. In *figure 2* a schematic of the device's operation can be seen.

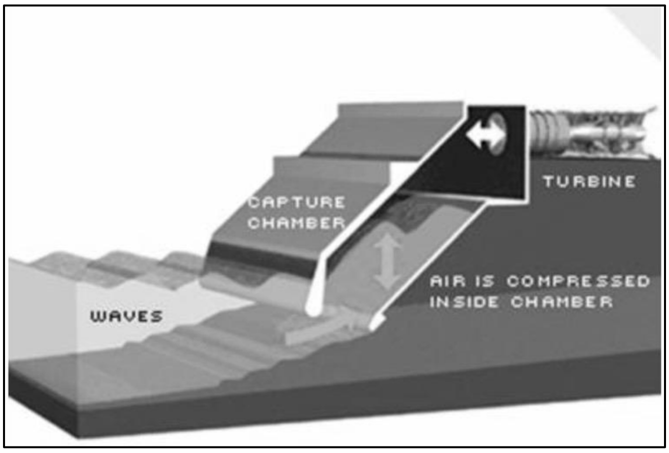


Figure 2: Limpet 500 Device (Strathclyde University, 2009)

Over-topping device

Overtopping devices, otherwise known as terminators, are unlike other wave energy devices. An overtopping device makes use of the potential energy, which is made possible by strategically locating the device. Allowing for waves to propagate over the edge tolerant, filling a reservoir type system. Once full, the water is released and travels through a turbine, generating electricity. A schematic in *figure 3* further explains this process.

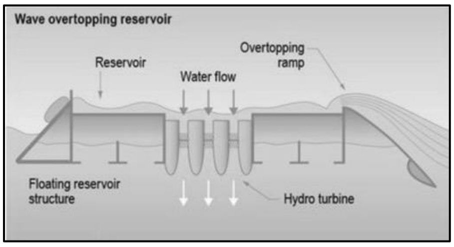


Figure 3: Overtopping Device example (Morgan & Hendrichs, 2015)

Point absorber

Point absorbers absorb the energy from ocean waves and can be situated in a variety of ways. One example is the AquabuOY, which has been developed by Finevera (McGrath, 2017). The device becomes operable through the pressurisation of water, which subsequently spins a turbine and thus generates electricity. This is outlined in *figure 4*. These devices, like others, can be combined, and one example of this is the WaveNet produced by Albatern. Based in Scotland, it has been operating for around 8 years. This is a phased project and Albatern are currently within the testing stage of their series-6 7.5kW device. This device combines both a point absorber and wind turbine.

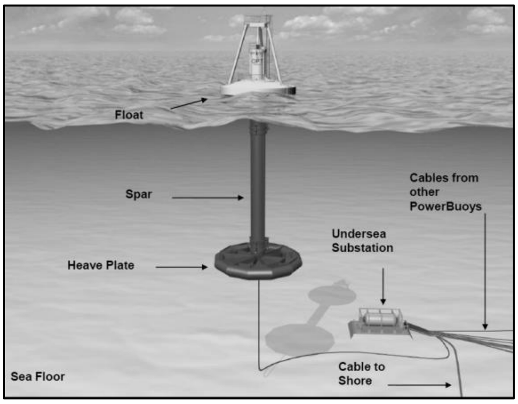


Figure 4: Point Absorber example (OPT, 2017)

3.3) Tidal Power

Tidal power is another source of energy which may be harnessed using tailored devices. Tidal power is dependent upon the gravitational allure of the Earth and Moon, as portrayed by Twindell & Weir (2006). In *figure 5*, an understanding of the way by which gravitational attraction affects tidal energy can be characterised with consideration to neap and spring tides. As the Moon orbits around Earth, a gravitational pull occurs. Water is influenced by this gravitational pull and as a direct result, tidal ranges occur.

Utilising tidal power may be suggested as being particularly challenging. However, with little development to prove this, it is still realistically a reliable and consistent source. According to a report released by the Sustainable Development commission (2011), it could be feasible to source around 10% of the UK’s electricity demand from tidal ranges and streams. Other sources oppose this and suggest that the UK could obtain up to 20% of its electricity demand from tidal power generation. In the UK, there are several sites which harness tidal ranges and generate from as little as 0.06 TWh/year, to as much as 17 TWh/year.

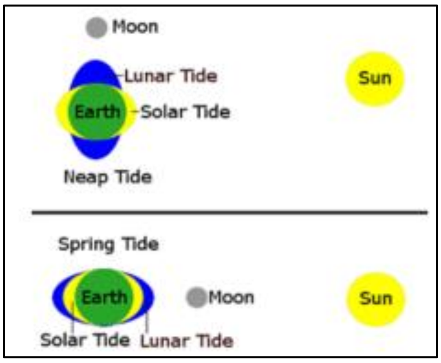


Figure 5: Spring and Neap Tides due to sun and moon (Tidal Power, 2013)

3.3.1) History

Tidal power has long been considered a viable method of resourcing energy. Dating back to around 900AD, tidal power has been used for 'power conversion' (Tidal Electric, 2017). Such devices include tide mills, which were used during the middle Ages (Le high, 2015). One example is located in Northern Ireland at the Nedrum Monastery. Upon discovery of this mill, it was established that it may date back to the year 619AD. According to Le high (2015) the mill was likely used to grind grains.

3.3.2) Current Devices

There are several devices available for use. However, conditions for these devices are very particular and at present there are only eight sites in the UK suited for utilisation of tidal power generation. This is out of a total of twenty sites around the world, which emphasises the importance of developing tidal power in the UK. One main site of tidal power generation has been operational for over 50 years, and is based at the mouth of the Rance River in France. This system achieves a collection of some 500GWhr/year and is composed of 24 'reversible turbines' which span across the estuary (Rosa, 2013).

To date, multiple prototypes and systems have been installed and tested. However, problems exist with this form of energy harnessing. It is incredibly expensive, and based upon an example of a plant in Cardiff, it would cost some $15,000 per kW. Comparing this to a wind turbine which would cost $1200 per kW, the difference is stark. Furthermore, this method has been known to cause multiple environmental issues and as a result, disruption to marine life and further damage to our environment may occur (Rosa, 2013).

Tidal power in the UK offers some of the greatest potential in the world, as mentioned above. This is further portrayed below in *figure 6*, which highlights areas of high tidal power availability across the globe.

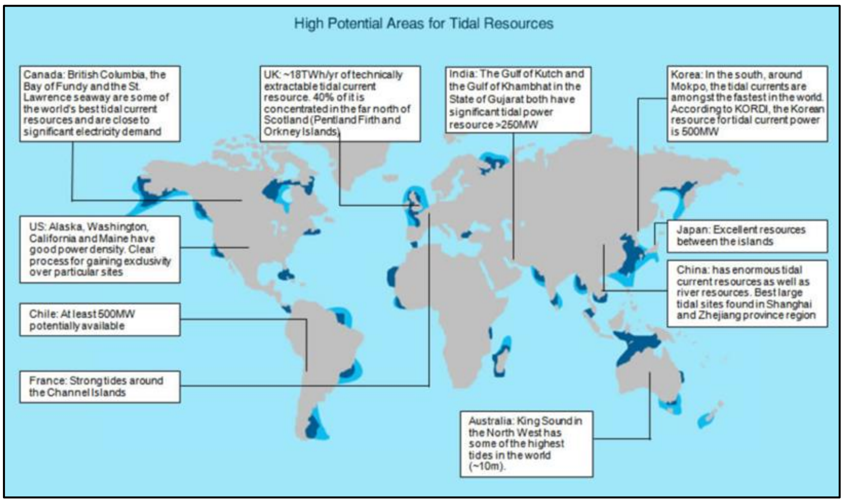


Figure 6: Tidal Energy Worldwide (Goldman, 2012)

Tidal Turbines

Tidal turbines are currently being developed for use in tidal power generation. These are comparable to wind turbines, however tidal turbines are driven by consistently occurring tidal currents (Atlantis, 2017). The turbines are generally much smaller, to accommodate the density of water, which is much higher than that of air. These can either be horizontal or vertical axis turbines which are outlined in *figure 7* and *figure 8*.

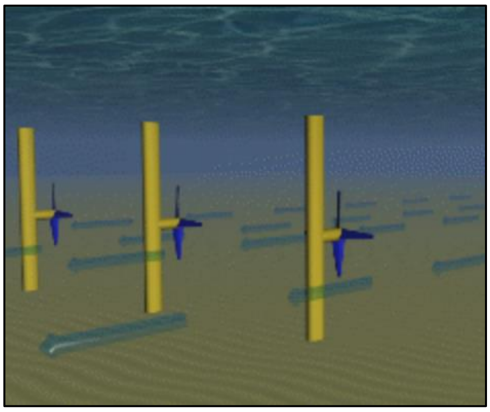


Figure 7: Horizontal Axis Turbine (Aquaret, 2008)

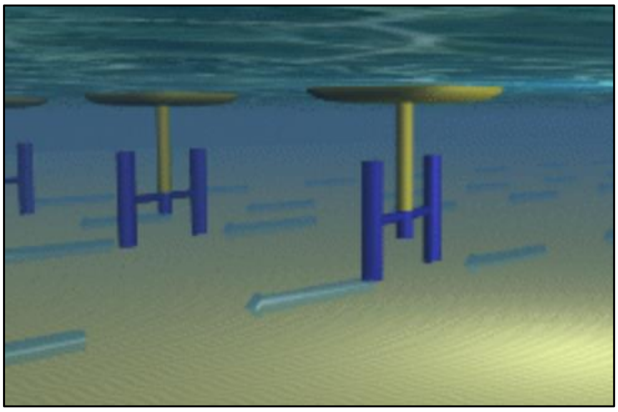


Figure 8: Vertical Axis Turbine (Aquaret, 2008)

Atlantis are producers of multiple tidal turbines. An example of one of their devices is the AR1500, which is a 1.5MW ‘horizontal-axis turbine’. The dynamic device can alter pitch and yaw to suit the variations in tidal ranges and ocean conditions. This model has a design life of 25 years and can typically generate up to 1500kW of energy at 14 RPM, whilst providing an efficiency rating of 97%.

Tidal Barrage

This system is constructed like a dam, and energy is generated through the flow of water. Two tidal barrage systems are available for use and include Ebb Generation and Two-way Generation. Where Ebb generation utilises one motion of the tide, two-way generation utilises both flood and Ebb tides. To contextualise this, Ebb tides occur when the tide level decreases and flood tides occur when the tidal level increases, as addressed in *figure 9.*

Tidal Lagoon

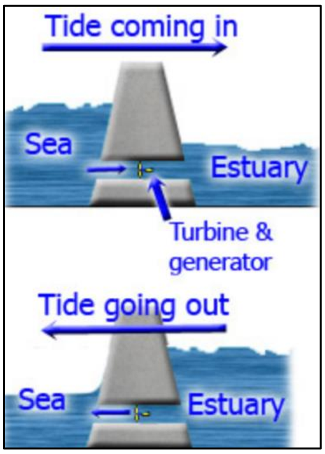


Figure 9: Tidal Barrage example (Tidal Power, 2016)

Tidal barrages are comprised of a system that collects large amounts of water through the utilisation of tidal movements. However, unlike a tidal barrage, a lagoon does not span over an entire water body (TLP, 2015). Instead, it covers a sectioned area across the coastline. This is to increase focus on greater and potentially more tangible tidal ranges. *Figure 10* suggests an example of a double tidal lagoon.

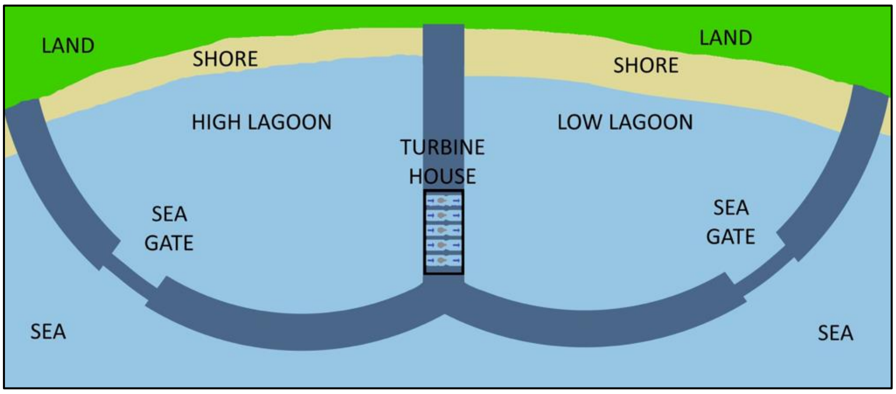


Figure 10: Double Tidal Lagoon System example (Scottish Scientist, 2017)

3.4) Review of Combined Renewable Systems

Consideration has been given to individual devices which are often used in array style configurations. For example, large offshore wind farms around the UK are positioned in a specific manner in order to utilise power most efficiently, whilst still feeding directly to the power grid. As progression is made in the renewable energy sector, combinations of multiple devices are occurring more frequently. It is becoming increasingly apparent that this may be a more desirable approach of using the ocean's behaviour to produce energy. A review of current combined devices, understanding of their site situation and the highlights and challenges of each combination will be accentuated. Similarly, an understanding of costing and other relevant factors shall be outlined. Undertaking this review will provide a greater depth of understanding as to the possibilities obtainable in the UK.

3.5) Current Combined Systems

This section shall outline various combined devices, each of which are integrated, and suggest possible approaches which may be utilised in this project. Some of these devices are not presently commercialised and are still within the research and development stage (R&D).

3.5.1) Floating Power Plant Company

One distinctly respectable combined system has been designed and manufactured by a company named Floating Power Plant (FPP). This company has developed a system which incorporates both wave and wind power harnessing. The device consists of a single wind turbine and a platform which is secured at one point, providing the ability for the device to rotate to the most suitable direction given weather conditions. Roughly 80% of energy present in the waves can be utilised with this device. Renvall (2010) discussed the early stages of the FPP's venture, and how at that point in time the device was the largest of its kind to be developed. This device is known as the P37 device, and is the only device in the world able to produce 'joint power to the grid' (FPP, 2017). The company has developed exponentially since preliminary concepts were established in 1990. More recently, the development of a further device has occurred and is known as the P80. It combines both a singular wind turbine and a wave energy harnessing system, which is semi-submersible (FPP, 2017). An example of this can be seen in *figure 11.*

Power output & Location

There are currently two projects within the UK, which are based in Wales and Scotland. These are the first full scale units, and as mentioned above, are the P80 models. FPP has a target generation of 20GW and expect to locate their device in only 'high wave energy sites'. These two projects are commonly known as Katanes and Dyfed. The Katanes proposal consists of five combined devices, each of which are to be installed in Dounreay on the North Coast of Scotland.

Figure 11: P80 Device (FPP, 2017)

Cost

To date, the company has raised capital of €15m and by 2050 this is predicted to be €50bn. Although data is not widely available for the FPP Company, they have successfully tested the prototypes in Denmark. Speculation however, is currently the only means by which other important costs can be estimated.

3.5.2) WaveStar

WaveStar is another company investing time and research into the development of combined systems. The device currently undergoing a rebuild to improve efficiency is the WaveStar machine, which is primarily a wave device. However, it is strongly suggested that a wind turbine could be used in collaboration with the wave energy convertors. The system is comprised of fixed horizontal point absorbers, which move vertically under wave action (WaveStar, 2017). Development of the device has occured and multiple scaled prototypes have been built and tested. An artistic representation of the device can be seen in *figure 12*.

Power output & Location

A scaled version of the Commerical WaveStar unit has been tested on a site in Hanstholm. This device has a capacity of 110kW and is predicted to generate 45MWhr/year, whilst the commercial device has a capacity of 600kW, and is anticipated to produce 804MWh/year. This is based on a site, which according to WaveStar Energy, is not optimum for this device type, suggesting hindrance of power outputs may be caused.

Cost

Cost has not been officially disclosed, but it is likely to be comparable with other combined systems. This shall however depend on the overall situation, and limited information has restricted the costing statistics for this device.

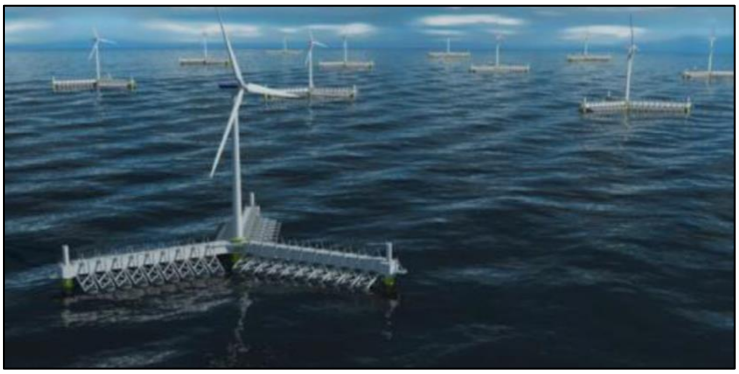


Figure 12: Wave Star Device array (WaveStar, 2017)

3.5.3) OWWE

OWWE is a company engaged in combining offshore energies to generate electricity. The corporation have developed a system based on a WEC patent from 2005, which assessed two fundamental methods to harness wave and wind power. Overtopping, point absorbers and wind turbines can be combined in the device to increase predictability and consistency of power generation. This is known as variability reduction, as was outlined by Fuso et al. (2009). It is known that consistency of power output is the key to success of renewable energy use.

Power output & Location

Stated by OWWE, the system can produce 1TWh per year if situated in an appropriate site for energy generation. Currently, further information is not provided for the OWWE device.

Cost

Information provided for the costing of the OWWE energy system is currently scarce. However, costs for electrical energy generation have been outlined by the company. They anticipate a cost of £0.04kWh ‘in a wave climate of 40kW/m wave front’ (OWWE, 2017).

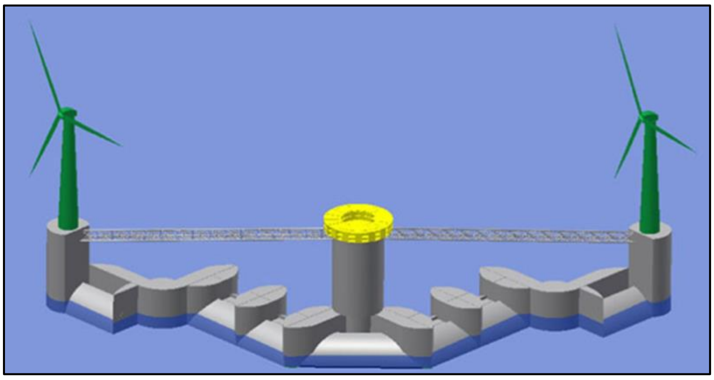


Figure 13: OWWE Wind and Wave Device Schematic (OWWE, 2017)

3.5.4) Wave Treader

Wave Treader has developed a system as a descendant of its previous WEC device. It is known as the Ocean Treader and is a free floating WEC. The sequel device, comprised of both wind and wave energy capturing devices, can generate power from both wind turbines and sponsons. The sponsons 'lift and fall' pressuring fluid, which subsequently spin hydraulic motors allowing for the generation of electrical power (Appleyard, 2009). One evident advantage of this system is its autonomous direction adjusters. Like the P80 device produced by FPP, it bestows the ability to adapt to variations in tidal ranges. This combined system has been recommended for use with stage three turbines, which are the 'third cycle in the government's development' (Appleyard, 2009). Round three turbines consist of stronger, larger and more efficient offshore components suited to rougher conditions, thus allowing the Wave Treader system to be located further offshore in deeper waters. See *figure 14* for a render of the combined device.

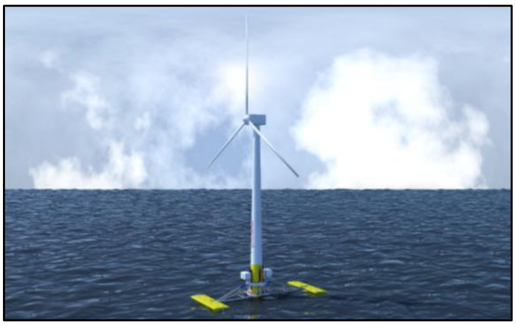


Figure 14: Wave Treader Combined Device (Focus, 2009)

<u>Power output & Location</u>

This device can be compared with the others outlined previously, as it is comprised of wind turbines and WECs. It has a combined power capacity of 500-700kW and commercially, units are expected to have a maximum capacity of 1MW.

<u>Cost</u>

Details on construction and energy generation costs are not conclusive at this stage due to the limited development of the device. Sourcing information for this combined device was particularly difficult, and it is assumed that costings may be proportional to other devices previously outlined.

3.6) Combined Case Studies

A relevant study undertaken in Ireland highlighted the importance of 'variable reduction' (Fusco et al., 2009). As mentioned above, this is a potential benefit of combining different renewable energy devices. The theory underlying this is to reduce the variations in 'power produced’ (Fusco et al., 2009). By exploiting more than one energy type simultaneously, power output consistency is more uniform. Analysis was undertaken in various sites, and calculations capturing power output possibilities were obtained. It was identified that the use of combined systems offers ‘a more reliable, less variable and more predictable electrical power production’ (Fusco et al., 2009), which suggests that this approach may be feasible.

Combined systems have long been considered an effective approach to power small isolated islands. Self-sufficiency is essential in these areas, which are not often connected to the main grid as a result of limited infrastructure and service links. Therefore, it is paramount that they have the resources to supply their own power and reduce CO_2 levels. The study undertaken by Ribeiro et al. (2011) emphasises this problem and although the renewable approaches are based on land, they are very comparable to the feasibility study undertaken in this project. A hybrid system based in Lençóis Island, was analysed and found to consist of two forms of renewable energy harnessing methods. Although a hybrid system varies from a combination of devices, they are still largely comparable. The system is made operational by combining multiple ‘wind micro-turbines’ and PV generators, both of which are connected to battery banks. For periods of low energy generation, a small diesel generator can be utilised for the continual provision of power. The battery banks store excess energy which can be distributed to the connected houses through an AC bus. This study provided further insight into combined cases and the benefits of such systems. Furthermore, it is suggested that by combining methods, power generation is less variable and consistency can be achieved.

This review predominantly highlighted that combinations of devices are considered most feasible when both wind and wave power harnessing methods are implemented. In the UK, the only other principle method of offshore renewable energy generation involves tidal power. This is a resource which shall be further reviewed during determination of devices.

Chapter 4. Site Selection Process

Research undertaken clearly establishes that many factors must be considered when determining the suitability of a site for renewable energy generation. The following sections highlight some of the crucial factors which govern the choice of sites. For example, Kim et al. (2012) highlight the importance of specific site characteristics in promoting the success of a renewable energy project. In particular, they emphasise the importance in attention given to both sea depth and the distance of the site from the shoreline. As these vary (or increase), they impact upon the total costs involved, due to increased challenges during construction. When selecting sites, this will be clearly outlined in the financial analysis stage, and this will be done through life cycle costing. Importantly, in the UK, site selection is limited, as there are many protected areas which are therefore inaccessible, and unable to be considered as potential areas for the instalment of renewable energy plants. Typically, these are sights of special scientific interest (SSSI), or are marine protected areas. Multiple reasons exist as to why these areas may be protected, which shall be outlined if encountered. Below are the main governing factors established, considering these factors, sites will be selected. Particularly where wind, wave and tidal energies may be found to be sufficient for power production.

For this project, two sites, named 'Site A' and 'Site B', will be considered, and selected on the basis of utilising different renewable energy methods. These sites will be discussed following the information reviewed in *sections 4.1-4.5.*

4.1) Site Governing Factors

A report released by the Scottish Government on Regional Locational Guidance (2012), gives a sound indication to site situation and governing factors which influence site choice. The report also contains information on sites which are being further researched for the feasibility of renewable energy implementation. The areas of interest outlined in the study may be considered when determining specific sites. This section contains the factors which influence choices and provides insight into the available offshore energies around Scotland. The Regional report released by the Scottish Government (2012), provided generous detail of the Scottish waters, which is where site A and B will be located. Due to data limitations, the rest of the UK was not considered.

4.1.1) Environmental factors

In the UK, multiple sites are protected from marine renewable activity, this results from various and prolific reasons. For example, installation of large offshore devices may be have a detrimental impact for the estimated 6500 species of sea creatures and plants, which habitats Scottish waters (Scottish Government, 2012). As stated by the Scottish Government (2012), there are 56 SSSIs which are protected, and therefore prohibit the construction of renewable energy device construction

4.1.2) Technical

The technical issues involved in determining a suitable site depend on the system and characteristics of the area considered. Primary factors for consideration include distance from shore, ocean depth, ground conditions and integration to the national grid. Furthermore, particularly rough conditions found offshore will be considered. Finding equitable energies is important and these greatly contribute to the success of a renewable energy project and the longevity of devices. Infrastructure is an important component of the technical aspects, and an understanding of grid connections and power lines has been established from the Regional locational guidance report (2012). Currently, there are 900km of power cables used to connect smaller sub-islands to the national grid (SG, 2012). Understanding the location of these cables may be particularly useful. Installing renewable energy with a direct link to the national grid could be particularly advantageous, resulting in savings with respect to time and cost. *Figure 15* depicts power cables around Scotland (SG, 2012). It is apparent that where smaller islands are disconnected from the mainland, the implementation of these cables has occurred.

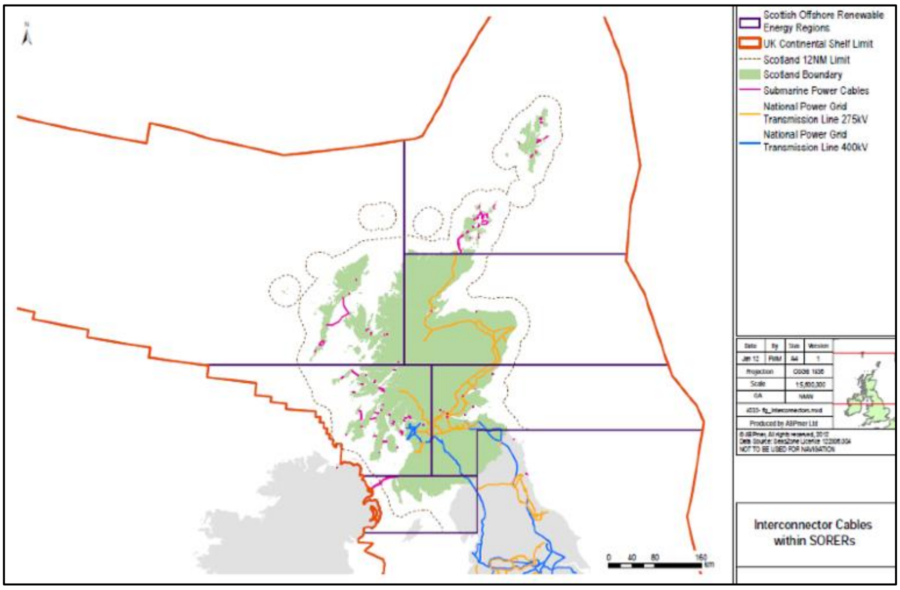


Figure 15: Submerged grid cables around Scotland (Scottish Government, 2012)

4.1.3) Planning

When planning and situating a marine renewable site, consideration of other stakeholders is of paramount importance. Planning with attention to the main activities which are present in the coastal areas around Scotland will ensure conflicts are minimalised. SG (2012) provide useful insight of current site uses, which provide excellent indication as to the suitability of location, whilst considering the impact for other parties using the site. Current site uses and functionalities vary from industrial to recreational activities. In *figure 16* understanding of oil and gas ventures can be understood, sites of which are primarily found in the North and North-Eastern areas of Scotland. However, in the West of Scotland oil and gas activities are less predominant. In total, the oil and gas sector employs around 440,000 people in the UK, and this is reflective of the number of sites in Scotland that utilise such resources. Areas which host oil and gas activities require careful attention, as it may be challenging to implement renewable devices in close proximity to these sites. Another aspect which should be considered when planning a site is military activity. The Regional Locational Guidance report (2012) states that this occurs with moderate frequency in the West of Scotland, with areas being used for training and equipment testing. The installation of offshore marine renewable energy in these areas would likely have a negative impact on the activities which currently take place. In *figure 17* below, are the areas which host defence activities. It must be noted that the use of the sites for military activities are limited, occurring at specific times throughout the year.

Multiple other activities also take place in Scottish waters. These include recreational activities such as fishing and water sports, which also require consideration. Below in *figure 18*, recreational activities included in the Regional Locational Guidance report (2012) are outlined. By taking these into account during the site selection process, disruption will be limited and integration can be more seamless.

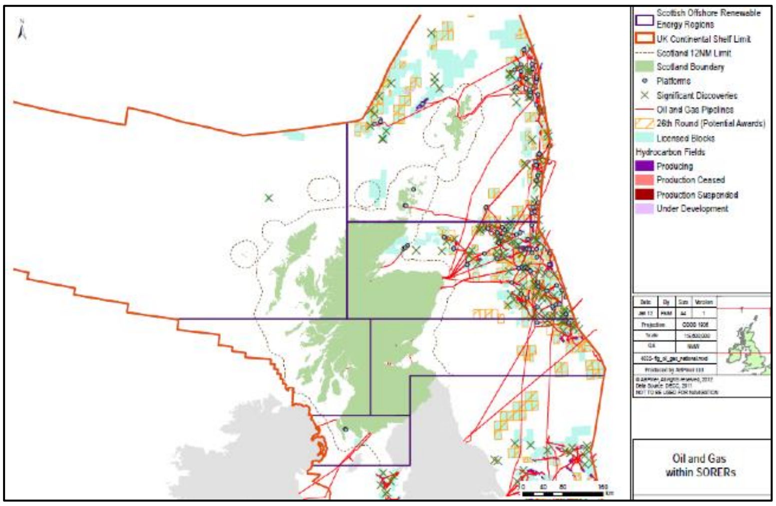


Figure 16: Oil and gas sites in Scottish Waters (Scottish Government, 2012)

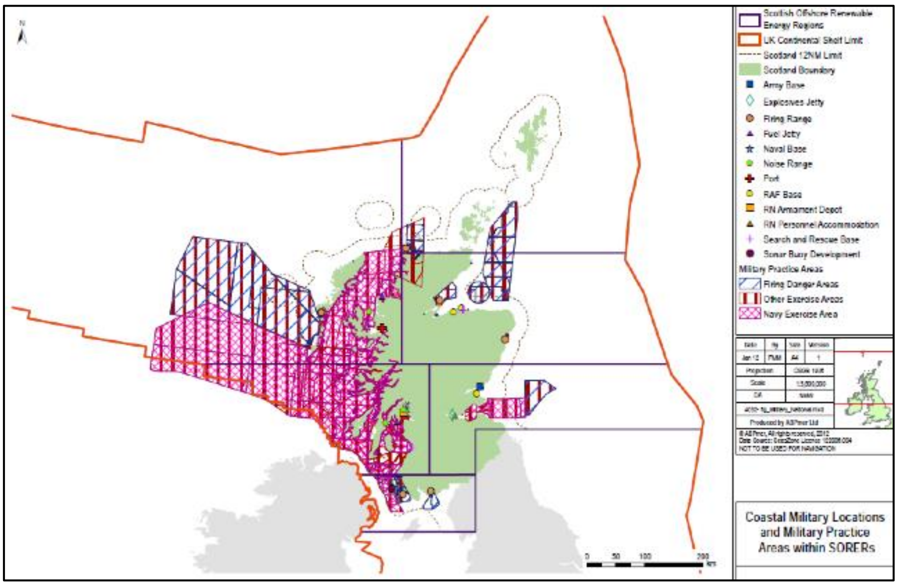


Figure 17: MOD site use in Scottish Waters (Scottish Government, 2012)

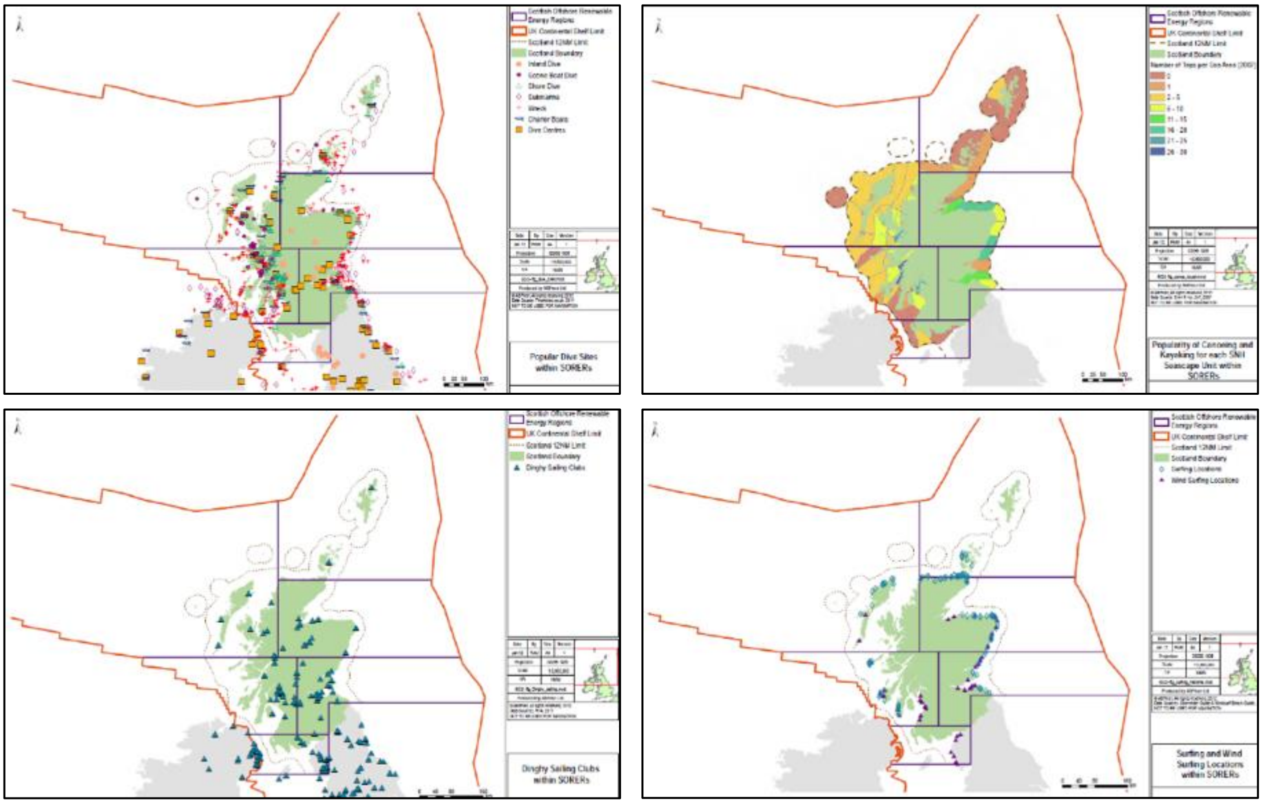


Figure 18: Recreational activities (Scottish Government, 2012)

Furthermore, a crucial factor of site selection to be considered in site selection are the shipping and ferry routes around Scotland. This infrastructure links into many crucial ports, and in 2008 67.4Mt of cargo was transported across Scottish waters. Therefore, it is apparent that Scottish waters are significantly populated by dense shipping routes. *Figure 19* depicts the designated routes around Scotland, and it has been identified that particularly busy routes exist in the

Western zone. Routing is likely due to bathymetry factors, where deeper waters are utilised to prevent beaching of vessels.

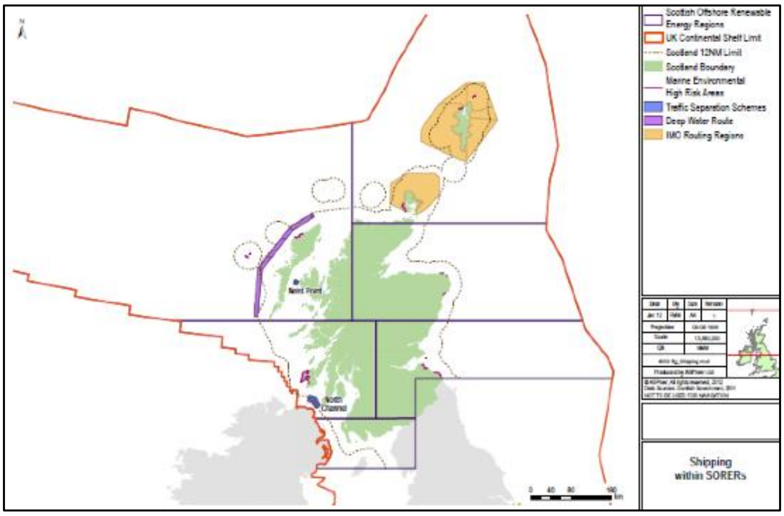


Figure 19: Shipping routes around Scotland (Scottish Government, 2012)

In association with industry, fishing also significantly contributes to the Scottish economy. According to the Scottish Government, roughly £500M worth of fish per year are sourced from Scottish waters. The implementation of renewable energy devices could hinder this industry, and negatively impact the quality and frequency of catches. Coul et al. (1998) mention that the ‘spawning and juvenile fish’ can be disturbed by renewable energy activities, highlighting the importance of appropriate site selection.

4.2) Offshore Regions

For ease of understanding, the Scottish Government (2012) outlined geographical locations. The Regional Locational Document considers the feasibility of offshore renewable energy in these areas and outlines typical wind speeds, wave heights, and power potential. This provided a greater insight into the possibilities of site location, *see figure 20* and *table 1*.

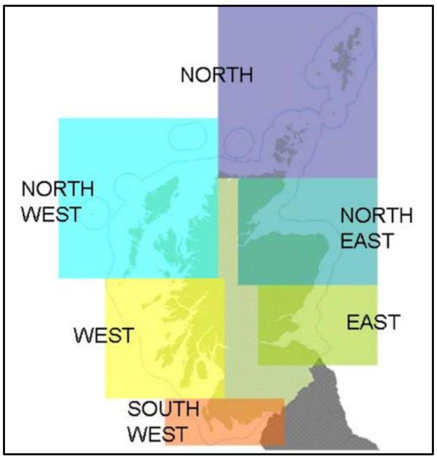


Figure 20: Scottish Offshore Renewable Energy Regions (Scottish Government, 2012)

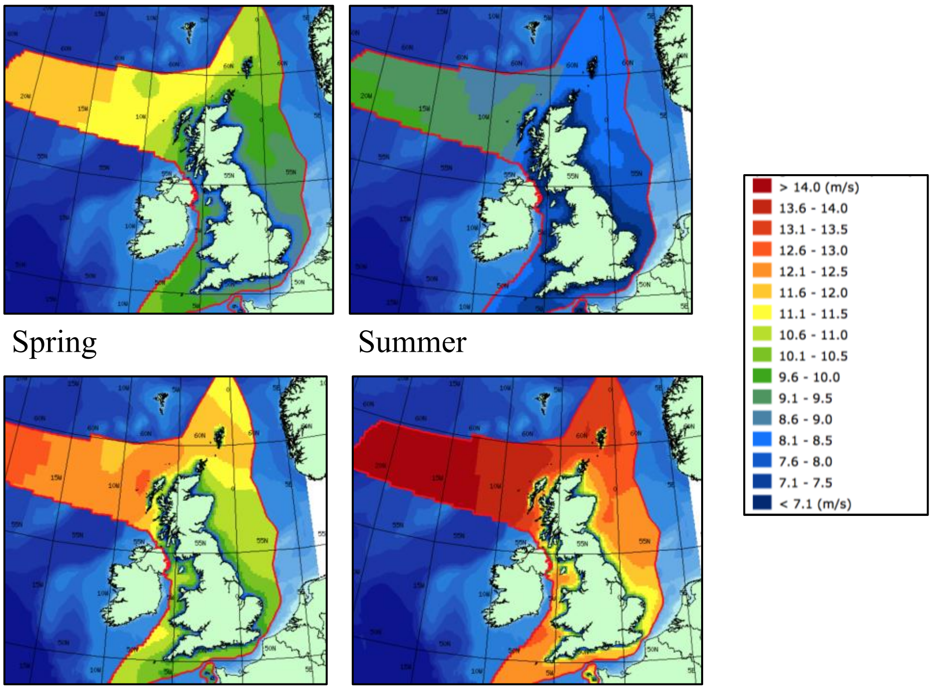
North	North West	North East	West	East	South West
6120 km^2	2250 km^2	2265 km^2	6289 km^2	2640 km^2	980 km^2

Table 1: Regional area sizes (Scottish Government, 2012)

4.2.1) Wind

Some key sites of high wind energies have been established by the Scottish Government (2012). These have been outlined below with respect to the offshore regions outlined *in figure 20 and table 1*. These areas encompass the Scottish territorial waters within 12 nautical miles (nm) and out with this area into the deeper waters up to 12 (nm), which may be utilised with floating structures with expected wind speeds of up to 11.8 m/s.

According to the SG (2012), it could be possible to harness wind power around all coastal areas in Scotland. However, it is suggested that Northern and Western areas are capable of providing the best wind energies. Below are the maps of available energies throughout each season of the year. Following the *figure* and key below, it is possible to depict significant wind speeds. This data has been sourced from the Renewable Atlas (2008), which provides information for wind, wave and tidal energies, and can be seen *in figure 21*. From this, it is suggested that wind energies are plentiful during the spring, autumn and winter. Whilst during summer, wind levels are lower and as a result, energy harnessing is less reliable. This will vary given specific site details, which will be pursued later within this *chapter*.



Spring Summer

Autumn Winter

Figure 21: Wind energies available (Renewable Atlas, 2008)

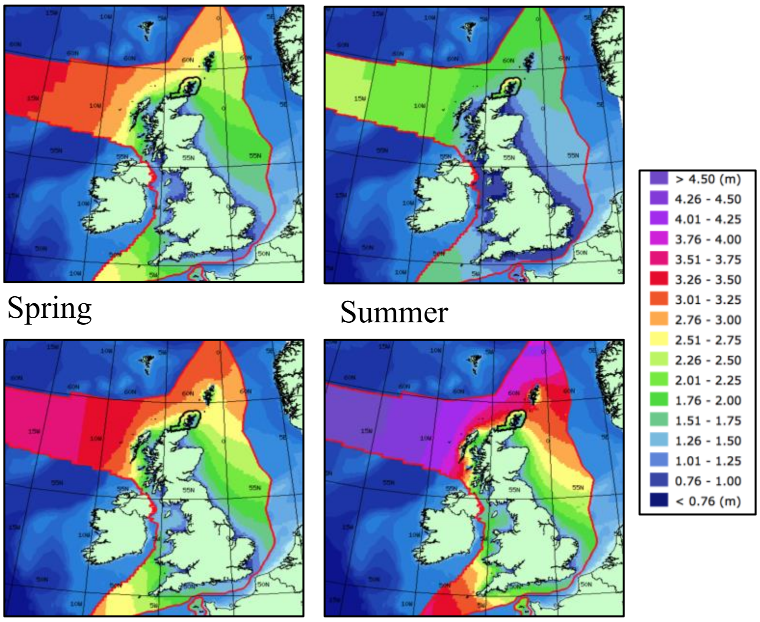
Location	Area
Firth of Forth	East
Moray Firth	North East
Orkney	North
Shetland	
North Minch	North West
Argyll	West
Kintyre	

Table 2: Areas of interest (Wind) (Scottish Government, 2012)

The Scottish Government outlined the locations above as ‘areas of interest’, which suggests that they may be suitable for renewable energy devices. These may be considered as possible site choices. It is particularly clear that northern, western and north-western areas are a good first port of call.

4.2.2) Wave

Below are the available wave energies throughout the seasons of the year. This data has similarly been sourced from the Renewable Atlas model (2008).



Spring Summer

Autumn Winter

Figure 22: Wave energies available (Renewable Atlas, 2008)

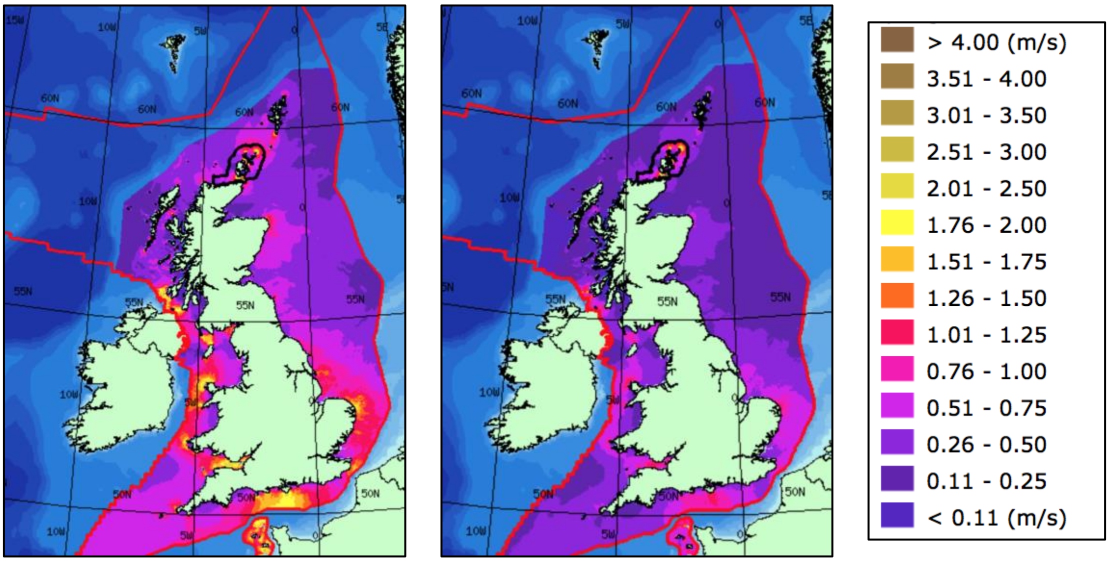
This data suggests that energies for wave power are particularly rich in spring, autumn and winter. From this, a trend can be established with wave energies, which are very comparable to wind energies outlined previously. For example, the locations in which wave heights are seen to be highest, wind energies are also frequently most substantial. Below are the sites of interest outlined by the Scottish Government, as mentioned in *section 4.1*. These will be considered as possible options for site selection.

Location	**Area**
Orkney and Shetland	North
North Sutherland Coast	
North West of Cape Wrath	
West Hebrides	North West
North Cape Wrath	
The Solway Firth	South West
West of Hebrides	West

Table 3: Areas of interest (Wave) (Scottish Government, 2012)

4.2.3) Tide

UK tidal data has also be sourced, with particular focus on Scotland, as outlined in *section 4.0*. *Figure 23* illustrates the available tidal spring and neap flows. It can be seen in the map that where water spans are reduced, tidal speeds generally increase. For example, between Ireland and Scotland (west area), tidal speeds are much higher.



Spring Flow Neap Flow

Figure 23: Tidal energies available (Renewable Atlas, 2008)

Table 4 below outlines primary regions which are suggested by the Scottish Government as being most suitable for the situation of tidal energy generating devices. These will be considered in site selection.

Location	**Area**
The Pentland Firth	North
Orkney and Westray	
Sumburgh and Fair Isle	
North Skye	North West
South West Islay	West
The Solway Firth	South West

Table 4: Areas of interest (Tidal) (Scottish Government, 2012)

4.3) Site Selection Review

From the sourced literature and current documents released by the Scottish Government (2012), it is apparent that multiple areas of interest exist. These areas have been considered when determining suitable locations for the multiple renewable energy devices. The renewable energy devices will be selected with consideration given to the energies present at the chosen sites. Furthermore, due to the limited information available for the rest of the UK, the devices will be placed in Scottish waters. Following a review of the available energies shown in *section 4.2*, it was possible to narrow the search for suitable sites. Initial decision on site selection was based on the energy generation potential encountered. From this point, selection was finalised based on the governing factors outlined in *section 4.1.* Future ventures would require more detailed site information, which was unavailable at the time of this study. Information regarding social, technical and planning aspects has been outlined above. These allow for a greater understanding of site suitability, as well as the assets and liabilities of each area. These will be highlighted upon selection of each site.

4.4) Determined Sites

Through reviewing literature, it was possible to gain a greater understanding of the waters and site characteristics of areas around Scotland. This crucial task allowed for progression of this project. Consideration of the weather, bathymetry, social, planning and environmental factors have been outlined for each site. The main governing factors which were important in choosing sites have been previously outlined in *section 4.1.* As a result of this, it is possible to determine suitable devices and power outputs. Site data for wave, wind and tidal information was relatively scarce and difficult to obtain. Where data was limited, assumptions were made, which are outlined when implemented.

4.4.1) Site A (57.233683, -7.555986)

Site A shall be located on the North West of Scotland, this shall allow for utilisation of higher wind levels and more predominant wave propagation, which is generally witnessed in this region. Implementation of devices which utilise both wind and wave energies would be suitable. The site is situated in the waters close to South Uist, a settlement which has a total population of 1818 people, and is comprised of several small towns on the Outer Hebrides Island. Below in *figure 24*, is a map of the proposed location. An indication of water depth at this site and relevant weather data can be reviewed in this section. According to the SG (2012), typical electricity consumption is higher than the Scottish average of 5.7MWh. Based upon 2009 figures, the rate in this area per household is 8.2MWh.

Figure 24: Site A location (Google Earth, 2017)

Site A: Characteristics

Site A is located off the coast of South Uist. The proposed location is approximately 6.00km from shore, and below are the characteristics of this selected site.

Energies

CEFAS (2017) provided data for the area chosen, which allowed for the determination of wave periods, whilst significant seasonal values of wave heights were provided by the Renewable Atlas resource (2008). Similarly, the Renewable Atlas (2008) proved useful in the determination of wind speeds.

Wave

Using one year's worth of data provided by CEFAS (2017), it was possible to establish wave periods and average these seasonally. Also adopted are the significant wave heights provided by the Renewable Atlas (2008), combining these with the determined average wave periods, power output from specific devices is achievable.

Overall, throughout the months of autumn and winter, wave heights their subsequent periods are predominantly higher, whilst in summer and spring, these are generally lower. Illustrated below, are the average wave heights and periods which have been determined by utilising the data obtained from CEFAS (2017) and the Renewable Atlas (2008). The buoy data, graphed in *figure 25* allowed for estimation of the wave periods (s). The significant wave heights (m) taken from the Renewable Atlas (2008) appear much lower than the wave heights (m) experienced at the buoy, shown in *figure 25*. This is likely due to the location of the buoy, which is positioned some distance from the proposed site and considerably further from shore, resulting in greater exposure. Wave information has been summarised in *table 5* and will be particularly relevant during the calculation of power outputs, upon determination of devices.

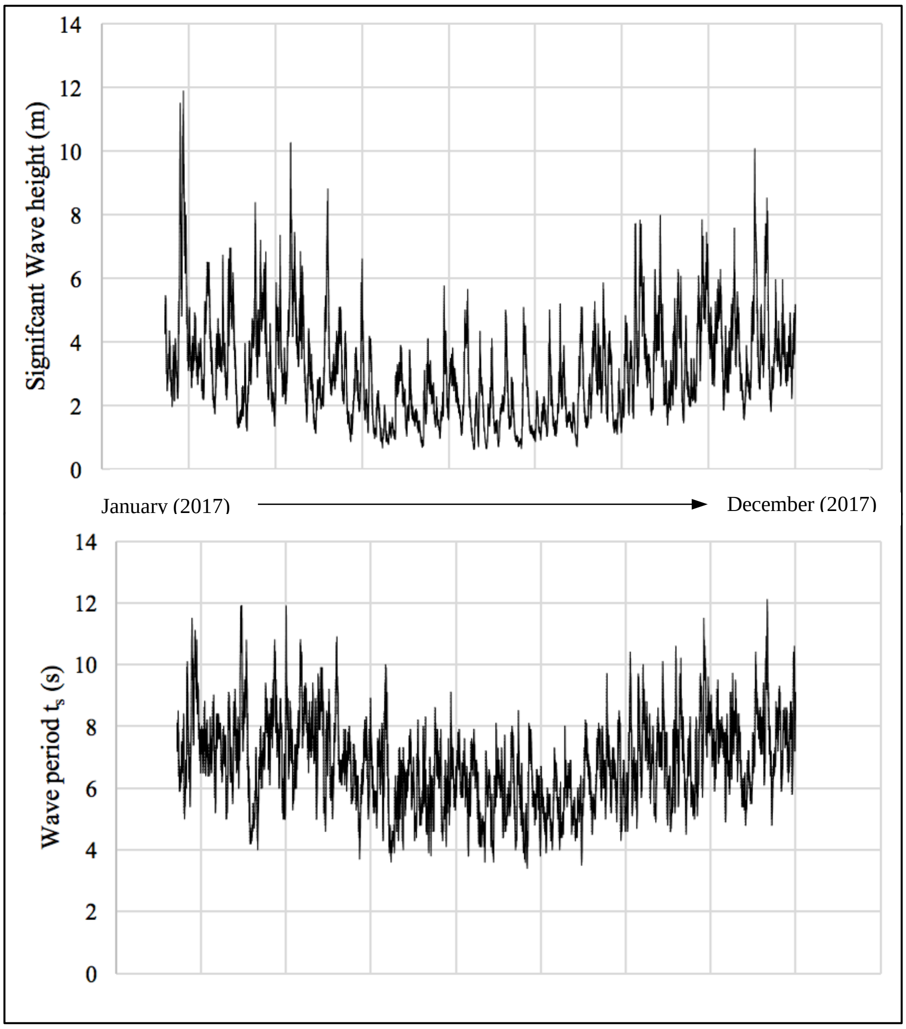


Figure 25: Wave heights and periods (Site A) (Cefas, 2017)

Season	Significant Wave height (m) (RE Atlas)	Wave period (s) (CEFAS)
Winter	2.88	7.44
Autumn	2.63	6.71
Summer	2.13	5.71
Spring	2.88	7.14

Table 5: Significant wave heights and periods (Site A)

Wind

Wind data has also been acquired from the Renewable Atlas (2008), significant wind speeds (m/s) for each season are shown in *table 6* for site A.

Season	Significant Wind Speed (m/s) (RE Atlas)
Winter	13.3
Autumn	10.8
Summer	9.3
Spring	12.3

Table 6: Significant wind speeds (Site A)

Bathymetry and Seabed Conditions

Water depth has been considered as an important factor, which will influence the choice of structure used to support the structure. It must be appraised during the feasibility study, as increasing depths can result in significantly larger costs and complexity of construction. The water depth at this site is roughly 20 metres, at this depth issues are unlikely to be experienced and conventional methods previously outlined shall suffice. Through the use of geological maps made available on Google Earth, it has been established that the seabed mainly consists of course sediment. These ground conditions may pose difficulties when determining foundation types. However, for this project, it has been assumed that they shall be appropriate.

Social Factors

Previously outlined in *chapter 2*, overall offshore social factors in Scotland suggested some issues may arise by means of locating offshore renewable energy devices in a given area. This site provides opportunities for the enjoyment of specific recreational activities, and thus members of the public may be averse to the installation of large structures. However, this has been considered, and the site is deemed far enough away from the shore to be overly obstructive. More positively, installing renewable energy devices in this area would likely produce employment opportunities, satisfying the resultant requirement of both skilled and non-skilled labour. Generating electricity will also provide wealth for the area, presuming that the devices generating energy are equitable. Information regarding profit and costing will be outlined in the economic analysis, *see chapter 7*.

Planning Factors

Planning aspects have been considered in choosing this site. According to the SG (2012), numerous fin and shellfish habitats exist in this area and throughout the whole North-Western region. However, these are predominantly found on the most Easterly side of the Island (South Uist), and therefore pose little obstruction for the suggested site.

Military movements in this area must also be examined, as the selected site falls within Navy exercise areas. As previously outlined, these occur annually and infrequently. With advanced planning, they are unlikely to prohibit activity. Installation of offshore renewable services, should not cause major issues in this area.

Consideration of flight paths and zones of low flying aircraft are important as there are numerous small airports located in the Outer Hebrides. However, conflicts are unlikely to occur due to the scale of the renewable project, which is relatively minute. The site should directly interrupt shipping routes and it can be said that the site does not conflict particularly with any harbour. However, adequate lighting and illumination of turbine masts should be implemented and adequately mapped for marine movements, such as shipping routes.

Recreational activities in this area are relatively high, with numerous sports undertaken in the North-western waters, as outlined above. It has, however been deemed that the site is distanced far enough from the coastal areas where greater densities of recreational activities take place, thus causing little conflict.

Environmental Impacts

Situating renewable energy devices entails risk for marine life, particularly during device construction. Therefore, it is crucial that appropriate measures to reduce disruption are in place. For example, pile drilling as opposed to driving would reduce noise and vibration levels heard and felt by sea creatures. This area is home to various large sea mammals such as seals and basking whales, and therefore some form of deterrent should be used to discourage animals from approaching the renewable device. Subsequently, this would protect sea creatures from harm and prevent downtime of devices. Non-moving parts such as foundations, do not pose any immediate risk to sea-life, aside from the disruption caused by construction and contamination of water. In addition to sea creatures, birds are also affected by the undertaking of offshore renewable energy projects. Harm to birds can occur if they are struck by turbine blades, and this must be considered. The site has numerous RSPB reserves and adequate planning should be considered when installing turbines.

Summary of Choice

The information outlined above suggests the site may be suitable for renewable energy harnessing. The North-Western region is known to have no main power stations, as mentioned by SG (2012). However, there are various subsea cables in-situ which can be used to transfer power back to the mainland. The site appears to host numerous beneficial factors, which typically govern the feasibility. By determining power outputs and performing an economic analysis further feasibility will be established.

4.4.2) Site B (55.568734, -6.369026)

Site B will be in the West of Scotland and, as it is situated relatively close to shore, it will accommodate the systems of tidal and wave power. It is based approximately 4.00km from shore and almost 15.00km to the nearest port. The site is based around the small island of Islay which occupies 3228 inhabitants and 1479 households, as outlined by the Islay census report (2011). In the West region, electrical consumption per household according to 2009 figures suggest 5.0 MWh, which is 0.7MWh less than the Scotland average (SG, 2012).

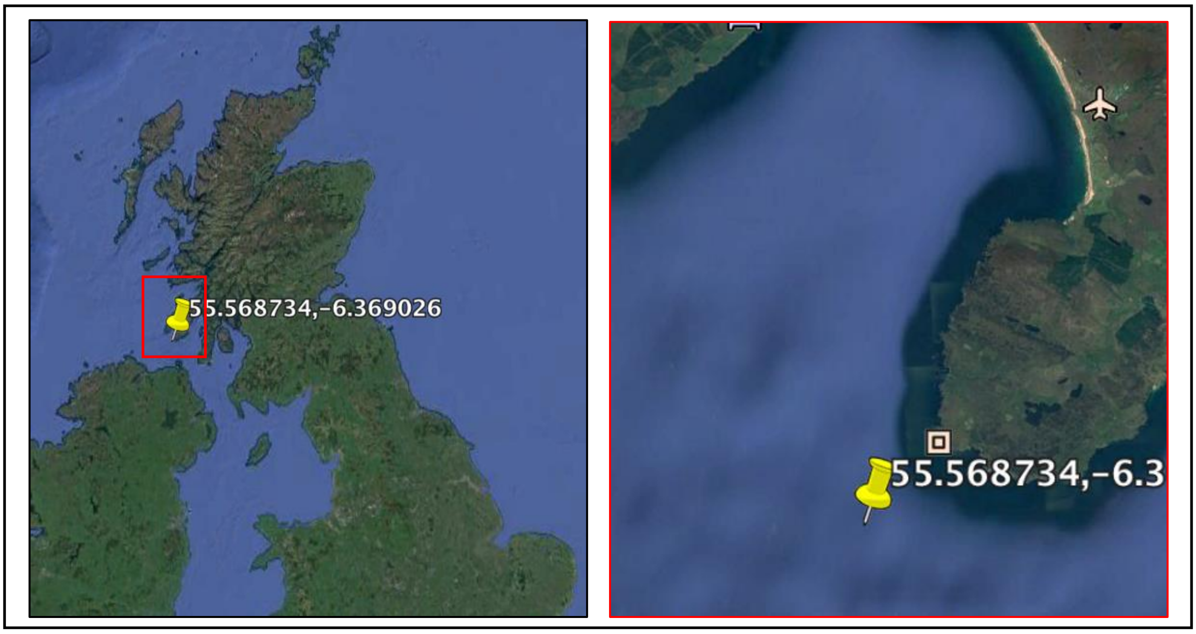


Figure 26: Site B location (Google Earth, 2017)

Site B characteristics

Energies

It has been established that tidal ranges in this site are particularly strong as are wind speeds which suggest potential feasibility. *Table 7* outlines annual wind and tidal speeds.

Annual Average Spring Tide (m/s)	**Annual Average Neap Tide (m/s)**	**Annual Average Wind Speed (m/s)**
3.01-3.50	1.51-1.75	10.1-10.5

Table 7: Average tidal & wind speeds (Site B)

Table 7 above provides annual average expectancies for the chosen site. It is known that seasonality shall not affect tidal ranges drastically, and therefore tidal velocities will be considered by their neap and spring tide values. Further to the outlined average velocities, a report which considers varying tidal velocities in numerous sites throughout the UK, outlines tidal velocities of a nearby port. *Figure 27* depicts the tidal velocities which have been outlined by Clarke et al. (2004). These velocities are provided for a 24-hour cycle, for both neap and spring tides.

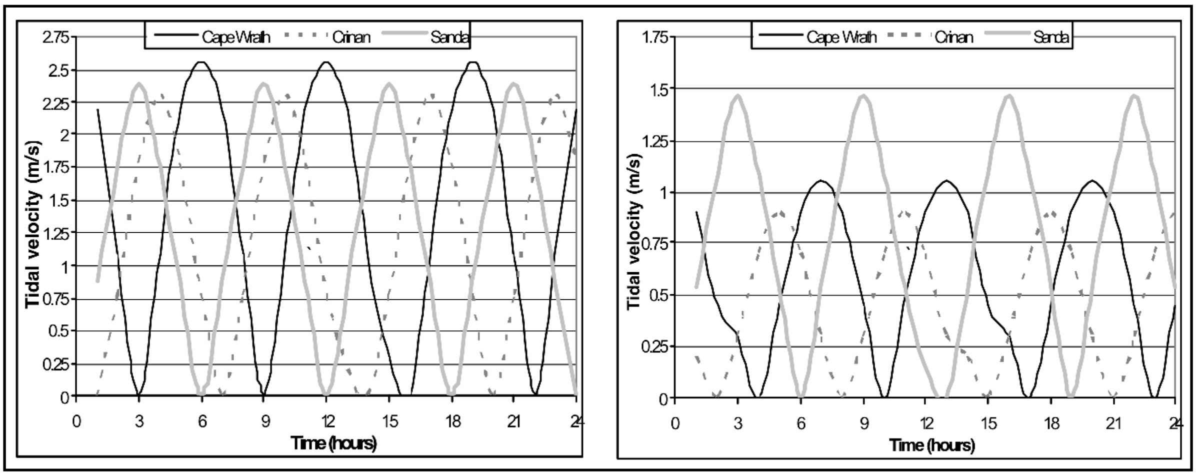


Figure 27: Tidal velocities (Site B) (Clarke et al., 2004)

Below in *table 8*, are the expected significant wind speeds during each season at this given site. This information has been sourced from the Renewable Atlas (2008), the methodology used by the Renewable Atlas to determine these significant values is further expressed in the data analysis section of which can be found in *chapter 6*.

Season	**Significant Wind Speed (m/s) (RE Atlas)**
Winter	11.3
Spring	10.8
Summer	8.3
Autumn	10.8

Table 8: Significant wind speeds (Site B)

Bathymetry and Seabed Conditions

Water depth at site B is comparable to that at site A, it has been determined to be 15-20 metres deep. It has also been determined that the seabed is comprised of primarily sand, and muddy sand. Taking this into account, it is likely simple foundations systems can be utilised. The tidal device will sit on the seabed and a gravity based foundation (GBS) will be a suitable option.

Social Factors

Numerous social benefits would occur as a result of renewable device installation in this coastal area. Firstly, many jobs would be established and cleaner energy would be procured. Through the passage of time, it would be expected that energy costs would be significantly lower and this potential of this shall be outlined in the economic analysis. Unfortunately, recreational sports, tourism and fishing would be negatively impacted as a result of this site situation. However, the disruption of recreational events would require further time and additional surveying. For this project, it is assumed that the negative outcomes of renewable energy device construction would not be substantial enough to render the site as unsuitable.

Planning Factors

An understanding of this site's main features, and the way by which they contribute to the logistics and planning aspects, are important. Like site A, aquaculture is quite plentiful in this Westerly region, with numerous finfish and shellfish sites presently occupying it. To reiterate, however, the site itself does not have an adverse impact on any of these farms.

According to the Marine document produced by the Scottish Government (2012), there are numerous major and minor airports in the vicinity, with low flying planes expected within the area. However, most flight in this area is controlled by air traffic controllers at NATS. By adequately illuminating wind turbines and the updating relevant flight path information, this issue will be remediated.

As was the case at site A, military activities also occur in this area. Therefore, adequate warning and future planning of these shall be required as essential knowledge. It is unlikely that coastal military training will pose high levels of disruption, and similarly, situating a renewable site is unlikely to cause major obstruction. The site is also home to numerous nature reserves and protected sites located close to the coastline. To reduce damage infliction of these protected areas, locating the renewable project out with the thresholds has been the most appropriate solution. The selected site does not pose any immediate disruption to the protected sites around the coast of Islay.

Environmental Impacts

As the environment is ultimately the main priority, ensuring that further damage is not inflicted is particularly important. The location of this site has been considered and determination of potential environmental impacts have been sought out, the conclusion drawn is that negative impacts upon the environment would be limited. However, further study is required to confirm this, and furthermore, the long-term environmental impacts of offshore renewable energy remain limited. Encouragingly, the positives outweigh the negatives, influence of marine life should however be considered and deterring large animals from being struck by submerged tidal turbines will be important. This can be achieved through several systems, which are likely to be incorporated in the devices selected.

Summary of Choice

Overall, it is apparent that this site is capable of harnessing energy from both wind and tidal resources. Consideration of the main planning issues and environmental impacts have been outlined above, which at a preliminary stage is suggestive of the site’s feasibility. Furthermore, the site is currently an area of research for the Scottish Government, which is immediately suggestive of its potential. It is now possible to select suitable devices and determine their estimated power outputs.

Chapter 5. Device Selection

In the previous *chapter 3*, harnessing methods were reviewed, and current devices outlined. The following analysis provides a more concise understanding of individual device performance and capability, in order to establish those most suitable for use at each site. In attempts to source energy continually, two different types of energy will be harnessed of which have been chosen following the outcome of site selection in chapter 4.

5.1) Wind Devices

The wind energy devices which shall be reviewed are outlined in *table* 9 below.

Device	Power Output	Manufacturer
HyWind (SWT-6MW) Siemens	6 MW	Masdar/StatOil
6.2M126	6.15 MW	Senvion

Table 9: Wind devices reviewed

Wind turbines currently available are all similar and relatively comparable. Offshore turbines are larger than traditional onshore turbines, and have power capacities ranging from roughly 4-6MW. Therefore, all devices display similar strengths and weaknesses.

5.1.1) Siemens SWT-6MW (Hywind)

This Siemens wind turbine has a power output of 6MW. It is currently commissioned and the most striking operation is on the first floating wind plant in Scotland. The devices are floating structures located further afield than most other offshore wind turbines, and general can be flexibility positioned. The Siemens turbine was developed in 2009 as a joint venture by both Siemens and Statoil, and is praised for its direct-drive, meaning gearless operation thus saving costly and timely maintenance throughout its servicing life. The floating farm is known as Hywind, and has previously been discussed in *chapter 2*. The positioning of the turbine is flexible, and it is best located at depths of between 120 and 700 metres. The turbine is inherently known for its flexibility, and in 2014, two SWT turbines were installed onshore in Germany. The device has also been supplemented with numerous technologically ‘innovative’ advancements. For example, the system can operate during times of particularly high wind speeds. Rather than shutting the system down as with traditional methods, it will lower the power-output above cut-out speeds, protecting components, whilst still generating energy.

5.1.2) Senvion

The Senvion turbine has a capacity of 6.15MW and is currently used in numerous offshore wind farms. For example, the Beatrice Project based in Scotland is hosts Senvion wind turbines. Unlike the Siemens device, the Senvion has a gearing system, which is a more traditional and proven approach. Device data mentions that this turbine has higher cut-out and lower cut in speeds than the Siemens turbine, likely due to the long-established gearing system utilised. In total, over 120 turbines are currently installed according to Senvion. Unlike the Siemens device outlined above, conventional methods of fixed foundations are used for the Senvion, and it is not currently used in floating conditions. The Senvion is therefore likely a more suitable device, given the ocean depths at the proposed sites, as outlined in chapter 4

5.2) Wave Devices

In *table 10* wave devices are outlined, which shall be analysed with the use of strength and weakness analysis. The devices selected for analysis vary in the way by which they utilise energy from waves. However, information on how they do this has been outlined previously in the review of renewable methods. Understanding the positives and negatives of wave energy devices proved particularly difficult. This is due to a competitive market where establishing relevant information can be taxing.

Device	**Power Output**	**Manufacturer**
AquabuOY (buoy)	3 MW	Finavera
LIMPET (OWC)	0.25 MW	WaveGen
WaveDragon (Overtopping)	7 MW	Wave Dragon
Pelamis (Attenuator)	0.75 MW	Pelamis Wave Energy

Table 10: Wave devices reviewed

5.2.1) AquabuOY

This device is a buoy (point absorber) which oscillates utilising the wave energies. Specifications stated by the manufacturer (Finavera) outline that this device has a power output of 3MW. The AquabuOY is 3 metres in diameter and at its current operational location, it is moored to the sea bed using a 22-metre shaft. One of the main concerns surrounding this device stems from a sinking, which occurred in 2007. Page (2007) outlined the event, and suggested that this has caused some controversy, as device was designed to withstand storms with the likelihood of occurrence being 100 years. System life expectancies were said to be of approximately 20-years, and the device failed after only seven weeks. At the time however, the scaled device had a life expectancy of around 3-months, according to Clark (2007). Encouragingly, modelling and real-time data correlated and the device was performing as conjectured.

5.2.2) LIMPET (Land Installed Marine Power Energy Transmitter)

The LIMPET device is an Oscillating Water Column produced by WaveGen. Based in Scotland, the device has been installed and in operation for 10 years (RE Focus, 2010). The main benefit of this device is location. Being situated on the coastline, the site is much more accessible in comparison to other wave energy devices. The device replaced a previous 75 kW system which was in service since 1989. The current system has been providing energy to the grid since installation. A further benefit of this device is that it is technologically proven, having survived countless large storms, including a one in 50-year storm. Disappointingly however, the device has produced lower outputs than anticipated, likely due to variating inputs and inefficiencies of device components (Whittaker et al., 2003).

5.2.3) WaveDragon

The WaveDragon is an overtopping device, produced by WaveDragon. The device is obtainable in four different sizes, which range from power outputs of 1.5MW to 12MW (WaveDragon, 2017). The first prototype was released in 2003 and is known to be one of the first WEC devices to generate energy to the grid. According to WaveDragon (2017), there are several positive factors involved with this system, primarily costs. The device has been designed to limit maintenance costs, and this has been accomplished through implementation of well standardised technology. It is described as a ‘scalable solution’, and their prototypes suggest that such a device would operate efficiently in a commercialised manner.

5.2.4) Pelamis

The Pelamis is another WEC device which can be utilised to source electricity through the energy conversion of waves. This device is known as a line-absorber, or an attenuator, and generates energy through strategic positioning, which is typically perpendicular to the waves. The system allows for a smooth power output through use of a ‘power take off system’. This is a hydraulic system used to reduce the motions present in waves, allowing for conversion to useable electricity. The device initially developed in the UK has been used to scale, being one of the first devices to send electricity to the grid through subsea cables. Numerous generations of the Pelamis had undergone testing, but in 2014 the company developing the Pelamis went into administration, and was bought for small value of £1.00 by the Orkney council. Despite this, the device will likely be assessed due to its developed nature and the availability of technical information. The Pelamis device boasted its ease of maintenance as it was possible to remove the device from the site and tow into shore for servicing and maintenance. Studies conducted during testing phases suggested that the Pelamis device did not cause significant disruption to marine life.

5.3) Tidal Devices

Tidal energy generation is a relatively new venture, with a rapid influx in research and development in recent years. Two devices have been outlined in *table 11* below and will be analysed using information available from the manufacturers and similar studies. From this, speculation of the most appropriate device for use in this project will be expressed.

Device	**Power Output**	**Manufacturer**
SeaGen (Turbine)	2 MW	SeaGen
Nova (Turbine)	100 kW	Nova Innovation

Table 11: Tidal devices reviewed

5.3.1) SeaGen

The SeaGen device is a tidal turbine which generates power through utilisation of the tidal ranges found offshore. Currently installed in Northern Ireland, it has been generating electricity for numerous years. This device is operating at a commercial level and is known for its high yields. By encapsulating both tides it is able to operate efficiently, achieving greater energy generation. There are however weaknesses which have been identified during the years of operation. Concerns that tidal devices cause disarray to marine life have been voiced. However, one study on the SeaGen device suggested otherwise. Tidal Energy Today (2016) stated that the tidal turbine situated in the Northern Irish Sea caused no real obstruction to seals. This was established following analysis of the tags attached to 32 seals. It was found that the seals did not react in an uncharacterised manner during operation of the SeaGen turbine. Upon completion of this testing period, the device was removed in 2017. Throughout 9 years of installation the device generated 10GWh of electricity. The latest device to join the SeaGen fleet is a 2MW version, a sequel to the previous SeaGen model.

5.3.2) Nova

The Nova turbine, like the SeaGen, is a fully submerged tidal turbine. The turbine itself has an output of 30KW. NOVA is one of the leading companies in the development of innovative methods of tidal energy. Currently based in Edinburgh, they have produced several turbines and installed them in array formations. One such formation is based in Shetland and is comprised of three NOVA turbines. These turbines are a development of their initial 30kW devices, the Nova 30. The Shetland array is connected to the grid and is producing electricity.

This is the first phase of development and they expect to situate more turbines here as phases transpire.

5.4) Analysis Review

Overall, the review showed that each device has multiple strengths. However, in many cases the disadvantages outweighed the advantages. Through consideration of this review, the following devices have been deemed the most suitable. *Section 5.5* outlines the determined devices for each site.

5.5) Determined Combined Devices

Below are the combinations, which are comprised of various commercial and research stage devices. The systems chosen adhere to the selected sites, A and B. They have been appropriately chosen based on the available energies of each site. The combination of devices complement each other and it is predicted that they will support a less variable power output as an outcome of utilising two forms of energy.

5.5.1) Combination of Devices: Site A

Combination A, outlined in *table 12*, utilises both wind and wave energy harnessing techniques. The device will be situated in waters which are not notably deep, allowing for the use of a fixed foundation for which the turbine will be installed. The wave device will be located nearby, taking advantage of the interconnected submerged cables in the vicinity. Pairing this with site A, as previously outlined, it is likely that the combination will reap the strong energies available.

Wind Device	**Wave Device**
Senvion (6.2MW)	Pelamis WEC (0.75MW)

Table 12: Combined device (Site A)

Technical Specifications

Technical specifications have been sourced from both manufacturers, and similar research studies, and shall be utilised in *chapter 6* when determining power outputs of the devices.

Senvion 6.2MW

Figure 28 below, illustrates the power curve provided by the Senvion manufacturer's handbook. This graph will require the use of linear interpolation to determine power outputs, in instances where wind speeds fall between two clear points. As a result, this allows for more accurate representation of the site's potential. Key information can also be seen in *table 13* below.

Cut in Speed (m/s)	3.5
Cut out speed (m/s)	30
Nominal wind speed (m/s)	13.5

Table 13: Key details (Senvion)

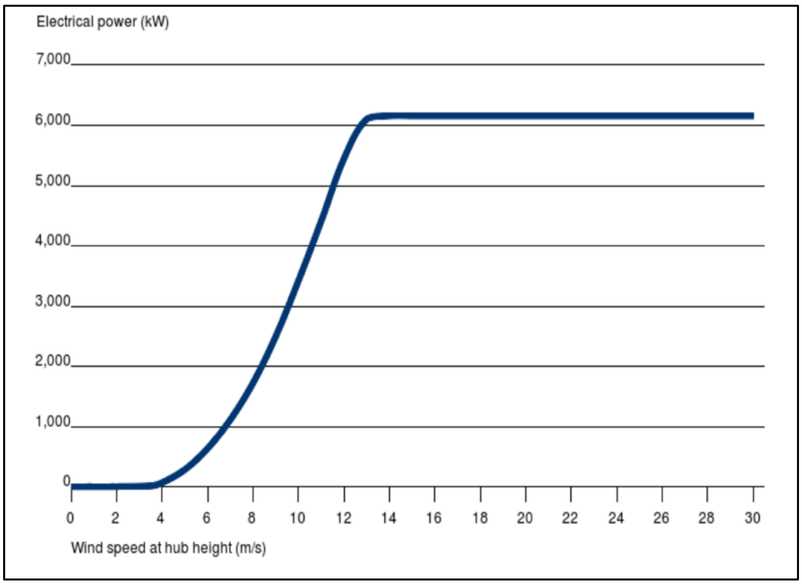
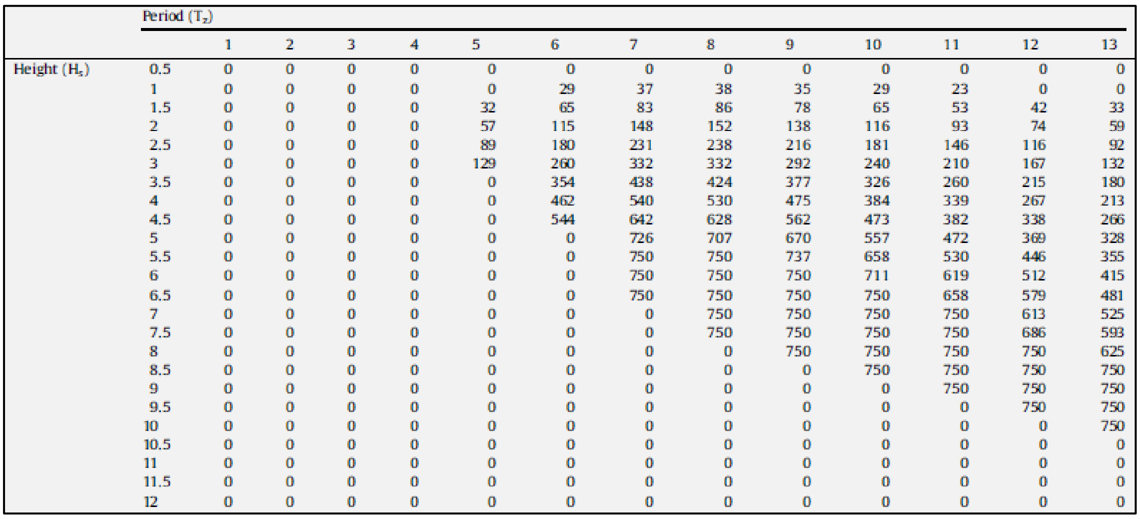


Figure 28: Senvion Power Curve (Senvion, 2017)

Pelamis

Technical information was arduous to obtain for this device, however a matrix was sourced from the work of Dalton et al. (2017) and can be observed below in *figure 29.*



		Period (T_z)												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Height (H_s)	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	0	0	0	0	0	29	37	38	35	29	23	0	0
	1.5	0	0	0	0	32	65	83	86	78	65	53	42	33
	2	0	0	0	0	57	115	148	152	138	116	93	74	59
	2.5	0	0	0	0	89	180	231	238	216	181	146	116	92
	3	0	0	0	0	129	260	332	332	292	240	210	167	132
	3.5	0	0	0	0	0	354	438	424	377	326	260	215	180
	4	0	0	0	0	0	462	540	530	475	384	339	267	213
	4.5	0	0	0	0	0	544	642	628	562	473	382	338	266
	5	0	0	0	0	0	0	726	707	670	557	472	369	328
	5.5	0	0	0	0	0	0	750	750	737	658	530	446	355
	6	0	0	0	0	0	0	750	750	750	711	619	512	415
	6.5	0	0	0	0	0	0	750	750	750	750	658	579	481
	7	0	0	0	0	0	0	0	750	750	750	750	613	525
	7.5	0	0	0	0	0	0	0	750	750	750	750	686	593
	8	0	0	0	0	0	0	0	0	750	750	750	750	625
	8.5	0	0	0	0	0	0	0	0	0	750	750	750	750
	9	0	0	0	0	0	0	0	0	0	0	750	750	750
	9.5	0	0	0	0	0	0	0	0	0	0	0	750	750
	10	0	0	0	0	0	0	0	0	0	0	0	0	750
	10.5	0	0	0	0	0	0	0	0	0	0	0	0	0
	11	0	0	0	0	0	0	0	0	0	0	0	0	0
	11.5	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 29: Pelamis power matrix (Dalton et al., 2017)

5.5.2) Combination of Devices: Site B

Combination B differs from combination A. The proposed devices will be situated even closer to the shore and shall utilise wind and tidal energy. Below in *table 14* are the devices which are used to create this combination.

Wind Device	**Tidal Device**
Senvion 6.2MW	SeaGen Turbine

Table 14: Combined device (Site B)

Technical Specifications

Senvion

Technical details for the Senvion wind turbine can be seen above in *section 5.5.1*.

SeaGen Turbine

Technical details of the SeaGen turbine have been sourced from the SeaGen brochure, which provided sufficient details required to conduct power output calculations. In *figure 30* below, the power curve for this device has been shown. It has been stated that the device cut-in speed is 1 (m/s) and the device will reach its capacity output at 2.5 (m/s) (Marine Current Turbines, 2017). It is also known that the drivetrain weighs a total of 60 tonnes. However, as designing foundations is not a main objective of this project, it is unlikely that the device weight will be utilised.

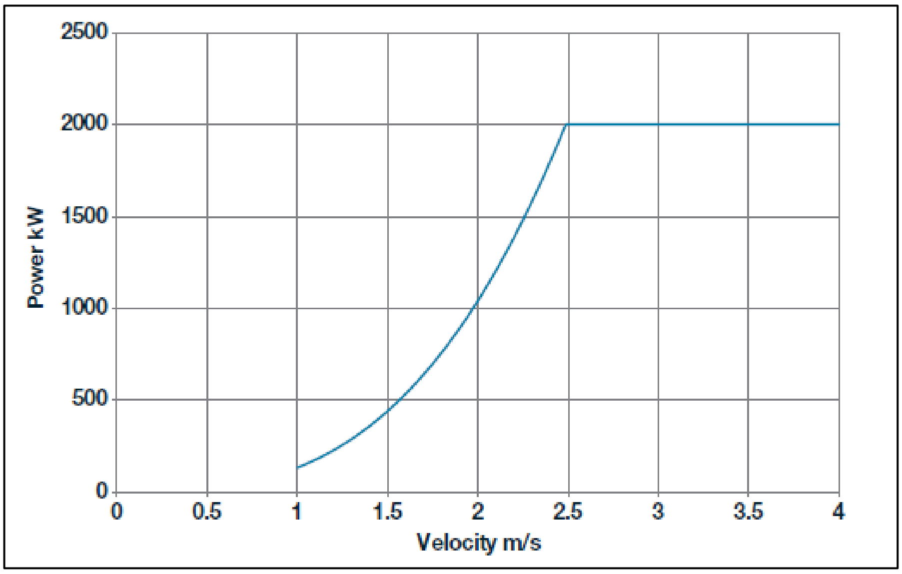


Figure 30: Power curve SeaGen Turbine (MCT, 2017)

Chapter 6. Data Analysis & Power Output

This chapter will consider the data available, and the methodology different bodies have employed to determine the availability of ocean energies. Following this, calculation of power outputs available at both sites will be performed. Analogising these to the total energy demand required on a seasonal basis will further indicate the feasibility of this project.

6.1) Data resources

Wind, wave and tidal energies require specific approaches in order to determine power output potential. This section provides the approach by which power determination can be estimated through use of data resources, primarily outlining the approaches other bodies have used.

6.1.1) Wind

Determining outputs from wind, or for wind turbines, is relatively uncomplicated. To do this manufacturer specifics are required, this entails utilisation of the power curve which varies for select devices, and these have been previously outlined in *chapter 5*. It is also likely that linear interpolation will be required to determine power outputs, specifically when wind speeds fall between points on the power curve. This will be clarified during power output calculations. Specific weather data has proven difficult to obtain, and attempts to receive data from the METoffice resulted in excessive costs. For this project, data was sourced from previous reports including the Renewable Atlas (2008). Within this chapter, a review of the approaches used to determine the available power can be found, which was sourced directly from the Renewable Atlas (2008).

The Renewable Energy Atlas resources report (2007) outlines the approach by which offshore wind data has been observed and utilised to provide annual and significant values of wind speeds. The METoffice provides a global module which is regularly updated with wind speed values recorded at a height of 19.5 metres above sea level. However, data used in the Renewable Atlas (2008) is simplified and provided at a height of 10 metres above sea level. For consistency, these values are ‘scaled’ back from 19.5 metres. This is conducted through applying a coefficient of 0.94 to the provided data. Wind turbines are situated at greater heights above sea level. Using the UK waters and global models, it was possible for the Renewable Atlas (2008) to obtain mean wind speeds for heights varying from 10 – 100 metres above sea level. Implementation of this information would render power output determination as more accurate. However, the mean power outputs outlined in the Renewable Atlas (2008) assume that no losses are expected, and therefore do not apply directly to variations expected in wind turbine devices. *Equation 1* outlines the approach utilised by the Renewable Atlas (2008) in determining expected power availabilities of wind resources in specific areas. However, when obtaining power outputs of specific devices, utilisation of power curves and device characteristics will be crucial.

$$[\mathbf{1}]P_w = 0.5 \cdot \rho \cdot V^3$$

V represents the mean velocity and ρ the overall air density, which in this instance is considered as 1.225 kg/m^3, and is generally perceived as the atmospheric pressure present at sea level.

The overall data used to create the model provided by the Renewable Atlas (2008), compiles the UK, Global and European Wave models. Recording are comprised of numerous periods of time, encapsulating both wind speed and directions.

The accuracy of the Renewable Atlas model (2007) must be considered. Initial comparison of the results determined using the model against raw data obtained through instrumental analysis, suggests that the model is unambiguous. The model follows closely to that of data received through physical recordings. *Figure 31* outlines one site whereby correlation between instrumental and model results has been established. Negligible differences can be witnessed between the two. This indicates that the Renewable Atlas (2008) is suitable in this instance, and will provide relatively accurate power outputs when considering individual device characteristics.

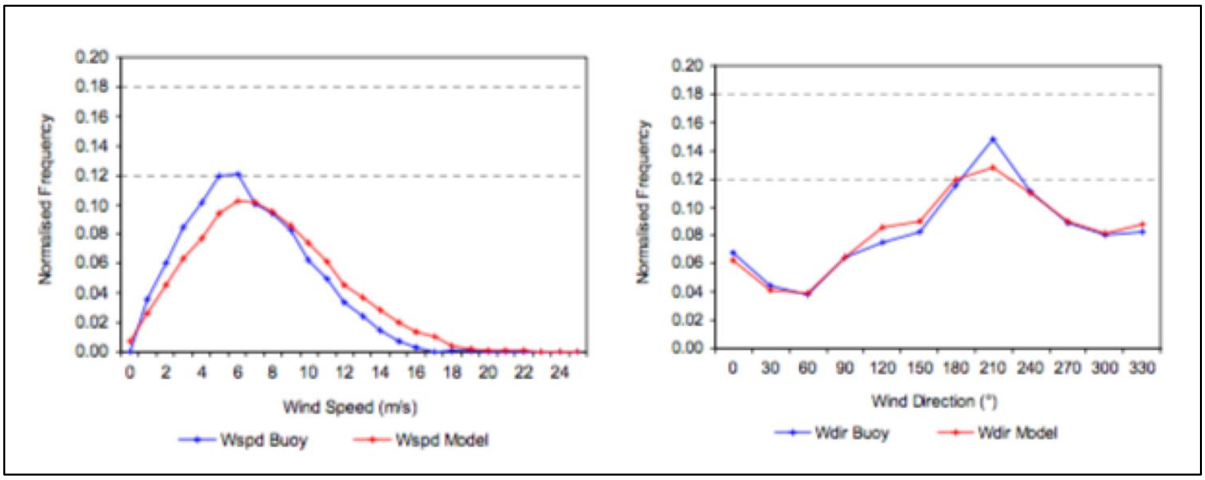


Figure 31: Modelling vs instrumental recordings (Wind) (ABP Marine, 2008)

6.1.2) Wave

Determining outputs from a WEC can be inherently challenging due to the number of variables which must be considered. Firstly, it is particularly difficult to obtain accurate wave information. In the case of this study, marine buoys are based very sporadically and therefore to utilise this data, understanding wave propagation is key. Wave heights vary drastically at different distances from the buoy, and this must be considered to ensure the accuracy of power outputs. According to Ortega et al. (2011), the most appropriate method by which this could be conducted involves undertaking a SWAN modelling process. This encapsulates main parameters such as wind, and the bathymetry of the surrounding site, allowing for greater estimation of wave propagation. The report published by Ortega et al. (2011) suggests this approach would be most viable for sites which are scarce of measurement apparatus, as was the case in a study they undertook in the Caribbean Sea. As stated by Ortega et al. (2011), this method is particularly effective, and proved crucial in determination of wave powers in areas of limited apparatus. The current project did not allow sufficient time to perform SWAN modelling. Alternatively, average data shall be employed from both the Renewable Atlas (2008) and CEFAS (2017), which was established in *chapter 4*.

This data has been provided as significant mean values, encompassing the variating seasons. The Renewable Atlas (2008) resource considers seasons as outlined below in *table 15*. This aided in seasonal averaging of available energies.

Season	**Month**
Winter	December
	January
	February
Spring	March
	April
	May
Summer	June
	July
	August
Autumn	September
	October
	November

Table 15: Seasonal distribution

A model produced by the METoffice similarly follows the approach adopted by the Renewable Atlas (2008). The METoffice model encompasses wave height, period and direction, which are primary parameters required for calculation of power output. The model utilises *equations 2 & 3,* as outlined below.

$$[\mathbf{2}]\ Significant\ Wave\ Height\ (m)\ H_s = 4\sqrt{m_0}$$

$$[\mathbf{3}]\ Zero - upcrossing\ periods\ (s)\ T_z = \frac{\sqrt{m_0}}{m_2}$$

Where m_0 considers the nth moment of said spectrum.

The Renewable Atlas report (2007) mentions that significant wave heights are 'derived' from the large archive available at the METoffice. These long-term values provide mean wave heights over an annual basis.

Unfortunately, the Renewable Atlas (2008) does not directly provide data for short time periods, and this has been considered. To resolve this issue, data has been further sourced from the CEFAS WaveNet data archive (2017), which provided data from a near-by METoffice ocean buoy. This raw data has been used to estimate the expected wave period for each month of the year. These values have then been averaged into seasonal segments as outlined in *table 15*. More information on the averaged wave periods can be established in *chapter 4*.

The report produced by the Renewable Atlas (2008) also outlines the method used to determine power outputs of a given site, which mirrors that used by Tucker & Pitt (2001). Using *equation 4* expressed below, it is possible to determine a rough power output for a given area. This method will not be utilised, as it was possible to obtain a power matrix for the wave device used. Many manufacturers provide power matrices, which aid in power output determination at governing wave heights and periods. For this project, these device specific power matrices shall be utilised.

$$[\mathbf{4}]\ P_w = 0.0623 \cdot \rho \cdot g \cdot H_s^2 \cdot c_g$$

This equation considers water density, where sea water is 1027 (kg/m^3). Also used to determine the power output, is the acceleration due to gravity, significant wave height (m) and overall wave group speed (m/s). It is assumed that values encompass effects of frictional loss, bathymetry conditions and subsequent variations, which hinder or variate the wave speed, height and period.

Accuracy is important, and care should be taken when using the data available. In this case, the model provides relatively accurate indication of potential outputs from a wave energy device.

Below, a comparison of observations taken from instruments and the model used by the Renewable Atlas (2008) is shown. The graph in *figure 32* suggests that information simulated and data obtained in the physical environment are comparable. Therefore, it is suitable to use the RE atlas model (2007) for significant wave heights. As mentioned previously, the raw data acquired from the buoy outlined in *chapter 4* allowed for the determination of wave periods.

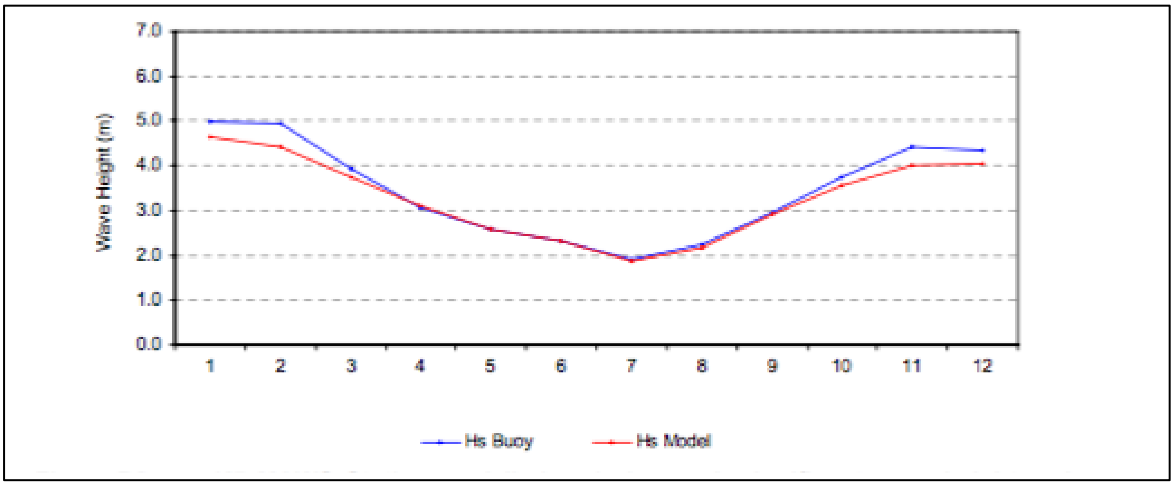


Figure 32: Modelling vs Instrument recording (Wave) (ABP Marine, 2008)

6.1.3) Tidal

Tidal energy is consistent and varies considerably less than other renewable energy approaches. Tidal currents, however, are affected by the span of water and bathymetry, which can cause inconsistencies in expected tidal ranges. Current literature outlines that determination of tidal power outputs can be relatively accurate, as tidal ranges do not often change. This is mentioned in a report by Clarke et al. (2005), who outline that ‘reasonable accuracy’ can be obtained. Having said that, in adverse conditions this statement may be a little less reasonable, and it should also be noted that turbulent effects can cause drastic variations in loading on the submerged tidal devices. Neap and spring tides are the basis from which tidal ranges can be understood. Neap and spring tides are a result of interaction between the sun, moon and earth, as outlined in *chapter 3*.

The method of determining power output involves understanding the velocity (m/s) of both neap and spring tides. By utilising these velocities, relatively accurate system outputs can be established. It is commonly known that tidal turbines for example, do not require cut-in or cut-out speeds, thus improving the accuracy of calculations.

Overall tidal velocities have also been sourced from the Renewable Atlas (2008). This service provided mean spring and neap current conditions. The approach adopted to determine these mean values provides relatively accurate and understandable readings for renewable sector work. It is outlined that there are certainly variations of tidal cycles, and a discrepancy of +/- 20% is countered in.

According to the Renewable Atlas (2008), the use of additional harmonics would not necessarily produce more accurate average tidal ranges, but simply provide more accuracy for differing spring ranges. Harmonics are the curves which make up the various constituents of a tidal range, and are denoted in a range of ways. The Renewable Atlas (2008) also states annual tidal energy yields, averaged and provided for one square metre of area. This provided a power output which suggests 100% efficiency. However, actual power outputs are dependent on individual device characteristics and their harnessing capabilities. The power output values provided also consider average power achieved over a complete year, and therefore consider the complete tidal curve or cycle. Specific power outputs will be provided in the power output section, and will utilise the power curve for the chosen tidal device as outlined in *chapter 5*.

The process by which these tidal ranges are acquired involves consideration of both semi-diurnal harmonic components (M2 & S2). These components suggest the timing and amplitude of the spring neap cycles. *Equations 5 & 6*, can be used to determine spring and neap tides.

$$[\mathbf{5}]\ Mean\ Spring\ Range\ (MSR) = 2(H_{m2} + H_{s2})$$

$$[\mathbf{6}]\ Mean\ Neap\ Range\ (MNR) = 2(H_{m2} - H_{s2})$$

Where H_{m2} is the amplitude of the M_2 harmonic constituent and H_{s2} is the amplitude of the S_2 harmonic constituent.

Through gaining the described velocities, power outputs can be established by using *equation 7*, whilst applying some coefficient of efficiency which can be determined from a specific device. This equation has been sourced from a study undertaken in Scotland by Clarke et al. (2005), from which a coefficient of 0.5 was provided as an estimate. However, in reality this would vary as a result of specific conditions. This approach underestimates the complexity of power output determination for the tidal turbine, for which use of the device's power curve shall be important, and utilised during the determination of power outputs.

$$[\mathbf{7}]\ P = \frac{1}{2} \cdot \rho A V^3$$

Similarly to wind and wave, comparing the information supplied for tidal parameters by the model to actual observed data is important. In the report by the Renewable Atlas (2008), a comparison of the model and observed data has been outlined in scatter plots. According to the report, variability between the model and observations are relatively small, suggesting that they are ‘in good agreement’.

In this instance, average velocities will be utilised, and will consider both neap and spring tides. Power output will be obtainable using these values, which are outlined above. Further tidal information acquired from the work of Clarke et al. (2005) will allow for more accurate power output determination. This report provided the tidal velocities of a near-by port over a 24-hour period, for both spring and neap tides. This information is displayed in *chapter 4*.

6.2) Power Demand Interpretation

Following a report on power demand in the UK, household consumption varies throughout the seasons. The Scottish Government (2014) outlines that during winter months, consumption is generally 36% higher than in summer and spring months. Utilising this information will be important when comparing generation with demand. *Figure 33* shows this seasonal variation in demand during both summer and winter days, as outlined in the Seasonal variation report by the Scottish Government (2014). Consideration of this will allow for estimation of power required during each season, as the data outlined in site selection only provided yearly consumptions.

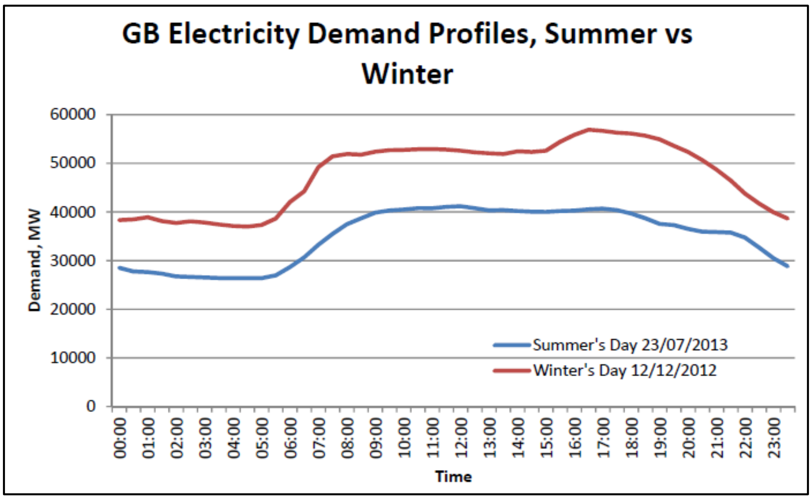


Figure 33: UK energy demand (Scottish Government, 2014)

6.3) Power Output

Information of individual device performance was outlined in *chapter* 5 and was utilised for determination of power outputs. Further information on site characteristics has also been implemented, *see chapter 4.*

6.3.1) Site A

Both wind and wave energies are resourced at site A and shown below are the subsequent power outputs. Excel extracts which compliment these values has been attached in the *appendix*.

Power output

Pelamis WEC

The power matrix for the Pelamis wave energy convertor has been previously outlined in *chapter 5.* Utilising the power matrix, data acquired from the buoy and the RE Atlas model (2008) it was possible to estimate the power outputs achievable during each season.

Season	**Power Output (kWhr/per season)**	**Power output (MWhr/per season)**
Winter	505,890	506
Spring	394,200	394
Summer	124,830	125
Autumn	505,890	506

Table 16: Pelamis power output (Site A)

These outputs may appear low, however, the device has a capacity rating of 750kWh, and combining multiple Pelamis devices in an array style would generally improve overall outputs. The use of multiple Pelamis devices will be considered if the energy demand levels are not met through the combined output of both the wind and wave device. The addition of further devices at this stage may be discouraged due to the increase in capital costs.

Senvion Wind Turbine

As previously outlined, wind speeds denote the significant values which will allow for estimation of power output over the entirety of a season. Utilising the power curve available for the Senvion offshore turbine, and the significant wind speeds available in the Renewable Atlas (2008), the total output per season has been approximated. Linearly interpolating the power curve provided more accurate depiction of device capabilities, allowing for power output determination. See *appendix* for excel transcripts, resultant values can be seen in *table 17.*

Season	Power Output (kWhr/season)	Power output (MWhr/season)
Winter	12,658,200	12,658
Spring	7,227,000	7,227
Summer	5,343,600	5,344
Autumn	11,344,200	11,344

Table 17: Senvion power output (Site A)

Understanding of these power outputs can be established below, where graphing of both power outputs and the demand from the total number of households situated at site A, has been shown. As expected and can be seen in *figure 34*, the wind turbine provides substantially more power than the wave device.

Power Demand

Figure 34 shows that at present, the devices would supply adequate power to the South Uist area and offer a year-round solution. Total annual consumption per household has been divided, and displays consumption for each of the four seasons, with the expectancy of winter and autumn months having higher demands. Whilst spring and summer have lower consumptions as shown in *table 18*.

Season	Household Energy Consumption (kWhr)	Total Household Energy Consumption (MWhr)	Total combined power generation (MWhr)
Winter	2788	2381	13,164
Spring	1312	1120	7621
Summer	1312	1120	5468
Autumn	2788	2381	11,850

Table 18: Total power demand and generation (Site A)

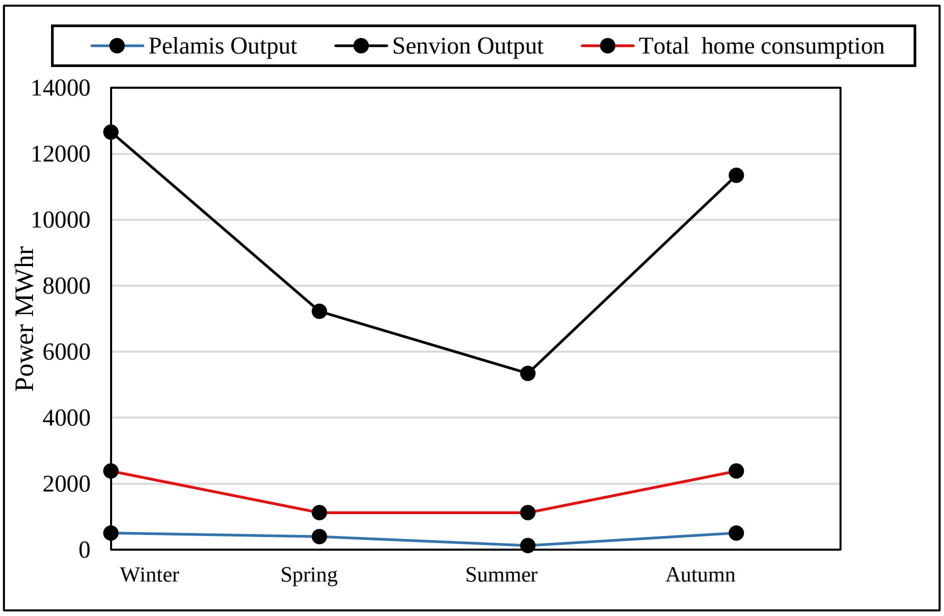


Figure 34: Seasonal energy generation and demand (Site A)

6.3.2) Site B

Following the methods previously outlined and utilising data highlighted in *chapter 4*, estimation of the power output was achievable.

Power output

Senvion Wind Turbine

As previously outlined, the seasonal significant wind speeds have been taken from the RE Atlas (2007). Below in *table 19* are the estimated power outputs from the Senvion wind turbine situated in this site.

Season	Power Output (kWhr/per season)	Power output (MWhr/season)
Winter	9,417,000	9,417
Spring	8,322,000	8,322
Summer	6,044,400	6,044
Autumn	8,322,000	8,322

Table 19: Senvion power output (Site B)

Seagen Turbine

The methodology used to determine tidal ranges has been previously outlined. For this study, data has been sourced from a report produced by Clarke et al. (2005). The data provided spring and neap tide speeds for sites relatively close to the location of site B, which both occur approximately twice a month. The power output has been estimated as consistent over the yearly period, however, realistically, the tidal velocities used to generate power may fluctuate slightly. This is likely a result of device longevity and variations in tidal ranges over the passage of time. Initial calculations performed over 24-hr periods were then averaged into monthly and seasonal outputs, and although these power outputs may not be strictly accurate, they are indicative of the potential power output achievable by the SeaGen turbine. The total output each season at site B has been shown below in *table* 20. For consistency, a plot of power output over 24-hour periods has been graphed and can be seen in *figure 35.*

Season	Power Output (kWhr/per season)	Power output (MWhr/season)
Winter	847,616	848
Spring	847,616	848
Summer	847,616	848
Autumn	847,616	848

Table 20: SeaGen Power Output (Site B)

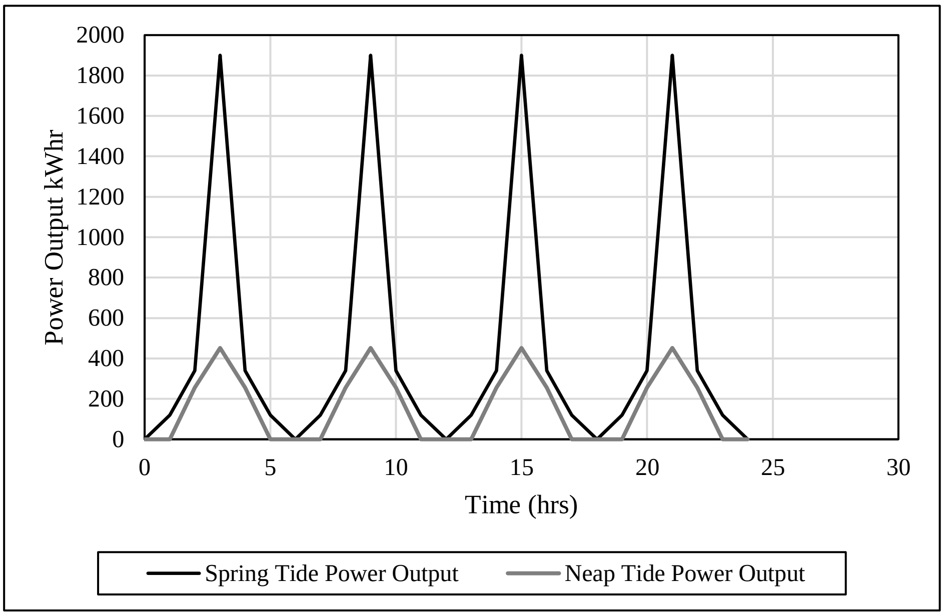


Figure 35: SeaGen Power Ouput (Site B)

Power demand

Following the Scottish Regional Locational Guidance report (2012), and the Census report (2011), it is known that there are 854 homes, each of which consume roughly 5.0MWh per year. Considering the observation previously outlined, it is expected that during winter and autumn months, power demand is generally 36% higher (SG, 2014).

Season	**Household Energy Consumption (kWhr)**	**Total Household Energy Consumption (MWhr)**	**Total combined power generation (MWhr)**
Winter	1700	2514	10,264
Spring	800	1183	9169
Summer	800	1183	6892
Autumn	1700	2514	9169

Table 21: Total power demand and generation (Site B)

The graph below in *figure 36*, depicts the total required demand and the output of both offshore renewable energy devices. It can be witnessed that the output from the SeaGen tidal turbine does not suffice the consumption levels required by the 854 homes. The wind turbine however, produces adequate power to suffice these demands throughout the year. By combining these devices, power consistency is possible. In this case, it would be beneficial to add further SeaGen tidal turbines. However, in this instance only singular devices will be considered due to the scale and nature of the research being conducted. Further work and time could allow for development of an array of tidal turbines, which would supply further energy.

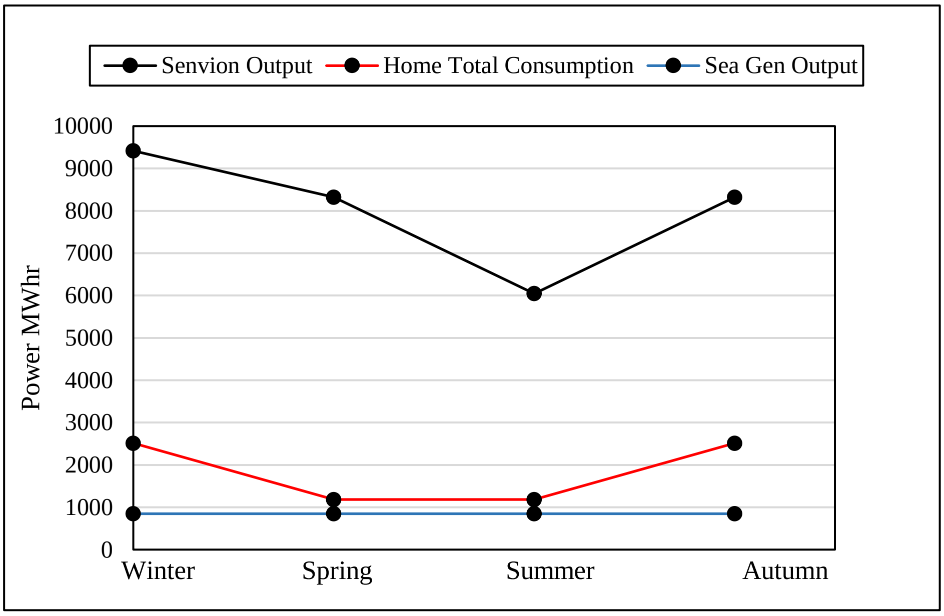


Figure 36: Seasonal energy generation and demand (Site B)

6.4) Power Output summary

It has been ascertained that both sites, when combined with the devices outlined, supply adequate power throughout the seasonal periods. It must be further emphasised that the assumptions made for determining power outputs could suggest approximated values, particularly for wind and wave power outputs. These largely depend on time specific conditions and the crude assumption of a singular wind speed or wave height for a whole season, provided relatively poor results. With greater time and data availability, further consideration should be given to the fluctuations in wind and wave conditions.

The outputs determined for the tidal device appear to be relatively accurate, and this is directly related to the quality of data used. The data was provided for hourly intervals, allowing for power output calculations over a 24-hour period, which can be viewed in the excel scripts, available in the *appendix*.

The power outputs provide general indication of feasibility with respect to supply and demand. Considering the assumptions made, one can conclude that during average seasonal weather conditions, power output served to supply the total demand for each site. Due to limited data, the power outputs established are likely to have a consequential effect on the economical computation. Fundamentally, the success of a renewable energy project is reliant upon the total power output from the devices, and the ability to generate a steady and predictable power output.

Chapter 7. Economic Analysis

As part of the feasibility study, an economic analysis for both sites A and B has been undertaken. The economic analysis is a fundamental stage of any feasibility study and provides clear insight into the financial viability or scalability of a project. The following chapter outlines the process of this analysis and its resultant outcomes.

To establish key capital costs and operational costs, use of the life cycle costing approach allows for a greater understanding of these values. Once these costs have been established, an economic analysis can be undertaken. The analyses undertaken were adopted from work by Dunnett et al. (2008), and entailed the involvement of numerous economic indicators. These allowed for an understanding of the overall scalability of each project.

Utilising the work of Dunnett et al. (2008), taken from the previous work of Szonyi et al. (2000), an understanding of economic analysis was possible. The approaches used are outlined below, with specific terminology outlined where appropriate.

7.1) Cost and Profit

7.1.1) Costs

To progress with the economic analysis, it was vital to outline the types of cost, whether capital costs, operational and maintenance or end of life deconstruction costs. These costs were sourced from previous reports and manufacturer brochures, which are outlined for both site A and B in the cost summary.

Although not entirely comprehensive, capital costs shall consider the overall cost of devices, construction, maintenance including linking to the grid and decommissioning costs as outlined previously. Construction costs will consider foundations costs, for example, the total cost of installing a wind turbine foundation, or the cost of mooring a semi-submersible structure. There after operational and maintenance costs will be factored in. This method follows closely mirrors the work of Dunnett et al. (2008), and will allow for estimation of the total cost expenditure and revenue made by each project i.e site A or B. Possibly most important to understand is the price and cost efficiency of electricity, in order for projects to break-even within a reasonable time period.

7.1.2) Cost of Electricity

In the UK, the cost of electricity for the consumer fluctuates. Currently, electricity rates per kilowatt hour are between 12.376 and 12.776 pence, as outlined by UK Power (2018). Ideally, the projects at sites A and B, would strive to be as close to or lower than the current cost of electricity. Below in *section 7.2* are the economic indicators which will suggest whether the projects at sites A and B can succeed whilst electricity is at this price.

It should also be mentioned, that the price paid for electricity by a home-owner, is not truly representative of final costs received by the energy producer. To elaborate, according to the BBC (2016), 16% of the £/kWhr paid by homeowners is used by the company to pay for distribution costs, similarly a small percentage goes towards metering costs. The threatening reality of this, is that renewable energy distributers receive limited profits. For this project, it is assumed that the price paid by a homeowner for 1 kWhr of electricity will equate to the money received by renewable energy producers. Although this assumption may appear crude and unrealistic, it was made necessary as a result of data limitations and time restrictions

7.2) Economic Indicators

7.2.1) Pay Back Periods

To understand the feasibility of the projects, determining a 'pay-back' period will allow for an estimation of profitability. The pay-back period is the overall time taken to meet the capital and annual operational costs, where this equalises, the project will begin to generate profits. Using the pay-back period will allow for simple analysis and utilising present values (PV), establishment of the lowest cost of electricity able to generate profit over the 25-year life is possible. Similarly, it is possible to determine the shortest period of payback. This method will be useful in estimating the price at which electricity should be sold. These pay-back periods may be shortened through financial support from, for example, the Government. However, for this project it is assumed government funding and any other bodies offering subsidies are not available.

7.2.2) IRR and NPV

Understanding economic viability will involve determining IRR values. The IRR value, otherwise known as the 'hidden' rate of return or internal rate of return estimates growth over an arbitrary number of years, in this case 25-years (typical life cycle). The higher the IRR percentage, the more profitable the project is likely to be. This calculation will be performed over a range of electricity costs, to gather a greater understanding of each project’s growth potential during the 25-year life span.

Net present values (NPV) shall also be calculated, this is another method which allows for the determination of profitability and growth over a fixed period. This method accounts for inflation rate and allows for application of a discount rate. *Equation 8* demonstrated below is required to determine the NPV, and this equation has been utilised in excel, extracts from which can be established in the *appendix.*

$$[\mathbf{8}]\ NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0$$

Where;

$C_t = net\ cash\ inflow\ during\ the\ period\ t\ (cost\ of\ electricity)$

$C_o = total\ initial\ costs\ (All\ costs\ assumed)$

$r = discount\ rate$

$t = number\ of\ time\ periods\ (per\ year)$

In lay person terms, the NPV considers the initial capital costs and present values at each year. By subtracting these from the initial capital costs, determination of the NPV is possible. Further to this, the NPV is zero where the IRR is determined as being equal to the discount rate applied.

Ultimately, for projects to be economically feasible, the rate at which the renewable electricity is sold should equate to current costs of electricity, *see section 7.1.2*. Ultimately, this determines success of the project, and can be interpreted through the graphical representation of IRR values. Where the IRR percentage is higher, this will indicate the likelihood of profitable growth. It is assumed for the project that the weighted average cost of capital (WACC) will be 10%, allowing for projections of IRR values. To determine the IRR values for a range of electricity costs, an excel function (IRR) will be used, which is displayed in the *appendix. Equation 9* below depicts this function, which involves setting the NPV to zero, rearranging for the discount rate.

$$[\mathbf{9}]\ 0 = \sum_{t-0}^{N} \frac{CP_t}{(1+IRR)^t}$$

7.2.3) Break-even

Using the methods outlined in *sections 7.2.1 and 7.2.2,* it is possible to gain a sense of the project’s feasibility. However, the primary flaw in the methods outlined above, involves the cost of electricity, where computation of economic feasibility has been undertaken over varying electricity costs. Alternatively, the break-even approach will utilise one expected electricity cost, which can then be plotted alongside the capital costs, with a scale of time. Where the revenue line crosses the capital costs line, the project will 'break-even'. In order to determine the point at which the project breaks-even, careful consideration of the IRR values for various electricity costs will be paramount. Subsequently, establishment of a suitable rate at which electricity can be sold will be outlined. According to Gallo (2016), an IRR value of around 13% would be regarded as acceptable. Establishment of electricity costs will allow for determination of an IRR of 13% and this will be particularly useful in determining a suitable break-even period.

7.3) Site A

Section 7.3.5 outlines the expected costs for site A, using the combination of wind and wave renewable energy devices previously established. Typical costings have been sourced from numerous research projects and manufacturers. Typical breakdown costs for the Pelamis wave device were sourced from WACOP (2018). Statistics describing capital and operational costs for the Senvion wind turbine were limited, and therefore numerous assumptions regarding capital, operational and deconstruction costs have been made. These have been respectively outlined where implemented and can be seen in *table 22.*

7.3.1) Construction Costs

Initial site set up involving subsea work shall be required, including installation of subsea cables. These will transmit to an onshore substation and then on to the onshore network grid. Following completion of the subsea cable work, installation of suitable foundations and mooring lines for each device will be required and the expected costs for all works has been outlined in *table 22.* Understanding site location is crucial in understanding costs. As previously outlined, Site A is located roughly 5km from shore and 14km from Port Ellen, which is assumed to be the best port from which devices can be distributed. This port will also accommodate the large tug boats required to transport the wind turbine components. Total construction costs have been outlined in *table 22*.

7.3.2) Device Costs

Device costs are expected to vary as a result of an ever-changing market. Estimated prices based upon previous literature, are outlined in *table 22*.

7.3.3) Operational and Maintenance Costs

Both devices are expected to incur additional operational and maintenance costs throughout their lifetime, which was previously stated as 25 years. The ocean and its hostile environment can be particularly detrimental to devices, particularly due to the sea-water which is known to corrode metals very quickly as a result of the rich chloride environment. Furthermore, Site A's location, is very close to open seas and large storms and these are expected to be in the range of 50-100-year storms with the assumption that a storm of that magnitude is expected in the devices life-time. Annual operational costs for the 25-year life have been outlined in *table 22*.

7.3.4) Decommissioning Costs

Decommissioning costs are expected to occur the end of the projects life-cycle and these must be considered in order to conduct a comprehensive economic analysis. These will vary significantly for each device, and it is anticipated that decommissioning costs for the wave device will be much lower, due to the device not having particularly large foot prints. In *table 22* decommissioning costs for both the Senvion turbine and Pelamis WEC are outlined. Decommissioning costs for the Senvion turbine are assumed 5% of the initial capital cost, work by Topham & McMillan (2017) estimated that decommissioning costs for the Senvion turbine would be 2-3% of the initial capital cost. However, to err on the side of caution, this project assumes that they shall be 5% of the initial capital cost. Decommissioning costs for the Pelamis WEC have been sourced from a cost breakdown undertaken by WACOB (2016).

7.3.5) Cost Summary (Site A)

Construction costs	**Cost (£)**	**Comments**
Subsea Cable Installation	10,000,000	(WACOB, 2016)
Mono-pile Foundation (Wind Turbine)	4,000,000	Assumption
Mooring Lines (Wave Energy Device)	289,228	(WACOB, 2016)
Transportation of resources	20,000	1000/per day *assume 20 days use
Device Costs		
Senvion Turbine	10,000,000	Assumption
Pelamis WEC	2,469,950	(WACOB, 2016)
Operation Costs		
Senvion Turbine	1,000,000	Assumption
Pelamis WEC	688,362	(WACOB, 2016)
Decommissioning Costs		
Senvion Turbine	1,000,000	Assumption
Pelamis WEC	710,000	(WACOB, 2016)

Table 22: Cost summary (Site A)

In summary, total capital costs invested in year zero include construction and device costs. Annual operational and decommissioning costs are established at a later stage of the project. From year one onwards, it is assumed the operational and maintenance costs occur each year and that decommissioning costs occur in year twenty-five. Using these figures, pay-back periods, NPV and IRR values it is possible to determine break-even points, which sufficiently indicate the economic viability of the project.

7.3.6) Pay Back Period

As outlined previously, the pay-back period can be used initially to indicate the likely success of a project, it should be noted that profitability will vary as the cost of electricity fluctuates. *Figure 37* below considers the combined power output of both the wind and wave devices. By determining the total initial cost, it was possible to determine the time taken to return costs and generate profit. The pay-back period, also includes the annual operational costs and decommissioning costs. It can be seen, that at a rate of 7.2 pence/kWhr, all costs incurred over the 25-year life span are funded.

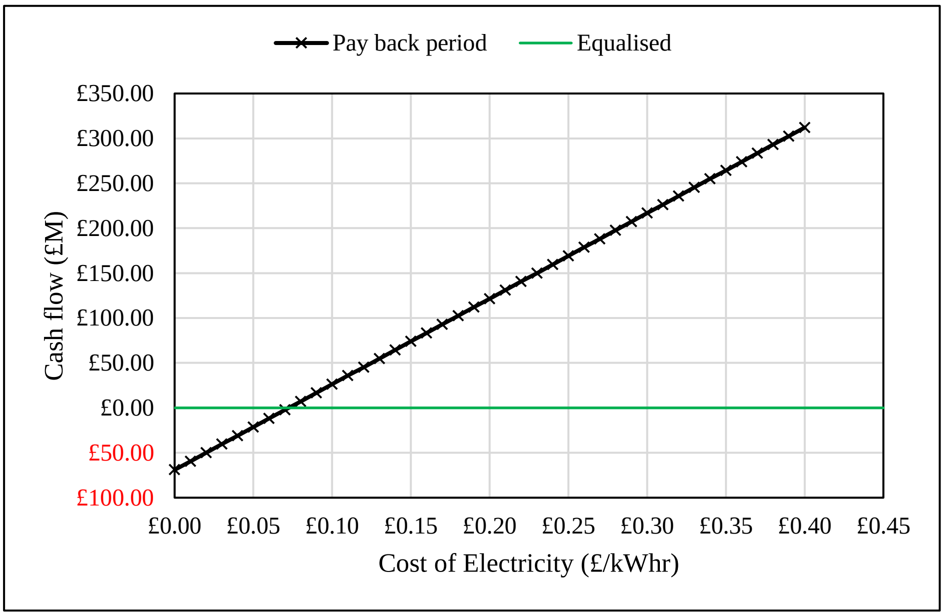


Figure 37: Pay-back period (Site A)

In *figure 38* the graph shows that as the cost of electricity increases for the consumer, the pay-back period decreases rapidly. Through linear interpolation it can be seen that costs incurred as a result of the project would be returned in 14.2 years, assuming current electricity costs (12.766 pence/kWhr)

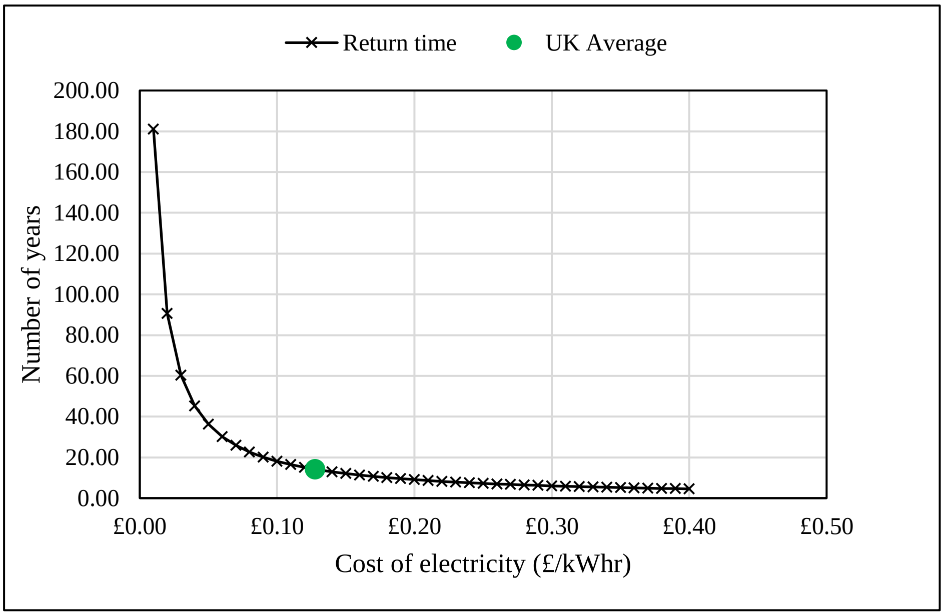


Figure 38: Cost return periods (Site A)

7.3.7) NPV and IRR

As outlined previously, utilising the IRR function in excel, provides some indication of the projected growth and success. *In figure 39* a plot for IRR values is shown, these have been evaluated over electricity costs ranging from £0.05-£0.40.

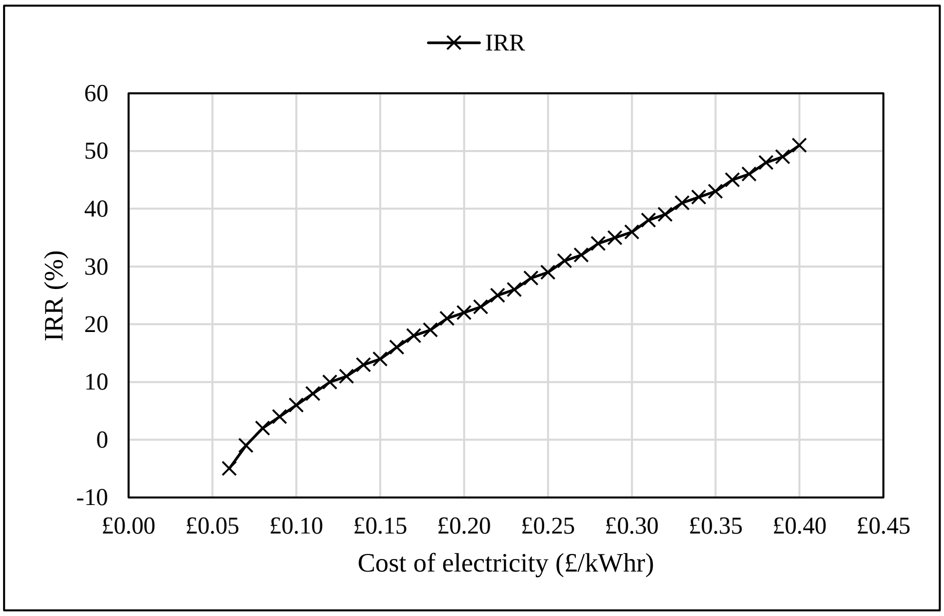


Figure 39: Internal rate of return (Site A)

From *figure 40* it can be established that as the cost of electricity increases, the internal rate of return for the project also increases, as expected. Previous observations in *figure 38* show that at a cost of electricity of 7.2 pence/kWhr, would generate a profit. The method utilised in *figure 37* did not consider inflation rates, and projections show that at this cost of electricity the internal rate of return would be -1%. According to Gallo (2016), an IRR of 13% suggests that a given project could be reasonably successful. From the IRR graph above in *figure* 40, it can be seen that for the project to be profitable over the 25-year period and to produce an internal rate of return of 13%, electricity would have to be sold at a rate of 0.14 pence/kWhr. With this internal rate of return, the subsequent NPV value is £6,159,439.55.

7.3.8) Break-even

Following the economic indicators above, analysis has shown that whilst the cost of electricity is 14 pence/kWhr, the project would be relatively profitable. Linear interpolation, suggests at this cost of electricity, the project would break even in 7.34 years, or 88 months. Break even periods are shown below in *figure 40.*

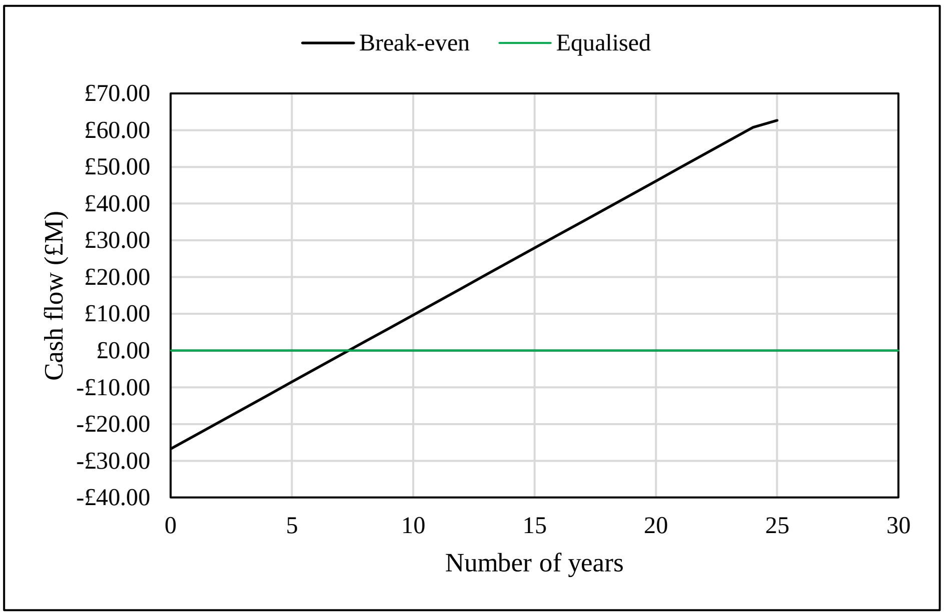


Figure 40: Break-even period (Site A)

7.4) Site B

Using the same process as carried out for site A, economic analysis for site B was conducted. Initial costs for the Senvion wind turbine are assumed the same as witnessed at site A. Costing for the tidal turbine has been estimated from a research report, released by Paterson (2017), this report provided insight into the breakdown of capital costs.

7.4.1) Construction Costs

Construction costs, for site B with a combination of wind and tidal devices are outlined in *table 23*. For the Senvion wind turbine, construction costs follow similarly to those estimated in site A. For the SeaGen tidal turbine, construction costs have been estimated based upon the work undertaken by Paterson (2017).

7.4.2) Device Costs

Device costs are further shown in *table 23*. For the SeaGen tidal turbine, the device costs were estimated using several sources. It should however be noted that these are vastly estimated costs and full reliability cannot be placed on the values stated. Device costs for the Senvion turbine are previously outlined in *table 22.*

7.4.3) Operational and Maintenance Costs

Operational and maintenance costs for the Senvion wind turbine have been previously outlined, and are repeated in *table 23.* It is expected that SeaGen tidal turbine will incur operational and maintenance costs, and these have been estimated using work undertaken by Paterson (2017).

7.4.4) Decommissioning Costs

The method used to determine decommissioning costs, has been previously outlined in *section 7.3.4*. For the SeaGen tidal turbine, this process will also be repeated assuming decommissioning costs are 5% of the capital costs.

7.4.5) Cost Summary (Site B)

Construction costs	**Cost (£)**	**Comments**
Subsea Cable Installation	10,000,000	2,000,000/per km
Mono-pile Foundation (Wind Turbine)	4,000,000	Assumption
Tidal foundation & installation	1,870,000	(Paterson, 2007)
Transport Costs	20,000	1000/per day *assume 20 days use
Device Costs		
Senvion Wind Turbine	10,000,000	Assumption
SeaGen Tidal Turbine	1,182,000	(Paterson, 2007)
Operation Costs		
Senvion Wind Turbine	1,000,000	Assumption
SeaGen Tidal Turbine	345,700	(Paterson, 2007)
Decommissioning Costs		
Senvion Wind Turbine	1,000,000	Assumption
SeaGen Tidal Turbine (MIT)	25,000	(Paterson, 2007)

Table 23: Cost summary (Site B)

7.4.6) Pay-back Period

Following the same method utilised in *section 7.3*, for site A, the pay-back period has been established for site B in relation to variating electricity costs. Considering all costs, in 25-years the lowest cost of electricity which would permit the project to equalise would be between 8 and 9 pence/kWhr. Interpolating between these values suggests, more accurately at a cost of electricity of 8.8 pence/kWhr the project would equalise with the total costs incurred.

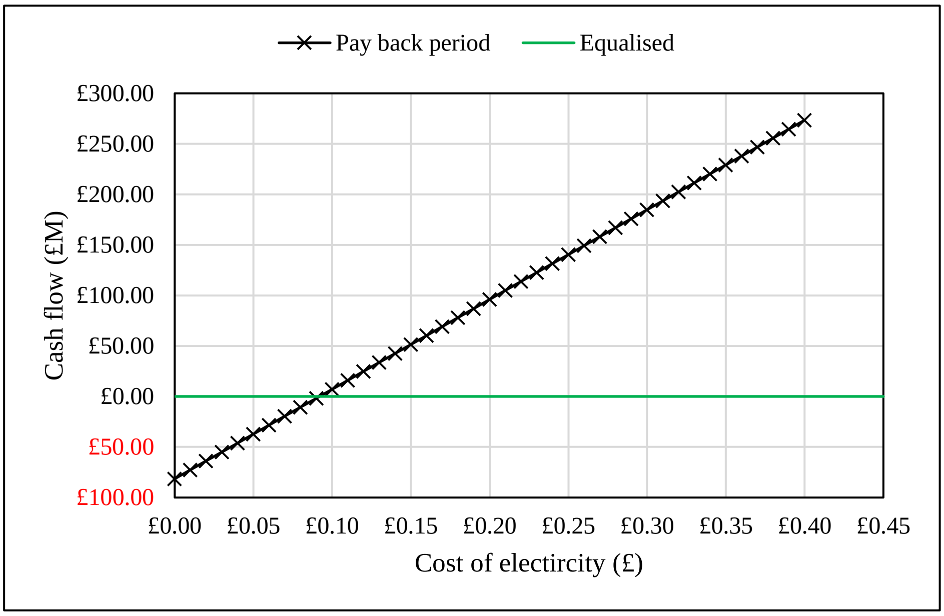


Figure 41: Pay-back period (Site B)

Similarly, considering all costs incurred, the time taken to begin generating profit has been plotted over a range of electricity prices and can be seen in *figure 42*. Considering the UK average of 12.766 pence/kWhr, using linear interpolation, it has been established it would take 18 years to begin generating profit.

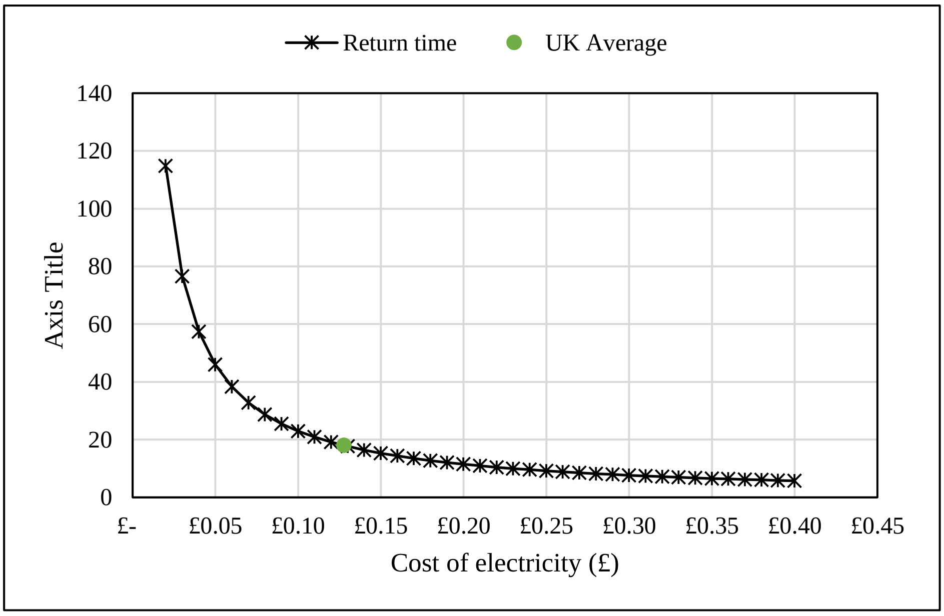


Figure 42: Cost return periods (Site B)

7.4.7) NPV and IRR

Figure 43 shows IRR values ranging from 0.05-0.40 pence/kWhr. Using the cost of electricity established in *figure 41* of 8.8 pence/kWhr would give an IRR of only 4.39%. Therefore, the profit generation of the project would be very limited according to Gallo (2016), who recommends an internal rate of return of 13%. In order to produce this recommended IRR, electricity costs of 14 pence/kWhr, would be required, as was the case for site A. This rate would provide a NPV of £5,820,660.17.

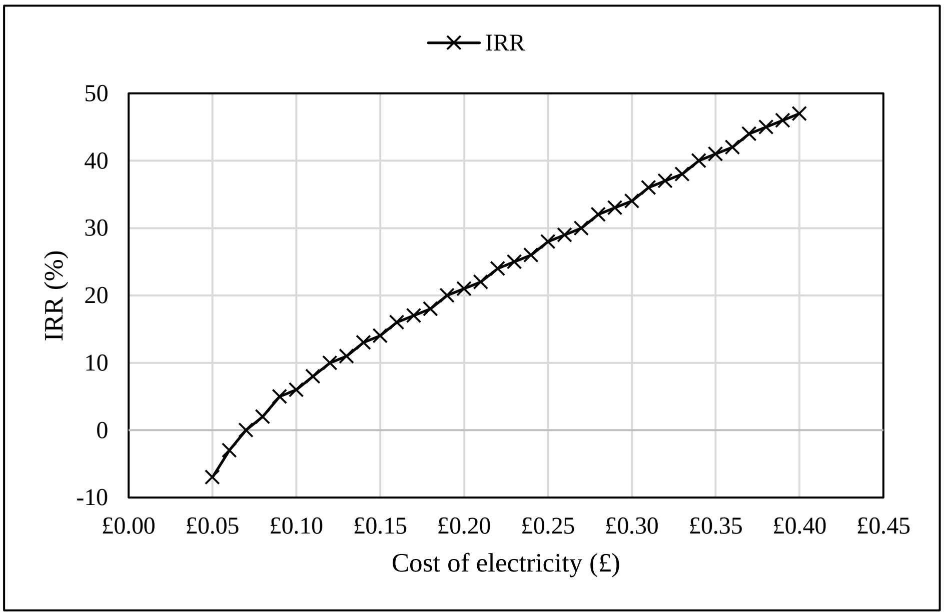


Figure 43: Internal rate of return (Site B)

7.4.8) Break-even

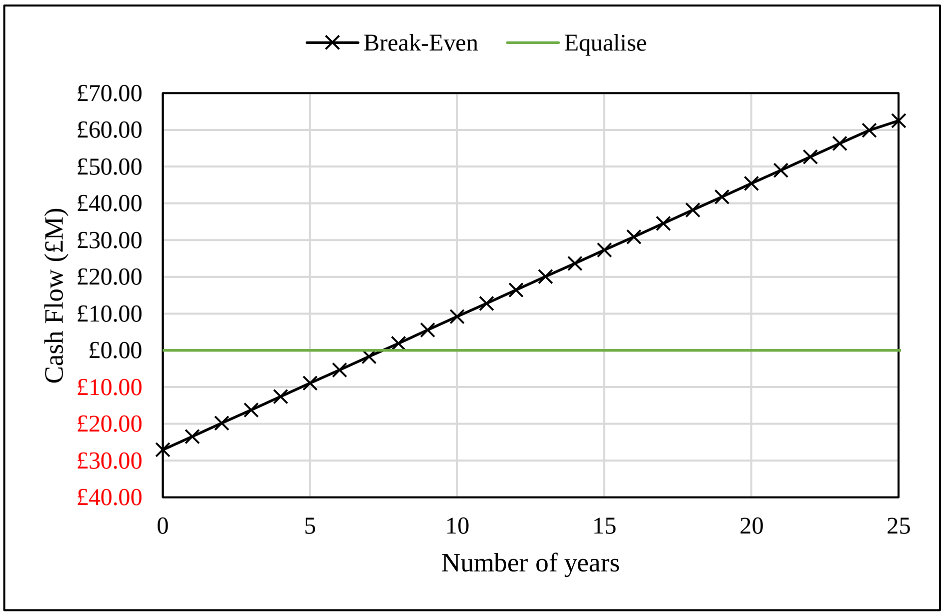


Figure 44: Break-even period (Site B)

Considering the cost of electricity required to provide an IRR of 13%, which has been outlined *in figure 43* as 14 pence/kWhr, a break-even graph can be plotted. Encompassing capital, operational and decommissioning costs the plot can be seen in *figure 44.* It has been established that it would take 7.47 years or 89.63 months for the project to break-even.

7.5) Economic Analysis Summary

Economic analysis is a fundamentally vital process in determining the feasibility of renewable energy projects. In this case, the economic analysis undertaken was relatively limited. There were a number reasons from this. For example, the data used and costs stated may not be entirely reliable. Most costings used during the economic analysis for this project were sourced from previous literature based upon similar research projects. However, where this was not possible assumptions were made, which have been outlined in the cost summaries for each site.

However, it could be said that the economic analysis undertaken for site A and B, produced conservative results, previously mentioned, government funding and subsidies have not been considered. Disregarding these factors, will likely have resulted in higher projected costs, ultimately increasing the price of electricity required for each project to ‘break-even’. With more time and economic understanding, a more in-depth study of costings would be possible. The economic analysis conducted for this project provided relevant indication of the possibility of success or failure in terms of costing, revenue and profitability, changing interest rates and fluctuations in electricity prices.

At site A, when the IRR was 13%, it was established that the project would cover the capital costs after 7.34 years, after which a steady profit would be generated. The cost of electricity required for this IRR was 14 pence/kWhr, which is slightly above the UK average of 12.776 pence/kWhr. With an NPV of £6,159,439.55, all expected costs would likely be covered by the earnings accrued through the generation of electricity over the 25 year life-span.

Similarly, to site A, the project at site B became profitable with an electricity cost of around 14 pence/kWhr, a little higher than the UK average. The internal rate of return at this cost of electricity was again 13%. With this rate of electricity, the project would break-even, equalising with capital costs in 7.47 years, this and can be further seen in *figure 44.* At this rate, the NPV value was determined as £5,820,660.17, which suggests that the costs generated throughout the lifespan of the project would be exceeded by the NPV, during the lifespan of the project.

Typically, projects of this nature often flop. The economic analysis undertaken for both site A and B suggest that profitability is possible without requiring ludicrously high electricity costs. It should be noted, that further accuracy of costs previously outlined would be mandatory to improve the quality of this economic analysis. However, preliminary observations, suggest that economically, both sites would be able to generate a generous profit over the 25-year life span. The revenue generated encompassed all costs expected, including annual operational costs in addition to end of life decommissioning costs.

Table 24 below provides a summary of the economic analysis, and subsequent indicators of feasibility acquired through undertaking the analysis.

Economic Indicator	Site A	Site B
Feasible cost of electricity	14 pence/kWhr	14 pence/kWhr
25-year payback cost	7.22 pence/kWhr	8.88 pence/kWhr
IRR	13%	13%
NPV	£6,159,439.55	£5,820,660.17
Break-even period	7.34 years	7.47 years

Table 24: Summary of economic indicators

Chapter 8. Feasibility Analysis & Conclusion

This project considered vital factors required to establish the feasibility of year-round renewable energy use. *Chapter 8* will summarise key findings, allowing for conclusions to be drawn. Following this, recommendations for future work which would address the weaknesses of the current study will be outlined. It may be difficult to conclude the absolute feasibility of year-round renewable energy use due to the weaknesses found with the current study.

Sections 8.1 and 8.2 summarise the key findings of this report for both sites, primarily highlighting power outputs determined and economic viability. Appreciation of each projects impacts will also be outlined.

8.1) Site A

Site A was identified as a feasibly promising location for the construction of renewable devices making use of both wind and wave energy resources. Governing factors caused little obstruction, as highlighted during the site selection. *Sections 8.1.1-8.1.3* summarise the key findings for site A.

8.1.1) Site

Site A was located on the North West of Scotland, where it was found that wind and wave energy could be utilised. The near-by settlement was home to 1818 people, whose average home energy consumption is 8.2 MWh, slightly higher than the UK average. In site selection, planning and consideration of the primary impacts caused by situating renewable devices here was outlined and it was established that little obstruction was caused. Overall, the selected site provided generous energies for electricity generation.

8.1.2) Performance

The power output of the Senvion wind turbine and Pelamis wave device met and exceeded the demand of total power required for the households of South Uist. The combined power output per year was determined as being 38,103,810kWhr.

8.1.3) Economics

Economically the site and device selection showed some potential. With its location close to the shore, and the suitability of the seabed quality in enabling construction to take place, costs were not particularly high and capitally these were primarily dominated by device costs. Profit was achieved within a reasonable period, when the cost of electricity was only slightly above that of the UK average. With the aid of government subsidies, these costs could be decreased further, with the aim to match the average electricity cost for consumers in the UK. Further information regarding economic indicators can be established in *chapter 7*.

8.2) Site B

Similarly to site A, feasibility was found in the sense of energy generation. *Sections 8.2.1-8.2.3* highlight the key details of site B.

8.2.1) Site

Site B was located on the West of Scotland and was also close to shore. Both tidal and wave energies were established for possible harnessing. The nearby island of Islay is occupied by 3228 habitants, whose average home energy consumption is a little below the UK average, 2009 figures stated that the consumption was 5.0MWh per year. Overall, whilst considering the possible impacts of situating the site here, little obstruction and impact to the site was established.

8.2.2) Performance

The total combined power output of using these resources was calculated, and totalled at 35,495,864 kWhr per year. The lack of available data limited the accuracy of power output calculated for site B. However, the outputs determined served to suffice the total household demand of the near-by town. The site itself was proven to have potential, and energy was widely available from both wind and tidal resources. In retrospect, the addition of multiple tidal devices would improve the total power output, as utilising just one tidal device, covered approximately 9.55% of the total combined output of wind and tidal power.

8.2.3) Economics

Economically, site B did also show potential, however tangible returns were only seen at greater costs of electricity. Although not significantly higher than the UK average, of 12.776 pence/kWhr. It could still be said, that consumers would experience the impact of the difference. For the project at site B, typically reputable profits over the 25-year life cycle, would be experienced when the cost of electricity rate was 14 pence/kWhr.

8.3) Further Work

This final section suggests the shortfalls encountered whilst undertaking this study and the way by which limited information led to assumptions, influencing the quality of the feasibility analysis. It is clear that time limitations affected the quality of the study in numerous ways, as did the lack of data. Outlined below are suggestions by which further work could improve the overall feasibility analysis of implementing offshore renewable energy as a year-round solution.

8.3.1) Site Selection

Site selection did prove difficult at certain stages, and numerous assumptions were made to enable progression of the project. For example, no consideration was given to the potential economic contribution from the Government, or to the legibility of site leasing. However, contemplation of most site factors were outlined, which did provide a relatively accurate gauge to the potential of using the sites selected. Realistically, further understanding of the planning process would be required to improve this study, particularly where the sites are close to the shore (less than 12 nautical miles). In this instance, both sites were relatively close to the shore, which could pose some issues both socially and environmentally, such as those outlined in the site selection process.

8.3.2) Technical Data

It was clear from the outset that offshore energy data would be particularly difficult to source, primarily due to the competitive nature of the current market. In numerous cases, attempts to acquire relevant offshore data would have incurred costs. As this was a student research project, funding was not widely available, which led to a scarcity of data and ultimately, a relatively vague understanding of potential power outputs from both sites. The calculation of power output was further hindered as a result of the difficulty in obtaining manufacturer data for devices. Where this issue was experienced, the device was simply rejected as an option. This issue was predominant during determination of wave energy devices. Many devices did not provide any form of power matrix, and is likely due to the stage of research. This led to inclusion of the Pelamis wave device, which provided adequate data required to conduct power output calculations, such as the power matrix.

8.3.3) Power Output

One of the main issues encountered which affected the feasibility study, was the variability in power output. The approach utilised did not give great consideration to fluctuations in power output. Therefore, taking significant mean parameters for each season likely overestimated the power generation potential. It did however, provide insight as to the potential generation levels. With greater quantities of data, the power output determined would be more accurate, and give greater indication of the feasibility of year-round use.

8.3.4) Power Consumption

Power consumption of the areas chosen was also likely not a truly accurate value. The power demand of the households present in the areas chosen was considered, however, industrial and commercial demands for electricity were not. It could however be said, by increasing the quantity of renewable energy devices at each site, higher demand levels could be met.

8.3.4) Economic Analysis

Numerous assumptions involved when performing the economic analysis. Such as device costs for the Senvion wind turbine, which were largely unobtainable, thus resulting in crudely estimated costs. In an ideal environment, the economic analysis would have been undertaken considering levelised costs (i.e capital costs outlined in £/kW). However, as the project was relatively small and did not consider farm-style situations, the approach used was a little more suitable given the limited availability of data.

8.3.5) Impact

This research project assumed that the lifespan of each project would be 25-years. The impact on the sites has, in certain respects, been ill-considered. Although comprehensive consideration was given to the immediate impact of renewable energy device construction on the sites, little emphasis was placed upon the negative impact that devices may inflict on the sites over longer periods of time. In order to investigate the long-term impacts for the sites considered, further investigation is needed.

8.3.6) Summary of Further Work

To summarise, conduction of this project indicated that the use of renewable energy at sites A and B may be feasible. However due to the limited data which was available for use, the study is inconclusive. With more time and additional information relevant to site choice and device selection, more accurate power outputs could be established. This would further strengthen the quality of economic analysis.

Encouragingly, the potential to source energy from the ocean in certain areas of the UK is particularly great, which makes it possible to consider offshore renewable energy as a year-round solution to satisfy the supply of power required. With time, technological advancements and a greater understanding of the ocean’s power, it certainly could be an approach provisional of environmentally friendly, more affordable and sustainable energy. This would satisfy the demands of an ever-growing population which requires increasing levels of energy, and displays a dependency upon electrical power.

Chapter 9. Coastal Protection from WECs

As part of an additional objective, research of the coastal protection generated as a direct result of utilising offshore renewable energy was conducted. Devices which possess this protective potential, and which shall be focused upon throughout this chapter, are wave energy converting devices.

The motivation underlying this additional objective was driven by the drastically increasing occurrence of destructive storms, which cause sweeping coastal damage. The desire to research the protective potential of WECs was fuelled by studying work undertaken by Mendoza et al. (2014). The scope of their work involved demonstrating the effects of situating numerous WEC devices at two different beaches, one of which is a partially enclosed area, and another which consists of an open straight line beach. To gather greater understanding of the possible effects they may have on coastal lines, Mendoza et al. (2014) performed a series of analytical processes and 2D modelling in order to interpret their results.

It is an established fact that within the renewable energy sector, installing WEC's will likely alter wave propagation due to the device absorbing some of the energy present in the waves. This can provide both opportunities and obstacles, and these will be outlined as part of this additional objective.

9.1) Study

Mendoza et al. (2014) placed numerous devices at the sites considered above. Through consideration of water depth, device dimensions and typical wave conditions enabled them to determine the effects of situating WEC devices at these different beaches. Whilst comparing these results to those obtained whilst the beaches were unprotected, they could acquire an understanding of the occurring effects as a direct result of WEC situation.

9.2) Results

Mendoza et al. (2014) could establish the response seen on the coastlines as a result, to evaluate this, they undertook two stages. Firstly, they determined the long-shore sediment transport (LST (10)), from which it was possible to use the 'continuity of sediment equation (11)'. The latter provided a greater understanding as to the tendencies of coastline evolution.

$$[\mathbf{10}]\ Q_t = 17.5H_{sb}^{2.75} \cdot T_p^{0.89} \cdot m_b^{0.86} \cdot D_{50}^{-0.69} \cdot \sin^{0.5}(2\alpha_b)\ \ m^3/s$$

$$\downarrow$$

$$[\mathbf{11}]\ \frac{\partial x}{\partial t} + \frac{1}{D_s} \cdot \left(\frac{\partial \cdot Q_1}{\partial y} - q\right) = 0$$

From the results, it was established that WECs can feasibly protector shorelines. However, there are a host of variables which may reduce this feasibility. Mendoza et al (2014) mention that situating WEC devices or farms close to shorelines may have direct impact on the fishing industry and other ocean activities They established that for the La Glorias beach (open beach), it would be necessary to carefully consider the positioning of devices in order for them to operate effectively, whilst also protecting the coastline. Whilst for the Santander beach (semi-closed beach), it was determined that there are more variables involved and determination of WEC situation would be inherently difficult.

Overall, the research suggested that using WECs is a feasible method by which coastal erosion can be reduced. However, relevant regulations must be met and the situation of devices close to the coastline must be accepted.

Numerous other researchers have also delved into this research area. Zanuttigh & Angelli (2012) also considered this possibility, and strived to meet similar objectives as Mendoza et al. (2014). Such as understanding the way by which wave fields are affected by device situation and climate change. Unlike the work of Mendoza et al. (2014), real scaled models were situated which allowed for physical testing. Their field tests included situating the devices in singular and array style formations, located in the wave basin at Aalborg University. Numerous constraints limited the quality of testing. Such as the basin size, which limited the distance in which waves may travel before hitting the hypothetical wave energy device.

9.3) Conclusion

In conclusion, research discovered that devices reduced the energy propagating from the devices marginally, in both cases, where singular and array styles were employed. They also determined, that variations in sea level as a result of climate change, did not drastically alter the aforementioned purposes. Final remarks included discussion of optimal characteristics and for a singular device, dimensions had to be altered with respect to the local peak wave length. Whilst meeting a compromise of $\frac{l}{L_p} = 1$ which provided the best outcome for both coastal protection and fundamentally, energy generation. It was also noted that a more substantial weighted device would improve coastal erosion protection. In the case of an array or farm style layout, it was determined that allowing the mooring lines to move freely would improve the coastal protection potential, as wave heights would likely be reduced. It was also mentioned that the devices should be ‘staggered’, which would lead to a reduced foot print, and enable greater absorption of the wave energy. Zanuttigh & Angelli (2012) suggest ‘staggering’ devices in up to 8 lines.

Zanuttigh & Angelli (2012) also highlight that DEXA (wave activated bodies) could be successfully involved in a coastal protection scheme. However, they mention that numerous characteristics may alter true performance.

In summary, considering the literature reviewed above, using WEC devices to reduce coastal erosion does appear a feasible scheme, where it is found that WEC are not massively affected by rising sea levels. It appears that this method could be a more dynamic and flexible approach to account for the changing sea levels and sea states. If time prevails, further research and model testing would prove beneficial to this area of research, with the possibility of real scaled testing in open waters.

Chapter 10. References

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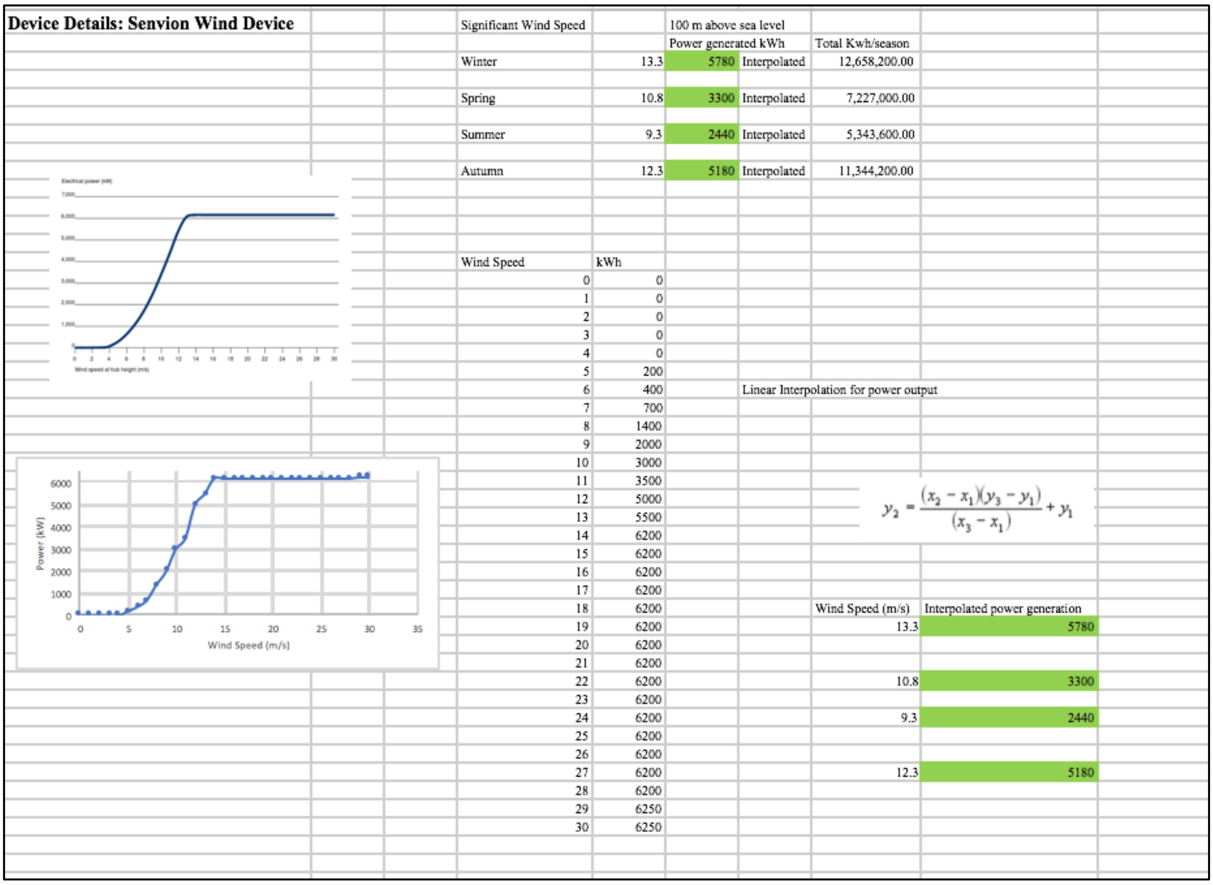
Chapter 11. Appendix

The following appendix provides, further information previously referenced in the body of the report. Included, primarily are excel extracts and email exchanges made with numerous parties to aid in progression of this project.

11.1) Power output



Device Details: Senvion Wind Device

Significant Wind Speed		100 m above sea level		
		Power generated kWh		Total Kwh/season
Winter	13.3	5780	Interpolated	12,658,200.00
Spring	10.8	3300	Interpolated	7,227,000.00
Summer	9.3	2440	Interpolated	5,343,600.00
Autumn	12.3	5180	Interpolated	11,344,200.00

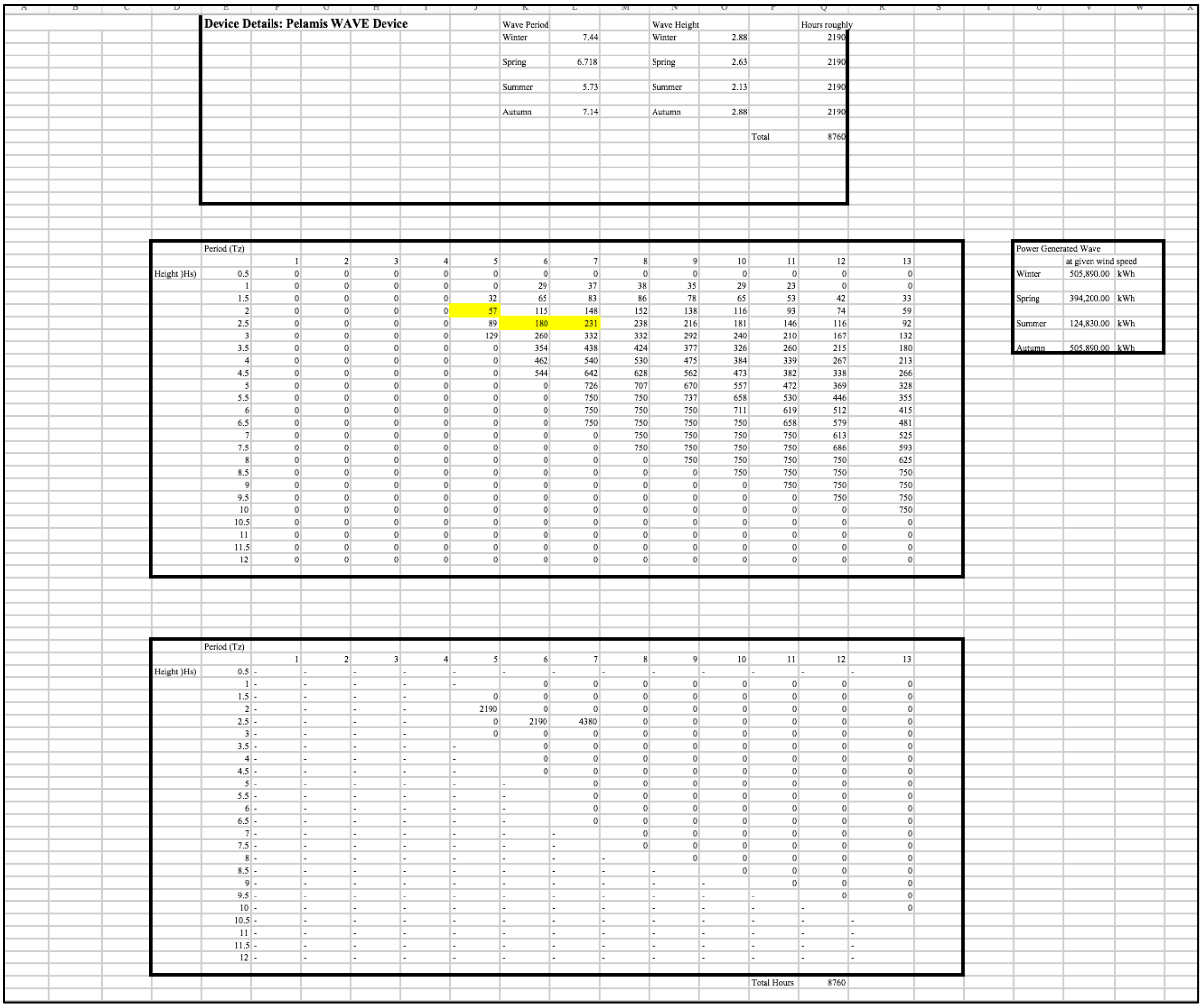
Wind Speed	kWh
0	0
1	0
2	0
3	0
4	0
5	200
6	400
7	700
8	1400
9	2000
10	3000
11	3500
12	5000
13	5500
14	6200
15	6200
16	6200
17	6200
18	6200
19	6200
20	6200
21	6200
22	6200
23	6200
24	6200
25	6200
26	6200
27	6200
28	6200
29	6250
30	6250

Linear Interpolation for power output

$$y_2 = \frac{(x_2 - x_1)(y_3 - y_1)}{(x_3 - x_1)} + y_1$$

Wind Speed (m/s)	Interpolated power generation
13.3	5780
10.8	3300
9.3	2440
12.3	5180

Figure 45: Power output calculation-Wind (Site A)



Device Details: Pelamis WAVE Device

Wave Period		Wave Height			Hours roughly
Winter	7.44	Winter	2.88		2190
Spring	6.718	Spring	2.63		2190
Summer	5.73	Summer	2.13		2190
Autumn	7.14	Autumn	2.88		2190
				Total	8760

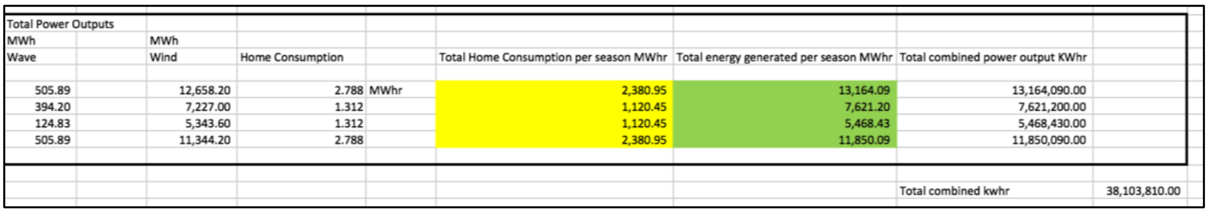
	Period (Tz)													
		1	2	3	4	5	6	7	8	9	10	11	12	13
Height)Hs)	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	0	0	0	0	0	29	37	38	35	29	23	0	0
	1.5	0	0	0	0	32	65	83	86	78	65	53	42	33
	2	0	0	0	0	57	115	148	152	138	116	93	74	59
	2.5	0	0	0	0	89	180	231	238	216	181	146	116	92
	3	0	0	0	0	129	260	332	332	292	240	210	167	132
	3.5	0	0	0	0	0	354	438	424	377	326	260	215	180
	4	0	0	0	0	0	462	540	530	475	384	339	267	213
	4.5	0	0	0	0	0	544	642	628	562	473	382	338	266
	5	0	0	0	0	0	0	726	707	670	557	472	369	328
	5.5	0	0	0	0	0	0	750	750	737	658	530	446	355
	6	0	0	0	0	0	0	750	750	750	711	619	512	415
	6.5	0	0	0	0	0	0	750	750	750	750	658	579	481
	7	0	0	0	0	0	0	0	750	750	750	750	613	525
	7.5	0	0	0	0	0	0	0	750	750	750	750	686	593
	8	0	0	0	0	0	0	0	0	750	750	750	750	625
	8.5	0	0	0	0	0	0	0	0	0	750	750	750	750
	9	0	0	0	0	0	0	0	0	0	0	750	750	750
	9.5	0	0	0	0	0	0	0	0	0	0	0	750	750
	10	0	0	0	0	0	0	0	0	0	0	0	0	750
	10.5	0	0	0	0	0	0	0	0	0	0	0	0	0
	11	0	0	0	0	0	0	0	0	0	0	0	0	0
	11.5	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0	0	0	0

Power Generated Wave		
	at given wind speed	
Winter	505,890.00	kWh
Spring	394,200.00	kWh
Summer	124,830.00	kWh
Autumn	505,890.00	kWh

	Period (Tz)													
		1	2	3	4	5	6	7	8	9	10	11	12	13
Height)Hs)	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-
	1	-	-	-	-	-	0	0	0	0	0	0	0	0
	1.5	-	-	-	-	0	0	0	0	0	0	0	0	0
	2	-	-	-	-	2190	0	0	0	0	0	0	0	0
	2.5	-	-	-	-	0	2190	4380	0	0	0	0	0	0
	3	-	-	-	-	0	0	0	0	0	0	0	0	0
	3.5	-	-	-	-	-	0	0	0	0	0	0	0	0
	4	-	-	-	-	-	0	0	0	0	0	0	0	0
	4.5	-	-	-	-	-	0	0	0	0	0	0	0	0
	5	-	-	-	-	-	-	0	0	0	0	0	0	0
	5.5	-	-	-	-	-	-	0	0	0	0	0	0	0
	6	-	-	-	-	-	-	0	0	0	0	0	0	0
	6.5	-	-	-	-	-	-	0	0	0	0	0	0	0
	7	-	-	-	-	-	-	-	0	0	0	0	0	0
	7.5	-	-	-	-	-	-	-	0	0	0	0	0	0
	8	-	-	-	-	-	-	-	-	0	0	0	0	0
	8.5	-	-	-	-	-	-	-	-	-	0	0	0	0
	9	-	-	-	-	-	-	-	-	-	-	0	0	0
	9.5	-	-	-	-	-	-	-	-	-	-	-	0	0
	10	-	-	-	-	-	-	-	-	-	-	-	-	0
	10.5	-	-	-	-	-	-	-	-	-	-	-	-	-
	11	-	-	-	-	-	-	-	-	-	-	-	-	-
	11.5	-	-	-	-	-	-	-	-	-	-	-	-	-
	12	-	-	-	-	-	-	-	-	-	-	-	-	-

Total Hours 8760

Figure 46: Power output calculation-Wave (Site A)

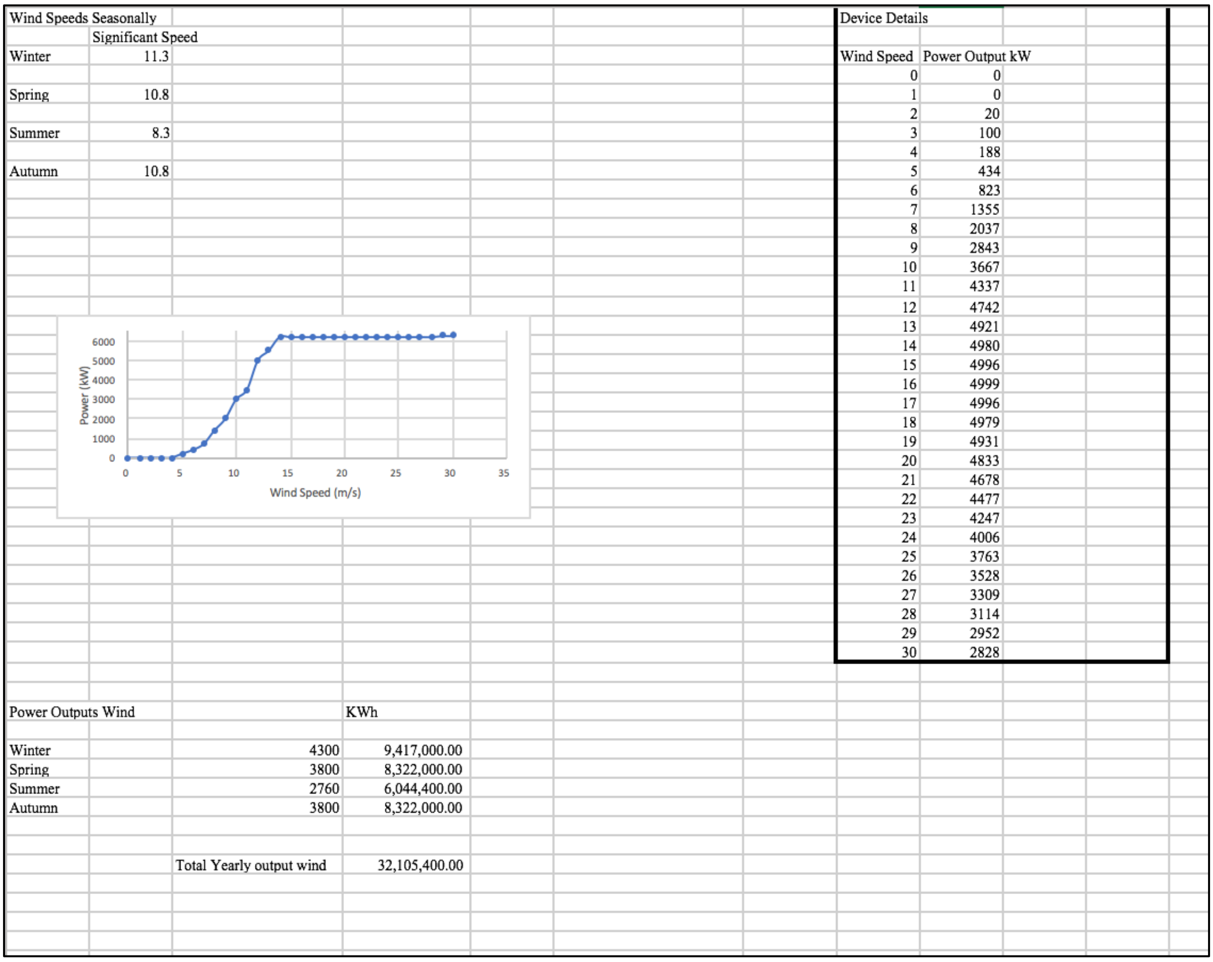


Total Power Outputs

MWh Wave	MWh Wind	Home Consumption		Total Home Consumption per season MWhr	Total energy generated per season MWhr	Total combined power output KWhr
505.89	12,658.20	2.788	MWhr	2,380.95	13,164.09	13,164,090.00
394.20	7,227.00	1.312		1,120.45	7,621.20	7,621,200.00
124.83	5,343.60	1.312		1,120.45	5,468.43	5,468,430.00
505.89	11,344.20	2.788		2,380.95	11,850.09	11,850,090.00

Total combined kwhr 38,103,810.00

Figure 47: Summary of power outputs (Site A)



Wind Speeds Seasonally

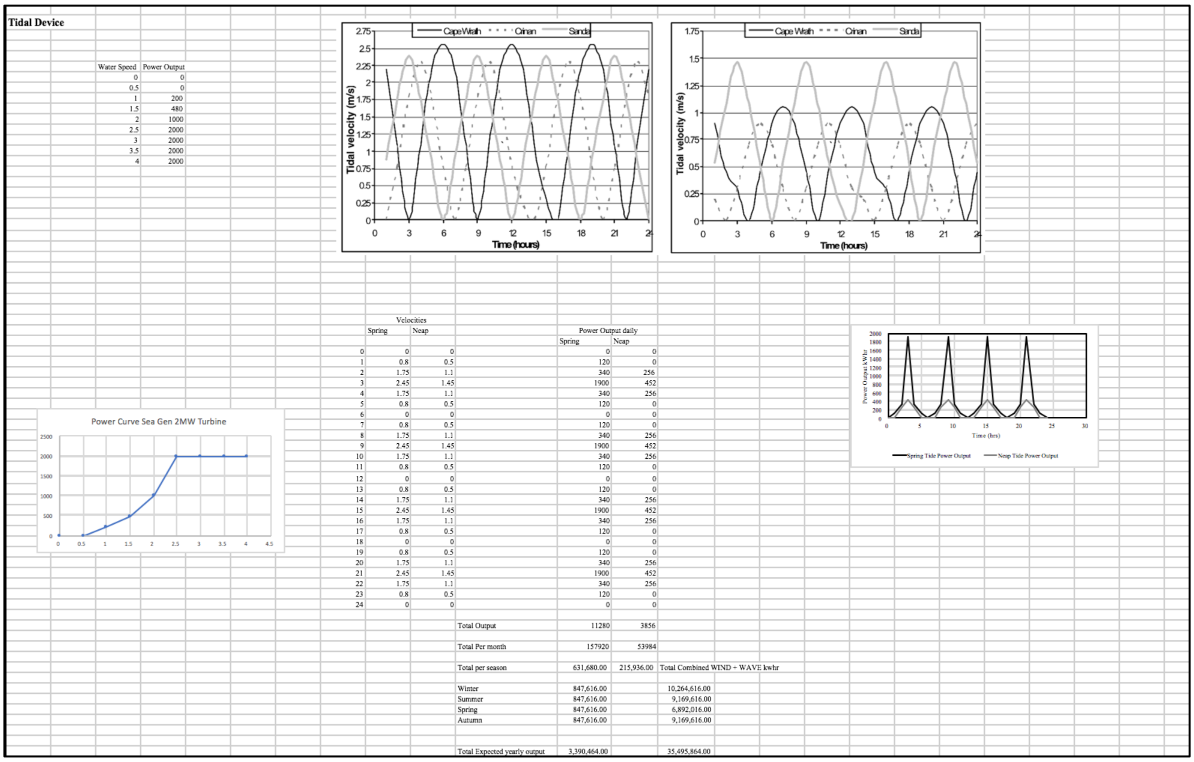
	Significant Speed
Winter	11.3
Spring	10.8
Summer	8.3
Autumn	10.8

Device Details

Wind Speed	Power Output kW
0	0
1	0
2	20
3	100
4	188
5	434
6	823
7	1355
8	2037
9	2843
10	3667
11	4337
12	4742
13	4921
14	4980
15	4996
16	4999
17	4996
18	4979
19	4931
20	4833
21	4678
22	4477
23	4247
24	4006
25	3763
26	3528
27	3309
28	3114
29	2952
30	2828

Power Outputs Wind		KWh
Winter	4300	9,417,000.00
Spring	3800	8,322,000.00
Summer	2760	6,044,400.00
Autumn	3800	8,322,000.00
Total Yearly output wind		32,105,400.00

Figure 48: Power output calculation-Wind (Site B)



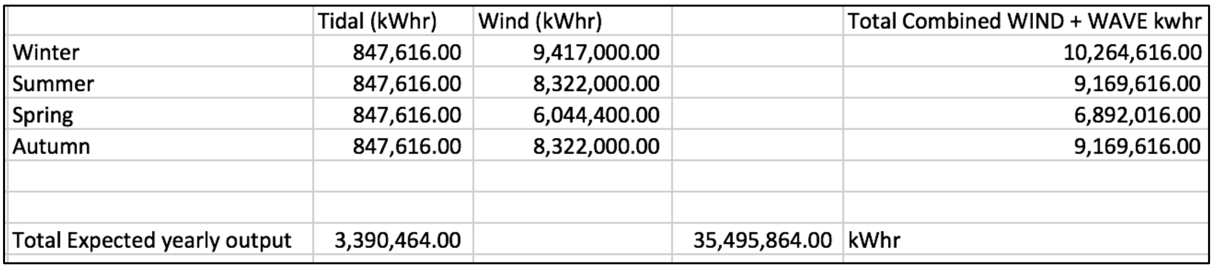
Tidal Device

Water Speed	Power Output
0	0
0.5	0
1	200
1.5	480
2	1000
2.5	2000
3	2000
3.5	2000
4	2000

	Velocities		Power Output daily	
	Spring	Neap	Spring	Neap
0	0	0	0	0
1	0.8	0.5	120	0
2	1.75	1.1	340	256
3	2.45	1.45	1900	452
4	1.75	1.1	340	256
5	0.8	0.5	120	0
6	0	0	0	0
7	0.8	0.5	120	0
8	1.75	1.1	340	256
9	2.45	1.45	1900	452
10	1.75	1.1	340	256
11	0.8	0.5	120	0
12	0	0	0	0
13	0.8	0.5	120	0
14	1.75	1.1	340	256
15	2.45	1.45	1900	452
16	1.75	1.1	340	256
17	0.8	0.5	120	0
18	0	0	0	0
19	0.8	0.5	120	0
20	1.75	1.1	340	256
21	2.45	1.45	1900	452
22	1.75	1.1	340	256
23	0.8	0.5	120	0
24	0	0	0	0

Total Output	11280	3856	
Total Per month	157920	53984	
Total per season	631,680.00	215,936.00	Total Combined WIND + WAVE kwhr
Winter	847,616.00		10,264,616.00
Summer	847,616.00		9,169,616.00
Spring	847,616.00		6,892,016.00
Autumn	847,616.00		9,169,616.00
Total Expected yearly output	3,390,464.00		35,495,864.00

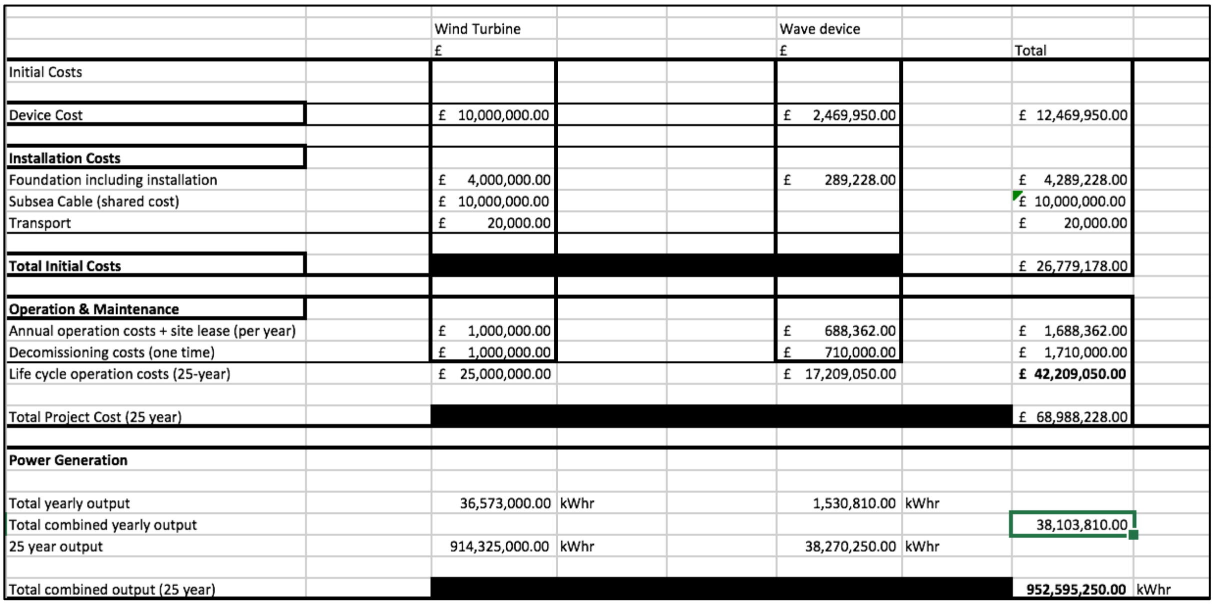
Figure 49: Power output calculation-Tidal (Site B)



	Tidal (kWhr)	Wind (kWhr)		Total Combined WIND + WAVE kwhr
Winter	847,616.00	9,417,000.00		10,264,616.00
Summer	847,616.00	8,322,000.00		9,169,616.00
Spring	847,616.00	6,044,400.00		6,892,016.00
Autumn	847,616.00	8,322,000.00		9,169,616.00
Total Expected yearly output	3,390,464.00		35,495,864.00	kWhr

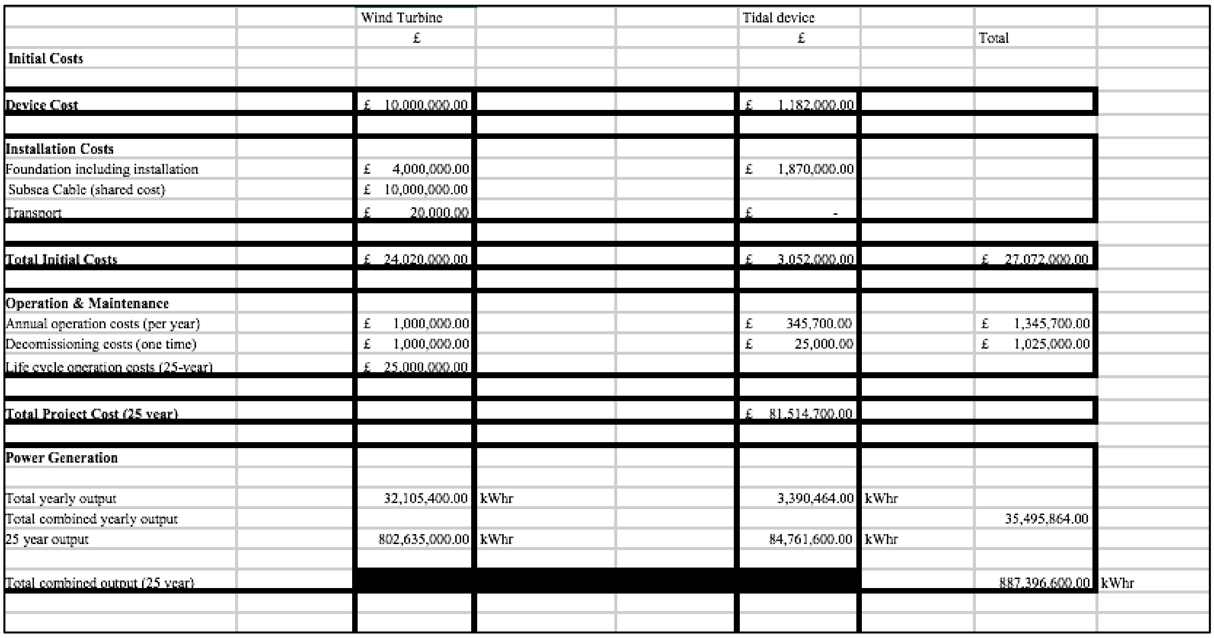
Figure 50: Summary of power outputs (Site B)

11.2) Economic Analysis



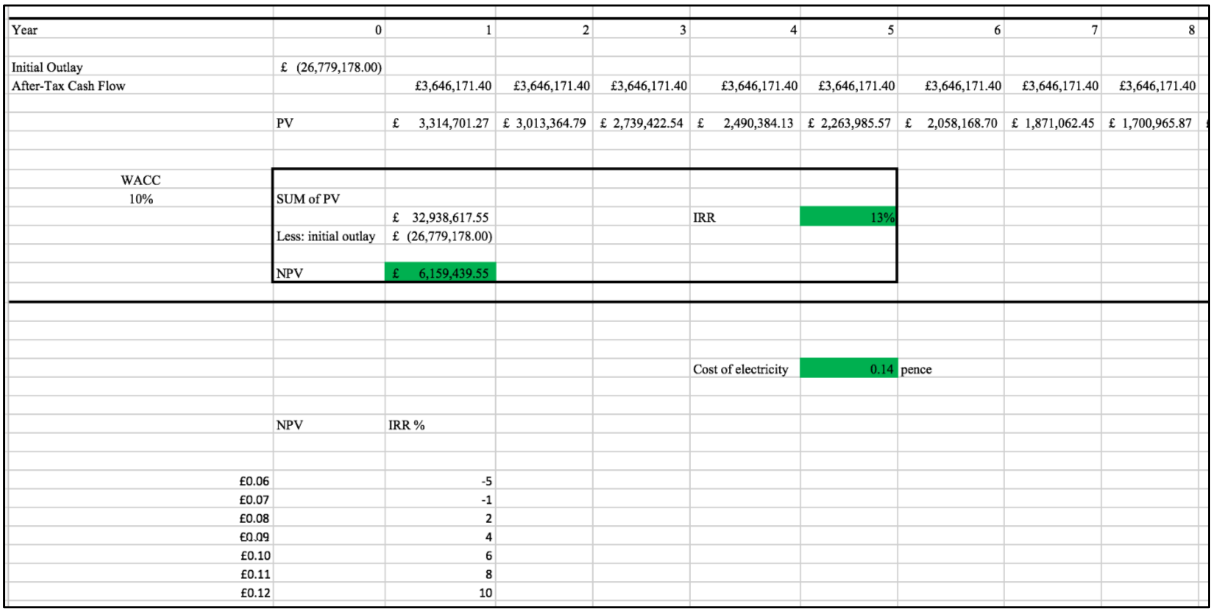
	Wind Turbine £		Wave device £		Total	
Initial Costs						
Device Cost	£ 10,000,000.00		£ 2,469,950.00		£ 12,469,950.00	
Installation Costs						
Foundation including installation	£ 4,000,000.00		£ 289,228.00		£ 4,289,228.00	
Subsea Cable (shared cost)	£ 10,000,000.00				£ 10,000,000.00	
Transport	£ 20,000.00				£ 20,000.00	
Total Initial Costs					£ 26,779,178.00	
Operation & Maintenance						
Annual operation costs + site lease (per year)	£ 1,000,000.00		£ 688,362.00		£ 1,688,362.00	
Decomissioning costs (one time)	£ 1,000,000.00		£ 710,000.00		£ 1,710,000.00	
Life cycle operation costs (25-year)	£ 25,000,000.00		£ 17,209,050.00		**£ 42,209,050.00**	
Total Project Cost (25 year)					£ 68,988,228.00	
Power Generation						
Total yearly output	36,573,000.00	kWhr	1,530,810.00	kWhr		
Total combined yearly output					38,103,810.00	
25 year output	914,325,000.00	kWhr	38,270,250.00	kWhr		
Total combined output (25 year)					**952,595,250.00**	kWhr

Figure 51: Capital costs and total power (Site A)



	Wind Turbine £		Tidal device £		Total	
Initial Costs						
Device Cost	£ 10,000,000.00		£ 1,182,000.00			
Installation Costs						
Foundation including installation	£ 4,000,000.00		£ 1,870,000.00			
Subsea Cable (shared cost)	£ 10,000,000.00					
Transport	£ 20,000.00		£ -			
Total Initial Costs	£ 24,020,000.00		£ 3,052,000.00		£ 27,072,000.00	
Operation & Maintenance						
Annual operation costs (per year)	£ 1,000,000.00		£ 345,700.00		£ 1,345,700.00	
Decomissioning costs (one time)	£ 1,000,000.00		£ 25,000.00		£ 1,025,000.00	
Life cycle operation costs (25-year)	£ 25,000,000.00					
Total Project Cost (25 year)			£ 81,514,700.00			
Power Generation						
Total yearly output	32,105,400.00	kWhr	3,390,464.00	kWhr		
Total combined yearly output					35,495,864.00	
25 year output	802,635,000.00	kWhr	84,761,600.00	kWhr		
Total combined output (25 year)					887,396,600.00	kWhr

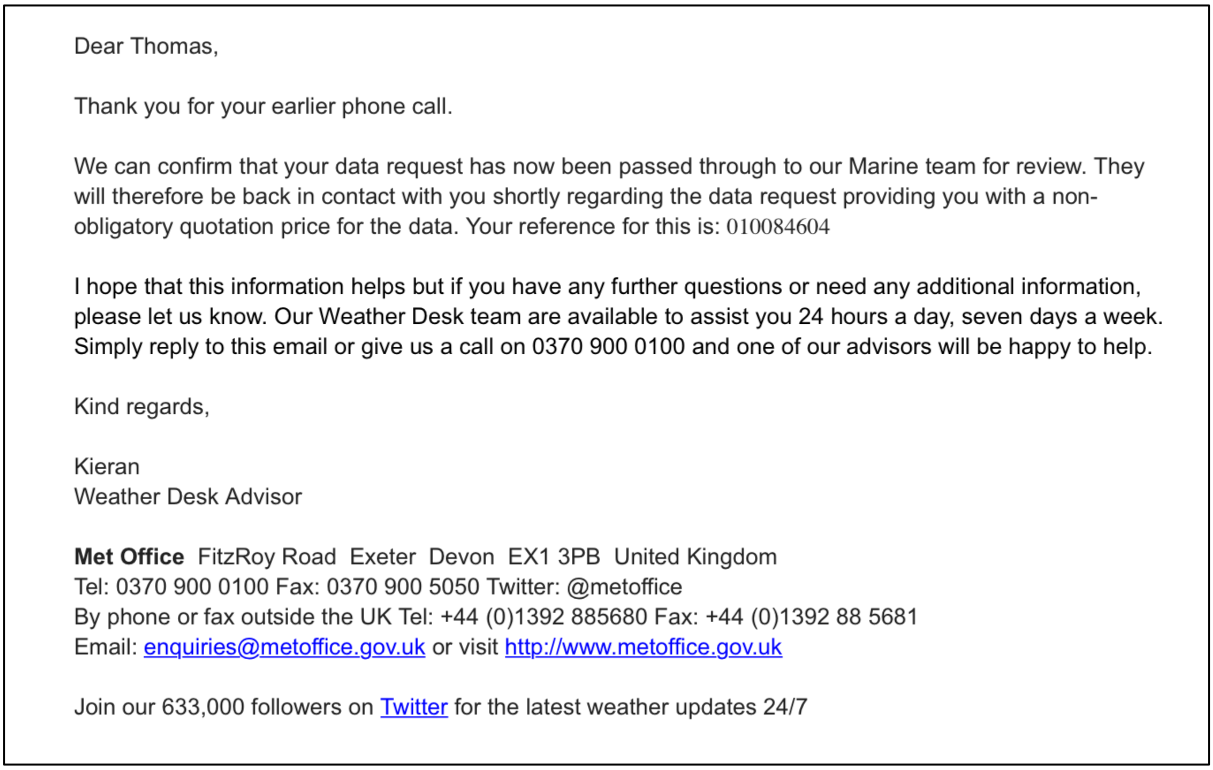
Figure 52: Capital costs and total power (Site B)



Year	0	1	2	3	4	5	6	7	8
Initial Outlay	£ (26,779,178.00)								
After-Tax Cash Flow		£3,646,171.40	£3,646,171.40	£3,646,171.40	£3,646,171.40	£3,646,171.40	£3,646,171.40	£3,646,171.40	£3,646,171.40
	PV	£ 3,314,701.27	£ 3,013,364.79	£ 2,739,422.54	£ 2,490,384.13	£ 2,263,985.57	£ 2,058,168.70	£ 1,871,062.45	£ 1,700,965.87
WACC									
10%	SUM of PV								
		£ 32,938,617.55			IRR	13%			
	Less: initial outlay	£ (26,779,178.00)							
	NPV	£ 6,159,439.55							
					Cost of electricity	0.14	pence		
	NPV	IRR %							
£0.06		-5							
£0.07		-1							
£0.08		2							
£0.09		4							
£0.10		6							
£0.11		8							
£0.12		10							

Figure 53: Example IRR calculation (Site A)

11.3) Email Communications



Dear Thomas,

Thank you for your earlier phone call.

We can confirm that your data request has now been passed through to our Marine team for review. They will therefore be back in contact with you shortly regarding the data request providing you with a non-obligatory quotation price for the data. Your reference for this is: 010084604

I hope that this information helps but if you have any further questions or need any additional information, please let us know. Our Weather Desk team are available to assist you 24 hours a day, seven days a week. Simply reply to this email or give us a call on 0370 900 0100 and one of our advisors will be happy to help.

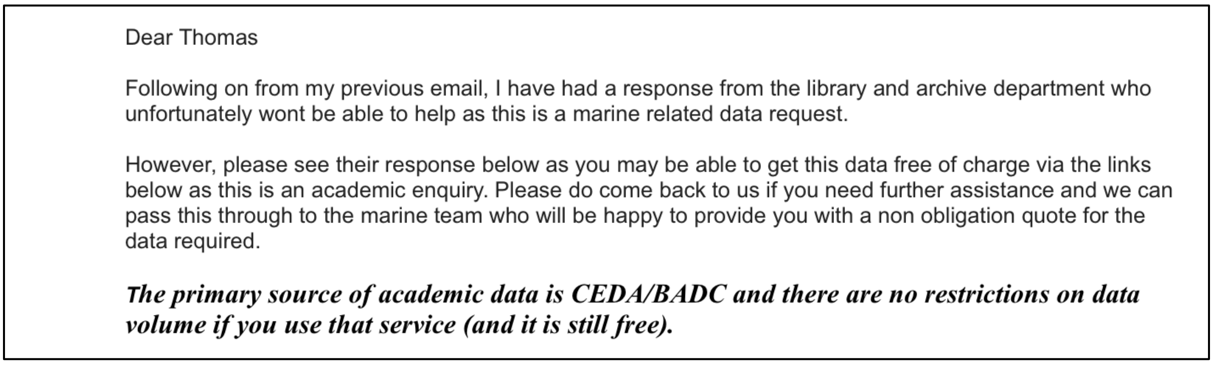
Kind regards,

Kieran
Weather Desk Advisor

Met Office FitzRoy Road Exeter Devon EX1 3PB United Kingdom
Tel: 0370 900 0100 Fax: 0370 900 5050 Twitter: @metoffice
By phone or fax outside the UK Tel: +44 (0)1392 885680 Fax: +44 (0)1392 88 5681
Email: enquiries@metoffice.gov.uk or visit http://www.metoffice.gov.uk

Join our 633,000 followers on Twitter for the latest weather updates 24/7

Figure 54: Met office data request



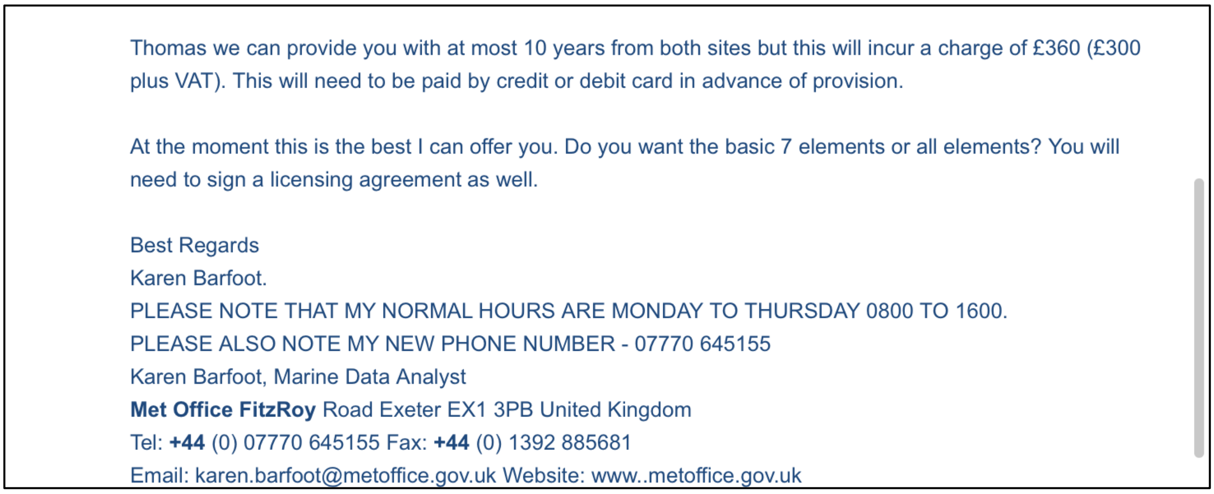
Dear Thomas

Following on from my previous email, I have had a response from the library and archive department who unfortunately wont be able to help as this is a marine related data request.

However, please see their response below as you may be able to get this data free of charge via the links below as this is an academic enquiry. Please do come back to us if you need further assistance and we can pass this through to the marine team who will be happy to provide you with a non obligation quote for the data required.

The primary source of academic data is CEDA/BADC and there are no restrictions on data volume if you use that service (and it is still free).

Figure 55: Data availability



Thomas we can provide you with at most 10 years from both sites but this will incur a charge of £360 (£300 plus VAT). This will need to be paid by credit or debit card in advance of provision.

At the moment this is the best I can offer you. Do you want the basic 7 elements or all elements? You will need to sign a licensing agreement as well.

Best Regards
Karen Barfoot.
PLEASE NOTE THAT MY NORMAL HOURS ARE MONDAY TO THURSDAY 0800 TO 1600.
PLEASE ALSO NOTE MY NEW PHONE NUMBER - 07770 645155
Karen Barfoot, Marine Data Analyst
Met Office FitzRoy Road Exeter EX1 3PB United Kingdom
Tel: **+44** (0) 07770 645155 Fax: **+44** (0) 1392 885681
Email: karen.barfoot@metoffice.gov.uk Website: www..metoffice.gov.uk

Figure 56: Data costs