Exploring Wave Energy Potential in the UK Using a Whole Systems Modelling Approach

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Abstract— The key market drivers for marine energy are to reduce carbon emissions, and improve security and sustainability of supply. There are other technologies that also meet these requirements, and therefore the marine energy market is dependent on the technology being cost effective, and competitive. The potential UK wave energy market is assessed using ETI’s Energy Systems Modelling Environment (ESME) which uses a multi-vector approach including energy generation, demand, heat, transport, and infrastructure. This will be used to identify scenarios where wave energy forms part of the least-cost energy system for the UK by 2050, and will assess what LCOE reductions are required to improve the commercialisation rate.

Keywords— Wave energy, Economics, Whole systems modelling, Levelised cost of energy,

I. INTRODUCTION

There is no doubt that the wave energy resource has great potential to help the UK to meet the policy targets for renewable energy, and to reduce carbon emissions [1]. Wave energy has been an area of interest to the UK for several decades, initially as a means to improve the security of energy supply in the 1970’s after the oil crisis, and secondly from the 1990’s as a response to climate change awareness, and the need to reduce carbon emissions [2].

The practical wave resource in the UK is estimated as 70 TWh/year in offshore regions, and 5.7 TWh/year in nearshore. When economic constraints are applied, this total reduces to 32- 42 TWh/year (10 – 13 GW) [3]. If fully exploited, and compared with the UK’s annual demand of 360 TWh/year, could supply 10% of the expected 2050 electricity demand [4]. This potential has inspired many developers, with over 250 wave energy developers [5], as well as policy makers, who have set ambitious targets for marine energy. For example in 2011 DECC stated that a capacity of 27 GW of marine energy (wave and tidal stream) could be deployed in the UK by 2050 assuming a high deployment scenario [6].

According to the 2015 OES Annual Report however, there was 960 kW of installed wave power in the UK indicating that the DECC forecasts will not be met [7]. This slower than anticipated growth in the UK has meant several developers have had to cease operating as the full challenges associated with wave energy are realised [9, 10].

To fully exploit renewable energy sources however, it is essential to have a varied portfolio of complementary sources to reduce variation and reduce the impact of intermittency [10]. Several studies have highlighted the benefit of co-locating wind and wave power offshore, with locations with the greatest potential along the west coast of the UK and Ireland [12, 13]. This potential to share infrastructure and operations and maintenance, thereby reducing overall LCOE, means it is necessary to continue research into wave energy to complement the wind industry and enable the UK to meet the policy targets.

Current policy targets to drive the industry include;
- the 2008 Climate Change Act with the UK aiming to reduce greenhouse gas emissions by at least 80% (from the 1990 baseline) by 2050 [13],
- European commission renewable directive states 15% of all energy consumption met from renewables by 2020, and 27% renewable as final energy consumption by 2030 [14]
- Scotland’s green strategy outlining 2030 target for 50% of Scotland’s heat, transport and electricity consumption to be from renewable sources [15].

It is clear that improvements are required across the whole energy system including electricity generation, transport, heat, and demand management if these are to be met.

To aid the transition pathway and develop strategies that achieve a high penetration of renewable energy sources, modelling tools can provide a method to assess the technical and economic impacts of investing in such technologies [16]. Energy systems models have been developed since the second half of the 20th century for aiding long-term strategic planning [17], however including renewable energy sources presents a more complex problem due to the variability and spatial distribution [18]. Models are typically defined by scale, for example whole energy system or electricity system, and if they are to be used for scenario or forecasts. A full
comparison, and discussion of the challenges, of energy models and a can be found in [17].

In this paper an energy system optimisation model (ESOM) is applied, as these are primarily used to provide scenarios describing how the whole system could evolve [17]. These models comprise a technology rich, bottom up approach, and include all aspects of the energy system. One of the key challenges associated with ESOMs are defining an adequate resolution time and space. This has been addressed however, by the Energy System Modelling Environment (ESME) by dividing the UK into 12 onshore, and 12 offshore regions. The model was developed by Energy Technologies Institute to aid investment decisions for technologies that have the greatest potential to meet carbon reduction targets and it will be described in greater detail in Section III.

The aim of this paper is to assess what parameters such as LCOE, CAPEX, and capacity factor, are required for wave energy to be deployed as part of the least cost optimisation for the UK’s energy system by 2050, and in what scenarios. This will be achieved using the ESME model, and outputs will include a generation capacity breakdown, and large scale spatial data regarding the location for wave arrays.

This paper is organised in four sections. Section II presents background information and previous studies for assessing the levelised cost of energy for marine energy. Section III describes the ESME model and input parameters that were used in the analysis including resource data. Sections IV and V discuss the results from the analysis and identify what scenarios wave energy forms part of the least cost optimisation, and Section VI describes conclusions that can be drawn from the results.

II. LITERATURE REVIEW

A. Levelised Cost of Energy (LCOE)

LCOE is a standard metric used to compare the economic feasibility of energy generation technologies. It includes parameters; capital expenditure (CAPEX), annual operation and maintenance (OPEX), and annual electricity production (AEP), which takes the capacity factor and availability into account over the lifetime (N) of the technology as shown by equation 1 [19]. A discount rate (r) is included to calculate the present value of future costs, similar to Net Present Value (NPV) analysis.

\[
LCOE = \frac{CAPEX + \sum_{t=1}^{N} OPEX_t (1+r)^{-t}}{\sum_{t=1}^{N} AEP_t (1+r)^{-t}}
\]  

(1)

Current estimations of LCOE for marine renewables [11-13] indicate a range of 15 – 55 p/kWh for the second arrays, decreasing to 5 – 15 p/kWh with a cumulative deployment of 10 GW for grid level deployment. The results of a developer survey are summarised in Table I which is used as an initial case for this analysis [19]. As wave energy is at the early stages of development and no arrays have yet been installed, there is a large amount of uncertainty associated with these values, however the report does discount extreme values and includes developers with a device rated at a TRL greater than 3.

<table>
<thead>
<tr>
<th>Deployment Stage</th>
<th>Variable</th>
<th>Wave</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Project Capacity (MW)</td>
<td>1</td>
<td>3</td>
<td></td>
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<tr>
<td></td>
<td>CAPEX (£/kW)</td>
<td>3250</td>
<td>14706</td>
<td></td>
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<tr>
<td>First Array</td>
<td>OPEX (£/kW per year)</td>
<td>114</td>
<td>1219</td>
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<tr>
<td></td>
<td>Capacity Factor (%)</td>
<td>22%</td>
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<td></td>
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<tr>
<td></td>
<td>LCOE (£/MWh)</td>
<td>244</td>
<td>1422</td>
<td></td>
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<tr>
<td>Second Array</td>
<td>Project Capacity (MW)</td>
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<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CAPEX (£/kW)</td>
<td>2925</td>
<td>12431</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OPEX (£/kW per year)</td>
<td>81</td>
<td>406</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Capacity Factor (%)</td>
<td>30%</td>
<td>35%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LCOE (£/MWh)</td>
<td>171</td>
<td>544</td>
<td></td>
</tr>
<tr>
<td>Scale</td>
<td>First Project Capacity (MW)</td>
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<td>75</td>
<td></td>
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<tr>
<td></td>
<td>Commercial CAPEX (£/kW)</td>
<td>2194</td>
<td>7394</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OPEX (£/kW per year)</td>
<td>57</td>
<td>309</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Capacity Factor (%)</td>
<td>35%</td>
<td>40%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LCOE (£/MWh)</td>
<td>98</td>
<td>382</td>
<td></td>
</tr>
</tbody>
</table>

B. LCOE Comparisons

To be able to assess how marine energy can form part of the whole system, it needs to be compared with other electricity generation technologies. This is of particular relevance since the details of the Round 2 of Contracts for Difference (CFD) allocation show wave energy will be competing against offshore wind, and biomass. Despite a strike price of £300-310/MWh for wave, offshore wind is £100-105/MWh and therefore to be competitive, wave will likely have to decrease [22]. Table II shows the LCOE for a selection of energy generation technologies that are used by the ESME model. These figures have been calculated using information from ETI projects, industry knowledge, and published reports. References are available in the ESME data book [23].

<table>
<thead>
<tr>
<th>Technology</th>
<th>2010 LCOE (p/kWh)</th>
<th>2050 LCOE (p/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined Cycle Gas</td>
<td>3.80</td>
<td>5.40</td>
</tr>
<tr>
<td>Turbines (CCGT)</td>
<td>6.58</td>
<td>6.04</td>
</tr>
<tr>
<td>Nuclear</td>
<td>19.85</td>
<td>6.01</td>
</tr>
<tr>
<td>Solar farm</td>
<td>8.29</td>
<td>7.09</td>
</tr>
<tr>
<td>Onshore wind</td>
<td>13.58</td>
<td>6.14</td>
</tr>
<tr>
<td>Offshore wind (fixed)</td>
<td>12.15</td>
<td>5.6</td>
</tr>
</tbody>
</table>

III. METHOD

A. Model Overview

The ETI’s Energy Systems Modelling Environment (ESME) is based on the time scale 2010 – 2050 and is a multi-vector model including electricity generation, transport, storage,
demand, and transmission. As the detail of the model has been improved, the use of its outputs and insights has expanded into more strategic policy contexts, by not only its member organisations, but also third parties and academia.

The central approach taken in ESME is a policy-neutral cost optimisation that finds the least cost energy system, while meeting stipulated sustainability and security targets. The model takes account of technology operation, peaks in energy demand, and UK geography, and it includes power generation, heat, transport, demand, and their supporting infrastructures. The aim of the model is to examine the underlying cost and engineering challenges of designing energy systems, therefore taxes, subsidies and other policies which affect the price of technologies, or fuels are absent.

The model includes:

- Uncertainty analysis, different to other optimisation models such as MARKAL-TIMES [24], and therefore is able to complete many runs based on different combinations of parameters.
- Temporal variations are included in two scales; seasonal (summer and winter) and diurnal (each day is split into 6 time periods) this enables an element of demand and resource variation to be captured.
- Spatial factors are also included in the model as the layout shows in Figure 1. These include 12 onshore, 10 offshore, 3 and offshore carbon sequestration nodes which also distinguishes it from other optimisation models.

The constraints applied to the model include:

- Electricity, heat, and transport demands are met within each time slice,
- Carbon dioxide emissions meet the targets stipulated by the user annually,
- Resources are not used greater than the maximum available,
- Rate of deployment is within the limits of the technology,
- The security of the system is tested ensuring peak demands are met in all time periods.

More information about the model details are available in reference [25], and information about the data sources can be found in reference [23].

B. Model Parameters

In this analysis the variable parameters are the capital expenditure (CAPEX) for wave technologies, and the capacity factor, expressed as a percentage. The fixed parameters include the resource values and locations, transmission costs and distances, operational and maintenance expenditure (OPEX), electricity demand, discount rate, and the parameters for other generation technologies.

1) Wave Resource: The resource data has been summarised from previous ETI projects, and available reports including Carbon Trust and Black and Veatch wave resource [3, 4]. The practical resource was chosen as this would capture restrictions due to shipping, fishing, and environmental constraints, however it does not include the cost modelling assumptions. Figure 1 shows the resource values (TWh/year) and locations with the majority of wave resource being applied to the west coast of England, Wales, and Scotland. The resource values are considered to be consistent over the modelling time scale 2010 to 2050.

2) Transmission: The transmission grid is included in the whole systems analysis as this forms an integral part of the energy system. This is taken into account using a high level, and large scale layout with costs included for HVAC onshore, HVAC offshore, and HVDC offshore. These figures include installation and additional plant such as substations and power conversion. The offshore transmission distances were determined from the resource location to the coast, and an onshore cable transmission cost used from the coast to nearest onshore node. It is assumed that where the resource is greater than 70km from the coast, and HVDC cable will be used, and HVAC for less than 70km [27]. A summary of the costs is shown in Table III.

![ESME Spatial parameters and resource locations](image)
TABLE III
TRANSMISSION COSTS [27]

<table>
<thead>
<tr>
<th>Costs</th>
<th>132kV AC Offshore</th>
<th>HVDC Offshore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed: platform, connections (£/kW)</td>
<td>163.3</td>
<td>308.8</td>
</tr>
<tr>
<td>Cable (£/kW/km)</td>
<td>2.6</td>
<td>0.67</td>
</tr>
</tbody>
</table>

3) CAPEX: The CAPEX input profiles are shown in Figure 2 for wave energy generation technology. The 2015 values were fixed and were assumed to be £3250/kW as the minimum value given for a first array from the developer survey [19]. From the 2015 values, straight line profiles are assumed with varying 2050 predicted costs, with the exception of one wave run to model a steep reduction in cost in 2020. In this case the 2020 CAPEX is the first commercial scale project minimum cost from developer estimates. This scenario assumes there is a step change to the current technology as the sector is very much at the early stage of development with several areas for innovation potential [28]. The 2015 values were extrapolated back to 2010.

4) OPEX: As no commercial scale wave technologies have been deployed for a prolonged period of time, initial OPEX costs have been chosen based on developers’ estimates, using the minimum first array value for wave [19]. A decrease by 1.5% annually to 2050 was used, and 2050 OPEX estimates are a similar value to offshore wind, approximately £40/kW/year [29].

5) Capacity Factor: The capacity factor is a measurement of the average production of a plant over a period of time. It is calculated by comparing the amount of actual energy production during a given period to its theoretical output if it were possible for the plant to operate at full rate power over this same time period. This includes the wave to wire efficiency of the device and array. In this analysis the capacity factor will be varied from 15% to 40% at 5% intervals for each CAPEX profile. These were chosen based on the average capture width ratios discussed in reference [30]. Capacity factors are kept constant from 2010 to 2050 for each model run.

6) Financial assumptions: A Cost of Capital discount rate of 8% (real) is used when annualising capital costs over the lifetime of a technology and when calculating the cost of interest during construction. A discount rate of 3.5% is used for all net present value (NPV) calculations in ESME, as recommended by the HM Treasury’s Green Book [31]. Both these rates are used when calculating LCOE and these values were assumed for all technologies across the system. It is worth noting that the model assumes the technology would be at a mature level when deployment occurs at grid scale and therefore the combination of the two rates is considered appropriate when comparing many technology options.

7) Build rate and period: There is a limit applied in the model for the maximum capacity that can be installed each year. This is set as 0.01 GW for 2015 to 2020 to take into account the development time of the technology and 2 GW per year from 2020 to 2050. This is based on the same rate applied to offshore wind in the ODIs ‘Sustainable Growth’ scenario wind [32]. The construction period is also set at 2 years, and lifetime of the technology is 20 years.

C. Modelling Scenarios

1) Least Cost Optimisation: The first stage of the analysis is a least cost optimisation which was completed using ESME with stipulated carbon reduction targets based on current policies. This method chooses the optimum system that is able to meet these targets with the lowest overall cost.

2) Scenario Analysis – No CCS: Previous ETI studies have shown the importance of Carbon Capture Storage (CCS) to enable the UK to meet the carbon reduction targets at a low cost [33]. Due to uncertainty around this technology [34] however, a scenario where no CCS is installed was modelled to investigate how the energy mix may change.

3) Step Change in CAPEX: A steep reduction in CAPEX, that could occur from significant innovation activities, was modelled to investigate how this would affect the installed capacity of wave energy in the least cost optimisation.

IV. RESULTS

A. Least Cost Optimisation and No CCS

Figure 3 shows a breakdown of the electricity generation capacity breakdown where all stipulated carbon reductions and renewable energy targets are met, for the overall least cost. In this scenario, wave has a 2050 LCOE of 4.37p/kWh (CAPEX of £1000/kW and capacity factor of 40%), and the model shows 4.9 GW of installed capacity in 2050. The majority of the capacity is installed on the Lundy node, at the south west, with a small amount at Wales, and Pentland offshore nodes. No tidal stream is installed in this case as the 2050 LCOE is 5.6p/kWh and therefore a higher value than wave in this run, so it is not favoured by the model.
When there is no CCS included in the system, Figure 4, a greater capacity of renewables are required to meet the carbon reduction targets. Due to the variability, a greater overall capacity is required, from 140 GW in the least cost optimisation, to 220 GW with no CCS. This increases the total cost of the 2050 system, including transport, buildings and heat, infrastructure and power generation from £300 to £350 billion. Offshore floating wind is deployed at an earlier stage and at a greater capacity, as well as fixed offshore wind compared to the base scenario. Using the same parameter for wave energy, 0.7 GW is deployed in 2025 and an additional 10 GW in 2050.

Tidal stream is also part of the 2050 system in this case with 8GW installed, with a 2050 LCOE of 5.6p/kWh as a greater capacity of renewables is required to meet the carbon reduction targets, as well as electricity demand.
The economic boundaries where deployment of wave energy occurs are shown in Figure 5 for the base case (blue) and no CCS (red). The upper boundaries indicate where a deployment greater than 1 MW occurs, and the lower where no deployment occurs. This shows that in the least cost optimisation (blue), wave requires a CAPEX less than £1000/kW, and capacity factor greater than 30%, or a LCOE less than 4.5p/kWh.

When no CCS is deployed, the CAPEX can be up to £2500/kW with a capacity factor of 40%, or a capacity factor of 20% could still be economical with a CAPEX £500/kW which equates to a LCOE of less than 9p/kWh.

The grey area shows the predicted range for offshore wind in 2050 with a CAPEX of £1800/kW and capacity factor 45% as a comparison [24].

The total installed capacities for the least cost, and no CCS scenarios are shown by Figure 6 in relation to the 2050 LCOE values and how these compare with the estimations for offshore wind. In the least cost optimisation installation only occurs when then LCOE is less than offshore wind showing this is a preferred technology by the model, whereas when there is no CCS, wave is chosen at values above the offshore wind forecasted LCOE. This highlights the greater need for renewables to replace the CCS to meet the carbon reduction.

**B. Locations**

From the large spatial scale used in ESME, it is possible to broadly assess the location where wave energy is installed in the modelling scenarios. The least cost optimisation results are summarised in Figure 7.

Deployment occurs in the period 2045-2050 with the exception of 1 simulation where the 2050 LCOE is 2.8p/kWh. The location with the greatest installed capacity is Lundy in the south west, and a small percentage at the Wales, and Pentland nodes.

The locations show similar results in the no CCS case although there is a greater number of scenarios where it is deployed, and where the LCOE is less than 4.4p/kWh it is deployed before 2045. Installation occurs at the Hebrides node when the LCOE is less than 6p/kWh to compensate for the greater transmission distance required. The geographical locations and associated LCOE deployment limits are shown by Figure 7 and in all cases, the nodes in the south-west, which are closer to the higher demand centres, are favoured.

No capacity is deployed at the Shetland node in any scenario, most likely due to the long offshore transmission distance to the main grid, increasing the cost of deployment.
The step change CAPEX profile is shown by the red line in Figure 2 and represents the possibility of an innovative change in technology. The profile uses the same 2015 value as before, however reduces steeply to 2020, to £2194/kW, which was given as a minimum for a commercial array in the developer survey [19]. It then continues to 2050 with a gradual reduction and has a 2050 LCOE of 5.6-14.8p/kWh depending on the capacity factor.

The location of the installed capacity is shown in Figure 8, with zero deployed at the Shetland node in any simulation. This indicates that for significant installation in Scotland a 2050 LCOE of less than 7.4p/kWh is required, whereas for the UK, less than 11.1p/kWh would support deployment. The installed capacity shows that there is greater potential in Scotland for wave energy, however a lower LCOE is required to achieve this.

The step reduction also means that capacity is deployed between 2040 and 2045, 5 years earlier than the majority of previous scenarios. In the case where the 2050 LCOE is 5.6p/kWh there is approximately 0.8 GW installed at the Wales node in 2020-2025. This occurs just after the step reduction in CAPEX at an LCOE of approximately 9.8p/kWh.

### Table IV

<table>
<thead>
<tr>
<th>Capacity Factor (%)</th>
<th>2050 LCOE (p/kWh)</th>
<th>2050 Capacity England and Wales (GW)</th>
<th>2050 Capacity Scotland (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>11.1</td>
<td>5.2</td>
<td>0</td>
</tr>
<tr>
<td>25</td>
<td>8.9</td>
<td>9.4</td>
<td>0.4</td>
</tr>
<tr>
<td>30</td>
<td>7.4</td>
<td>7.9</td>
<td>2.1</td>
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<tr>
<td>35</td>
<td>6.4</td>
<td>6.7</td>
<td>5.8</td>
</tr>
<tr>
<td>40</td>
<td>5.6</td>
<td>6.5</td>
<td>11.9</td>
</tr>
</tbody>
</table>
In the least cost optimisation wave requires a LCOE less than 4.5p/kWh to be deployed at grid scale by 2050 which is lower than published targets and developers’ forecasts for wave technologies. When CCS is not included, the economic range for wave energy increases to 9p/kWh in 2050, and if there is a step reduction in CAPEX, a 2050 LCOE of 11.1p/kWh sees a deployment of 5.2GW. These values fall within the published targets, however reinforces the need for an innovative technology, compared to a gradual reduction from learning by doing of current technology.

The model considers the cost of the technology at the time slice being analysed, and does not take into account the previous deployment that would be required to achieve these reductions. As considerable reduction depends on learning by doing, the initial stages of deployment would require support for this target to be reached. As it does not become an economical option until 2045 in most cases, this is unlikely to be feasible. For deployment to occur earlier than 2040, there is a need for a step change reduction in CAPEX, with the exception of the scenario where the 2050 LCOE is 2.8p/kWh. The step change case sees deployment at the Wales node in 2020-2025 where the LCOE is approximately 9.8p/kWh and was given as a developers’ estimate. This shows that if significant reduction can occur in the next 10 years, there is an opportunity for wave to be deployed at grid scale. This deployment would then allow the industry to further reduce costs from learning by doing and economies of scale enabling wave energy to be competitive to other forms of renewable energy.

Although wave is identified as an economical option in some cases, the reality is that to compete with the more established renewable technologies such as offshore wind, and solar, there needs to be a competitive advantage. The more established technologies in the model have significant capacity deployed and therefore are experiencing real cost reductions based on learning, innovation, and economies of scale whereas the values used for wave are very much based on optimistic estimates.

One key advantage with wave is the possibility to co-locate with offshore wind. Swell sea states often occur at different times to peak wind speeds and therefore the overall variability of the two resources can be reduced. Wave spectra are also more predictable than wind, and therefore these factors have the capability to improve the security and stability of the grid.

Scotland has set even greater targets than the UK as a whole stating a target of 50% renewable energy by 2030. It would be very difficult to achieve this with wind alone, and based on resources available wave could form part of this. Although the LCOE limits were lower for deployment in Scotland in all the scenarios, cost reduction based on co-location is not included in the model. By sharing infrastructure and operations and maintenance costs, this could potentially increase the economical limits for wave in Scotland.

All scenarios show a large mix of renewables, with solar, offshore wind fixed and floating, nuclear (large and SMRs) all included, as well as wave, which shows importance of investing across many technologies to be able to have a low carbon, sustainable future energy system in the UK.

VI. CONCLUSIONS

This paper has demonstrated how ETI’s modelling tool ESME can be used to assess the potential effect of wave energy on the UK’s energy system through different scenarios. Wave technologies can remain competitive at higher LCOE values under certain conditions such as in a no CCS scenario. CCS provides a low cost approach to decarbonising both the power and industry sectors. In its absence more expensive options are required in order to meet carbon targets, such as deeper decarbonisation of the heat and transport sectors. Renewables offer a zero carbon solution to generating power, albeit at higher costs, but their low capacity factors combined with a lack of unabated flexible supply (in the form of CCGT with CCS) mean that higher levels of capacity are needed to satisfy demand.

This all increases the marginal abatement cost, the cost of removing an additional unit of carbon from the system. As the cost to decarbonise the system increases, technologies that ordinarily would not form part of a least-cost system become more cost effective (since the lower cost solutions have already been deployed). It is for this reason that wave power remains competitive at LCOEs above 4.5p/kWh when CCS is unavailable.

The results indicate that if marine energy can meet the minimum estimates given by developers and have the opportunity to deploy devices, and further reduce the LCOE by learning by doing, there is the potential for considerable deployment for wave technology. If there is a step change in cost reduction in 2020, deployment occurs earlier, and at a higher LCOE, of up to 11.1p/kWh in 2050.

The modelling has shown that locations closer to the demand centres, the south west of England and Wales in this case, are favoured, for deployment and therefore could be economically exploited at higher LCOE values.

As a final note, ESME is designed to illustrate different scenarios up to 2050 to meet policy targets. It is unlikely that the energy system will stop developing at this point, and therefore it is necessary to consider as many renewable options as possible to ensure a secure and sustainable energy system in future. The results from this analysis indicate that wave developers need to focus on innovative solutions, keeping in mind the challenge of targeting a certain LCOE range.

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