Capital, operating and maintenance costs

In another, the key factors affecting the cost of energy of marine renewables devices were introduced. These include performance, capital costs, operation and maintenance (O&M) costs and risks (e.g. due to offshore environment).

The previous article also introduced changes to the design of devices that could affect both performance and costs simultaneously, while we looked at performance in more detail. Here we add further to the picture of cost of energy by considering what makes up a marine energy device's capital costs and O&M costs, as well as opportunities to reduce these.

What influences a device's capital costs?

The capital cost of a marine renewable device is made-up of several parts, which generally can be divided into station-keeping, structural, and energy conversion components and sub-assemblies, and project costs. Station-keeping parts include the moorings or foundations (e.g. a monopile) and structural components are all the parts that hold the device together (e.g. the steel shell of a floating wave energy device). Especially for wave energy devices, there is some overlap between structural and energy conversion components because the structure's geometry and size has a significant bearing on the device's ability to absorb power. Other energy conversion components include parts of the powertrain or power take-off (PTO) system, such as hydraulic pistons, hydraulic motors, gearboxes, frequency converters and electrical generators. Finally, project costs are those items, excluding the device itself, which allow it to operate at the intended location. They include further hardware such as subsea cables and the processes of transportation, installation and commissioning. For large installations or farms of devices, station-keeping might be considered under the project costs category. It is convenient to describe capital costs for an installed wave device(s) in terms of cost centres, as is common in other capital projects. This allows costs to be compared on a functional basis without delving into the detail of particular components or systems. Cost centre breakdowns can be obtained in different ways and some examples from the Marine Energy Challenge are shown in Figure 1. Figure 1a is for a wave energy device before project costs are considered (i.e. to the point of final assembly on land), and Figure 1b shows the project costs for that same device installed as one of a wave farm. Effectively, the entire pie of Figure 1a is represented in Figure 1b as the 'device' segment.

Figure 1a: Capital cost breakdown for a particular wave energy device.

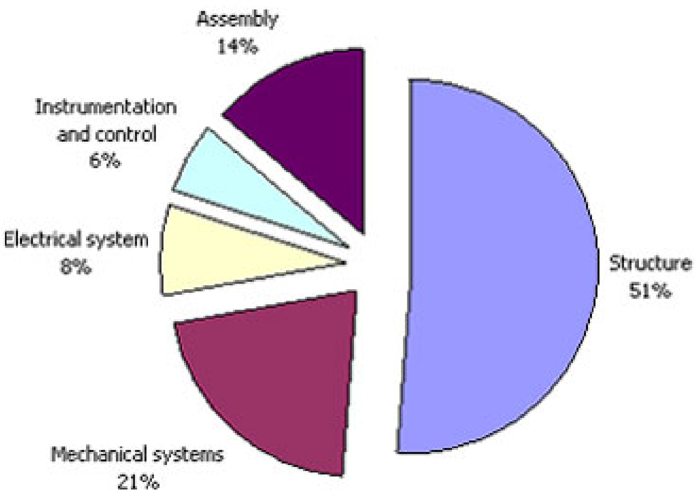


Figure 1b: Capital cost breakdown for installation of a particular wave energy device as one single unit

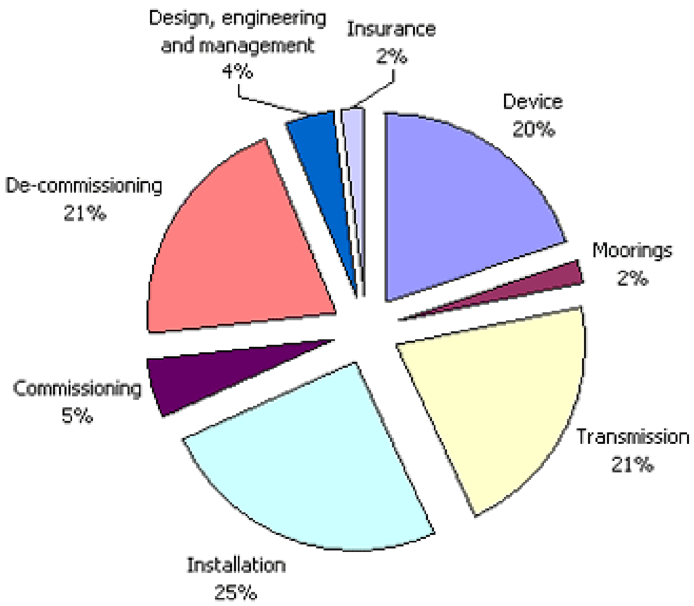


Figure 1c: Capital cost breakdown for installation of a particular wave energy device in a wave farm of a certain size

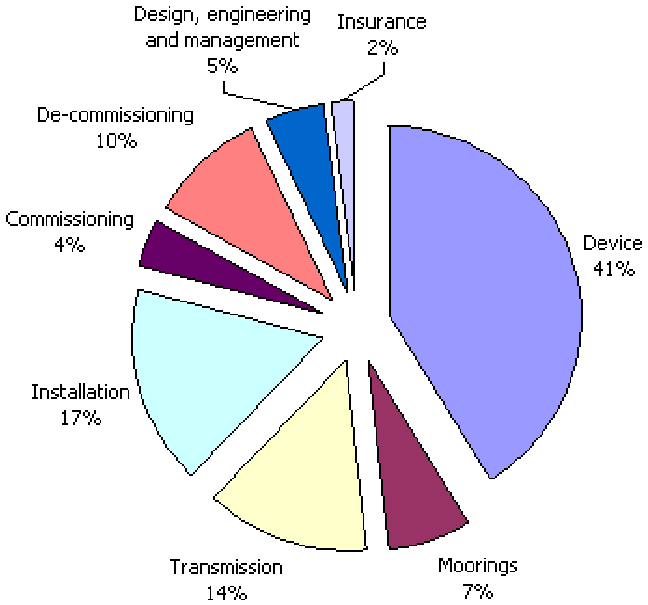
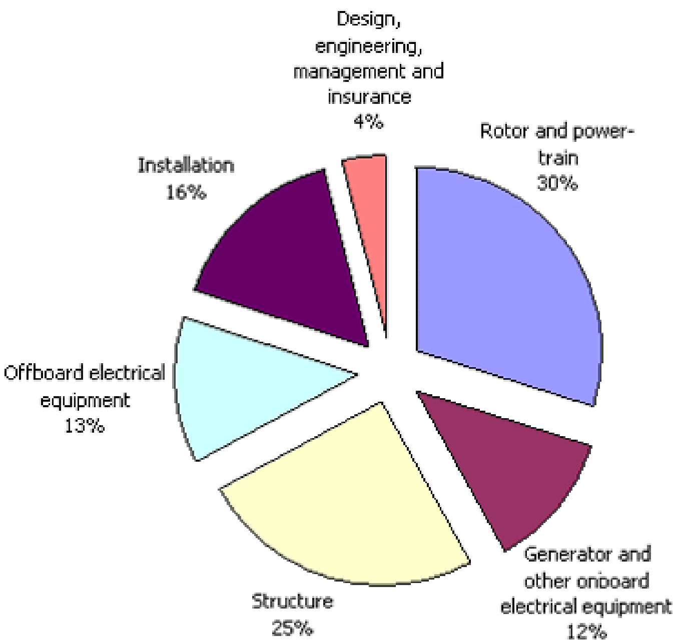


Figure 1d: Capital cost breakdown for installation of a particular tidal stream energy device in a tidal stream farm of a certain size



One can tell from Figure 1a that for any single device of this kind, structural costs dominate, while Figure 1b indicates that the costs of the device itself make up only one fifth of the total project. It is important to note, however, that this breakdown is for installation of only a single device. If we move on to look at a wave farm of several devices, as in Figure 1c, the proportions change considerably. Now the cost of devices is much more significant, although installation costs are still large. An important point to draw from this is that the project cost basis changes markedly with the amount of intended installed generation capacity. Indeed, a project of the size envisaged here (about 10 MW) might be considered relatively small in the long term of wave energy projects.
For rough comparison, Figure 1d shows a similar breakdown of installed costs for a tidal stream device. Again the structural costs are considerable, but in this case the largest cost centre relates to the energy conversion systems. Note that none of the Figure 1 pie charts should be taken as representative/typical of wave energy or tidal stream technologies as a whole. In fact, there are considerable variations between different device types and project locations. What's more, future design improvements, performance/cost optimisations and learning effects could radically alter the relative weight of certain cost centres. Referring back to Figure 1a, a possible example of this is due to the designer choosing a different structural material of equivalent strength but lower cost per tonne.

What influences a device's Operation and Maintenance costs?

Like capital costs, it is convenient to consider operation and maintenance costs in terms of cost centres. Figure 2a refers to an example wave energy project at a particular location involving a single wave energy converter. The cost centres shown are fairly typical, including planned and unplanned maintenance, licences to be stationed and generate electricity at the location (often referred to as consents and permits), insurance, and ongoing monitoring activities. For this particular technology, a mid-life refit has been selected as a good compromise between maximising availability and minimising costs. It can also be seen that about 1/7th of the total O&M costs are assigned to unplanned maintenance activities, which reflects a degree of uncertainty in the device's design for reliability.

Figure 2a: O&M cost breakdown for a particular wave energy device installed as a single unit

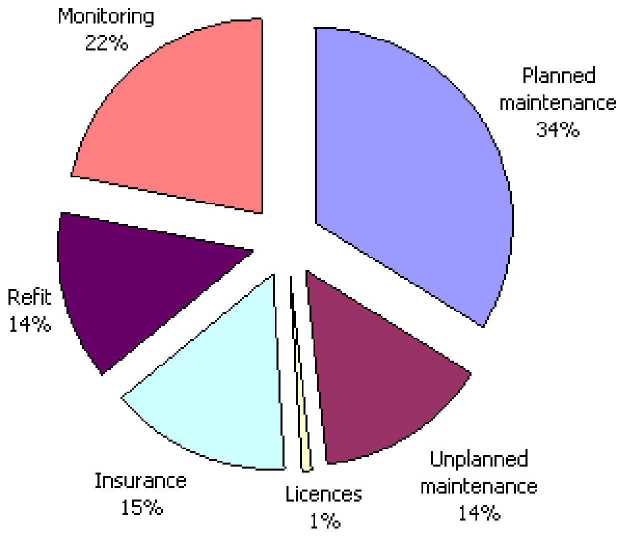


Figure 2b: O&M cost breakdown for a wave farm of a certain size involving one particular wave energy device

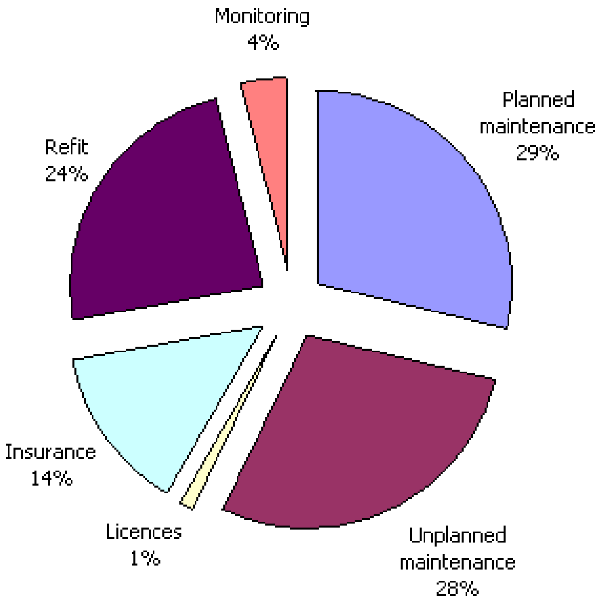


Figure 2b shows the same categories as Figure 2a but this time for a project of several devices. Some items retain broadly the same weightings, including licences and insurance, while others, particularly unplanned maintenance, become more important. This indicates that as well as capital

costs changing between projects of different sizes, operation costs can as well. Again, these illustrations should not be taken as representative of the wave energy sector as a whole; the cost centre weightings vary between different device technologies, projects sizes and locations.
Whereas Figures 1a to 1d are drawn from a plain, present-day cost estimate, it is worth noting that Figures 2a and 2b are based on a Discounted Cash Flow (DCF) calculation. (This is a standard way of assessing energy generation projects and indeed many other capital intensive projects).
Consequently the figures refer to annual average costs. In reality of course, operation and maintenance costs are unlikely to stay exactly the same year after year. For early installations, the relative lack of experience of O&M procedures and opportunity/need for equipment modifications post commissioning could mean that O&M costs are higher in the first few years than in the remainder of the project's life.

Relationships between capital costs and O&M costs

So far we have seen how both capital and O&M costs can be described in terms of cost centres, and examples of how these cost centres form total capital costs and annual average O&M costs. This treatment is fine for cost analyses, but during design of wave energy and tidal stream devices we need to look more closely at individual cost centres and how design decisions affect capital expenditure (capex) and operation/maintenance expenditure (opex) together.
In simple terms, the overall size of a device is likely to influence both it's capex and opex. Considering the device structure alone, size is obviously crucial to the amounts of structural materials needed and therefore the total material costs; a larger device may cost more. However, it may also require more time-consuming O&M procedures, such as inspections of structural integrity. As a further example, complexity of the control and operating system (most likely within the PTO system components) may be worth extra capex to achieve continuous high power generation. However, if this leads to poorer reliability, there may be a penalties in either costs of intervention (man-hours of maintenance crews) or replacement parts (on top of the cost of lost production revenue due to lower availability, as discussed in the previous article).

We can draw from these examples that greater capex can lead to greater opex. It is also true that greater capital expenditure can reduce opex. Redundancy (duplicating items so that if one fails, another can take over) is in some situations highly attractive to maintain performance. Quite considerable cost increases due to redundancy may be justified instead of incurring costs of intervention/parts and lower availability. However, in some cases it is difficult to engineer automatic redundancy, i.e. allow components to be 'switched in' without manual intervention. It may be better to bring replacement parts to the device (or the device to the parts) at the same time as the manpower. Note that redundancy need not be confined to the device level; whole projects could possibly afford to have redundant devices, which is equivalent to assuming lower availability for generation farms.

Further opportunities for capex and opex reductions

Changing structural material and size, and redundancy have already been mentioned as possible ways of reducing cost-of-energy (albeit possibly via decreasing opex with the penalty of increased capex, or vice versa). Some further design decisions to which a device's costs may be sensitive are as follows:

- Distance to shore. This has obvious implications for some of the project costs including length of subsea power cable, but the distances that installation/O&M vessels must travel from harbour need to be considered.

- Maintenance location: in-situ or onshore. There are arguments for and against these two options, and for certain types of device only one is appropriate. Complete retrieval of a device for any level of maintenance is one extreme, while the other is the ability to completely overhaul on-station. Working in situ may shorten the time needed to conduct maintenance and return a device to operation more quickly than if it had been towed to harbour. Also, man-access might possibly be achieved using a smaller and cheaper vessel than is necessary to tow the device. But both man-access and crane lifts will almost certainly be more hazardous than onshore. Furthermore, onshore operations are not subject to weather window constraints (see below), possibly easing the pressure on maintenance crews and allowing additional inspections and/or minor repairs to be made with subsequent long-term O&M benefits. Removal/replacement of sub-assemblies could have cost advantages and suggests a degree of modularisation of certain systems such as the PTO (as is already evident in some designs). 'Swapping-out' has potential to reduce time at sea (exposure) and/or the likelihood of maintenance activities overrunning planned durations.
- Frequency and duration of maintenance visits and balance of planned and unplanned maintenance. Since access is likely to incur significant costs and carries high risks, the number and length of visits should be minimised as far as practicable. In part this is likely to be achieved by condition monitoring and sophisticated remote control via wired or radio telemetry. The costs/risks of access place particular emphasis on the need for predictive maintenance.
- Types of vessels required for deployment, maintenance (man-access and component delivery) and retrieval, and availability and ownership of vessels. These are key considerations given the demanding and sometimes unfamiliar nature of wave energy and tidal stream energy sites. Indeed, since vessels are essential to maintain devices over the life of a project, vessel costs and availability are core project cost considerations. For some sizes of farm it has been suggested that acquisition and project owner operation of vessels may be more cost-effective than hiring.
- Weather windows/resource conditions and health and safety. Maintenance will only be possible in favourable weather conditions, and again due to the nature of wave energy and tidal stream sites, the frequency and duration of these is limited. Careful planning will be necessary to make best use of planned maintenance periods e.g. during calms. Unplanned maintenance may not be possible while weather conditions are poor. Regardless of the weather, certain health and safety equipment and procedures will be necessary when working with wave energy or tidal stream energy devices. These will necessarily contribute to both capital costs and O&M costs, and may influence the ease with which maintenance can be carried out and the time required. A basic consideration is that working on structures that are held stable or rigid is easier than devices that oscillate or otherwise move with the waves or tides.

Summary

- The capital cost of marine renewables devices consists of several parts: station-keeping, structural, and energy conversion components and sub-assemblies, and project costs.
- Capital costs can be described in terms of cost centres, and this allows comparisons by cost category.
- The split of capex between different cost centres varies considerably by project size. It also depends on the particular generation technology and project location.
- O&M costs can also be described by cost centres, and again vary by project size, location and technology. Annual average opex is a simplified description; opex will not stay the same in every year of a project.

- Capital and O&M costs are closely related and design decisions affect them both together. Greater capex can lead to either increased or decreased opex. Redundancy is a means of compromising costs and performance to reduce cost-of-energy, but may not always be possible.
- Other opportunities for cost reductions relate to: the distance from shore, choice of maintenance location (onshore or in situ), frequency/duration of maintenance visits and balance of predicted and unplanned maintenance; the type of vessels required and their availability. Weather windows and health and safety have a bearing on both capex and opex.