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Life Cycle comparison of a wave and tidal energy device

Introduction and Aim:

Tidal and wave energy devices are predicted, in the future, to provide up to 20% of the UK's energy requirement [1]. In comparison to other renewable energy technologies such as wind turbines or photovoltaic panels, these marine technologies are in their infancy. The aim of this project was to conduct a Life Cycle Assessment (LCA) of a wave energy device, in order to determine the embodied energy and carbon, and the time taken by the device in operation to repay this. The second stage of this project was to compare results for the wave energy device to those for a tidal energy device.

Marine Energy Devices:

There are two types of marine energy devices: Wave energy devices and tidal energy devices. Wave energy devices extract energy from the movement of waves, which are themselves driven by wind and sea conditions. Waves are unpredictable, making the output from these devices difficult to estimate. A common design of wave energy device incorporates a fixed base mounted on the seabed, with a buoyant flap section moving with wave motion (Fig. 1).

Tidal energy devices extract energy from the movement of the tides, and often look like underwater wind turbines (Fig. 2). Tides are governed by gravitational forces and the rotation of the earth, so are highly predictable.

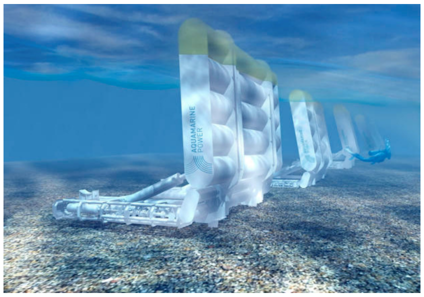

Figure 1 – Oyster wave device array

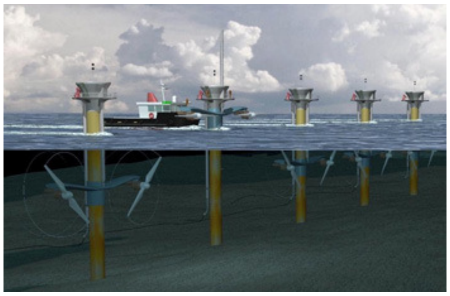

Figure 2 – SeaGen tidal device array

Although there are a number of devices in both categories currently being developed, the two devices chosen for this study were those shown above, the 1.2MW SeaGen tidal device, and the 315kW Oyster wave energy device.

Life Cycle Assessment

A Life Cycle Assessment (LCA) of the SeaGen device was carried out by Douglas, Harrison and Chick of the University of Edinburgh in 2007 [2]. The assessment was carried out on the test device installed at Strangford Lough, and included energy and CO_2 assessment of the device manufacture, transport, installation, maintenance and decommissioning. In order to allow a comparative analysis of the two devices, a similar assessment was carried out for the Oyster device installed at EMEC (European Marine Energy Centre) in 2008 as part of this study.

Oyster LCA: Overview

The LCA of the Oyster device was designed to include the same areas as that conducted for the SeaGen device, assessing the embodied energy and emissions from raw materials to installed operational device. A large spreadsheet was created to calculate the emissions and energy requirement of each stage of the device development, as well as the output of the device in operation. The methodology employed for each stage is detailed in the following sections of this report. The layout of the Oyster system is shown in Figure 3. The main device incorporates a base section and a moving flap, joined by a connector and two hydraulic rams. As the flap moves in wave motion, water is pushed through the pipe flow lines and to the onshore power system, which is contained within two shipping containers. In the mechanical container a pelton wheel drives a generator, and the electrical system contains the relevant rectifiers and safety systems for electrical connection to the national grid.

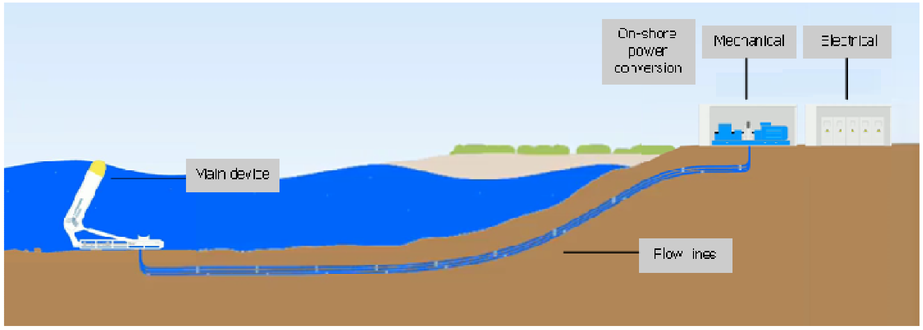

Figure 3 – Oyster wave energy device overall system

Data Collection

In order to ascertain the emissions and energy use of the Oyster device, a large volume of data was required, for example regarding the size, weight, construction methods and materials, and the processes used for the installation, transport and maintenance of the device. This information would ideally have been sourced from the device manufacturers. However, having contacted Aquamarine Power, the company were unable to supply data for the study. Fortunately, relevant data was available from the company website [3], a number of papers [4,5,6] and further sources such as the device patent [7], the installation contractor [8], and EMEC.

Although the lack of precise data from the manufacturer did lengthen the process of data collection, it is believed that the assumptions made are reasonable. Although there may be some small inaccuracies in the data used during the LCA, this is not expected to compromise the general results.

Materials

The materials section of the LCA analysed the emissions and energy use required to process raw materials into the basic form of the Oyster device. A large proportion of the device is manufactured from mild steel, with other prominent materials being iron (in the valves and hydraulic rams), copper (in the generator and electrical systems), stainless steel (rams and valves) and plywood for the bases of the mechanical and electrical containers. The total mass of the device is around 200 tonnes, and the total energy requirement for this stage was calculated to be 4 GJ, resulting in 310 tonnes of CO_2.

Transport

Following the manufacture of the components, transport was considered next. Many parts were manufactured by contractors in different locations. Where detailed information was not available, for each location the mass and volume of each part was considered in order to work out the transport method most likely to have been used. Following this, haulage and ferry prices were calculated, and the appropriate emissions per kilometre were applied [9] to ascertain overall transport emissions.

Installation

The installation of the Oyster device at EMEC was a complex process, costing £2.7 million. In order to ascertain the energy use and emissions of this process, the installation was broken down into a number of smaller processes, such as drilling the pile holes, placing the piles, and grouting the piles in place. A total of thirteen smaller processes were identified. For each process, general emissions were calculated based on the number of people required, transport method and distance. For large processes such as the drilling of pile holes and placement of the device using a Jack-Up vessel, the energy use and emissions data of the installation vessel was also calculated, based on data from the installation contractor [8]. Emissions of the generator used to power the pile drill were calculated based on a 300kW diesel model. Installation was calculated to emit 382 tonnes of CO_2, making it the highest emission process.

Maintenance

During the estimated 15 year lifetime of the Oyster device, regular maintenance will be required in order to ensure efficient operation. The frequency and details of maintenance vary in reality, but for this assessment three annual visits have been assumed. Each time it was assumed that four engineers travelled from the Aquamarine Power base in Edinburgh to the device, by car and ferry. No additional travel or haulage for parts was calculated at this stage, as it was assumed that any parts or equipment were likely to be transported with the engineers. This is an estimate, but is in line with the maintenance requirements of similar devices.

Decommissioning & Recycling

At the end of its lifetime, the Oyster will be decommissioned and recycled where possible. Decommissioning the device will use energy, cause carbon emissions and have a cost, but through recycling some of these can be recouped. In order to calculate recycling, the portion of each material involved in the device which could (firstly) be removed, and (secondly) be recycled, was calculated. In line with the SeaGen device, decommissioning was calculated as a partial reversal of the installation processes, with around 30% of specific installation processes reversed for decommissioning. Removable percentages were estimated from installation procedures, and recyclable percentages calculated from industry sources [10]. Based on replacing primary material with recycled material in future projects, decommissioning and recycling of the Oyster resulted in a net saving of 136 tonnes of CO_2, although a net cost of £830,500 was incurred.

Output

Having calculated the following totals for the Oyster device manufacture, transport, installation, lifetime maintenance and decommissioning, the next stage was to calculate the device energy output.

Energy	5,366,606 MJ
Carbon	559,692 $kgCO_2$
Cost	£ 3,800,952

Table 1 – Device totals (materials to installation)

Output was calculated using the Oyster device power matrix and historical wave data recorded at the EMEC site, shown in Figures 4 and 5. Using these data sets in comparison revealed a figure of 173 kW per annum estimated output.

Oyster power matrix assuming same Hs as deep water, wave saturated above Hs = 4.0m

Significant wave height (m)	Energy period (secs) 5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0
0.5	idle	idle	idle	idle	idle	idle	1	3	3
1.0	20	30	38	42	44	44	45	47	45
1.5	80	85	92	97	102	103	104	100	104
2.0	140	147	152	158	155	155	160	161	156
2.5	192	197	208	202	203	209	211	201	204
3.0	241	237	237	241	243	230	236	231	235
3.5	-	271	272	269	268	267	270	260	260
4.0	-	291	290	290	280	287	276	278	277
4.5	-	291	290	290	280	287	276	278	277
5.0	-	-	290	290	280	287	276	278	277
5.5	-	-	290	290	280	287	276	278	277
6.0	-	-	290	290	280	287	276	278	277

Figure 4 – Oyster device power matrix

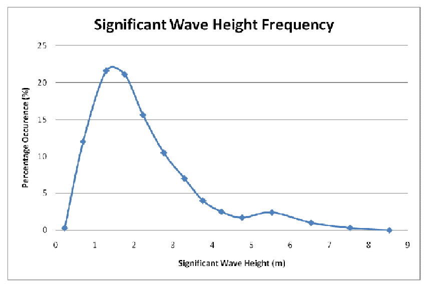

Figure 5 – EMEC historical site wave data

Results:

The data detailed above revealed that over its lifetime the Oyster device would produce 76.4 TJ of energy, offsetting 11,800 tonnes CO_2, but would not achieve financial payback, with a lifetime cost of around £1 million.

In order to compare the results to those of the SeaGen tidal device, the same headline figures were calculated for the Oyster. These results are shown below, along with comparative data for other energy sources (from [2]).

	Oyster	SeaGen	Wind Turbine	Fossil Fuels
Carbon (gCO2/kWh)	25	15	~10	400 – 1000
Energy (kJ/kWh)	236	214	~200	

Table 2 – Carbon and Energy intensity of Oyster, SeaGen and other energy sources

(Months)	Oyster	SeaGen
Carbon	8	8
Energy	12	14

Table 3 – Carbon and Energy payback periods of Oyster and SeaGen devices

Conclusions:

The Oyster and SeaGen devices exhibit very similar energy and carbon intensities and payback periods. Despite the infancy of the technology, these values are close to those achieved by large wind turbine installations so appear to offer the potential for promising returns as their development progresses. Installation of the Oyster formed a large part of overall cost, and presents an area for reduction as the device is commercialised further. Both devices are also envisaged to be installed in arrays, which is expected to reduce the per-device cost and intensity of many processes.

Many details have not been included in this summary; please refer to the full length report for more information.

References:

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[10] – *Metals – aluminium and steel recycling* – Waste Online. Available online: http://www.wasteonline.org.uk/resources/InformationSheets/metals.htm