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Marine Renewables

Marine renewables are technologies that can generate electricity from the motion of tides and waves. The technologies have been slow to develop, despite early optimistic projections for their growth. This POSTnote examines the causes of this delay and how the sector might develop.

Overview

- Marine renewables include wave energy, tidal stream and tidal range devices.
- The UK has led the world in developing marine renewables since the 1970s, though most technologies have not reached commercialisation. Tidal energy technology is more developed than wave energy.
- Marine renewables could contribute to climate goals, provide local economic benefits and have export potential.
- A lack of revenue or subsidy support, as well as unique engineering challenges, have made the sector less competitive compared with other renewable technologies.

Background

Due to its extensive coastline, the UK has the largest marine renewable resource in Europe.[1] The UK has historically been a centre for marine renewables R&D, launching its first Wave Energy Programme (WEP) in 1975.[2] Recent surveys suggest that 80% of the public support marine renewable deployment.[3] Sector stakeholders suggest that, if developed, marine renewables could have significant export and supply chain potential. As a group, marine renewables have the technical potential to supply a significant proportion of current UK electricity demand.[4] They produce electricity without directly emitting greenhouse gases (GHGs), so could contribute to the UK's net zero GHG targets. However, marine renewables remain at an early stage of development, having not yet been deployed at scale or proven commercially, despite decades of research and their technical potential. Projections for global marine energy generation, such as the International Energy Agency's projection of 15 terawatt-hours (TWh) per year by 2030, have proved to be over-optimistic.[5] Other technologies, such as wind, have scaled up to supply a large fraction of UK electricity demand at competitive prices.

This POSTnote updates POSTnote 324. It describes the current state of the marine renewables sector. It examines the technologies underpinning it, potential benefits if developed at scale, challenges faced by the sector, and potential solutions to these. The POSTnote does not consider technologies that generate power from ocean salinity,[6] and thermal gradients (differences in ocean temperatures and saltiness),[7] which have been trialled but are in earlier stages of development.

Marine renewable technologies

Tidal energy

Energy from tidal movement can be captured in two ways:

- **Tidal stream devices**, often turbines, generate electricity from the flow of currents in the ocean due to the motion of the tides. As the tide flows in and out of narrow ocean channels, fast and energetic currents can result.[8]
- **Tidal range devices** use the difference in height between tides to extract energy. Water is held behind a barrier at high tide and then released through a turbine at low tide. Generally, tidal range devices require large natural differences between low and high tide, so that a significant amount of energy can be harnessed.[9] **Tidal barrages** dam across bays or river outlets, while a **tidal lagoon** is an artificial barrier constructed out to sea to enclose water (see CBP-7940).

A small number of tidal barrage power stations operate internationally: the La Rance Tidal Power Station[10] in France (since 1966) and the South Korean Sihwa Lake Tidal Power Station[11] (since 2012). Tidal lagoons have been proposed in the UK (Box 1). Tidal stream devices have been deployed in small-scale grid-connected pilot projects. There is currently around 10 megawatts (MW) of tidal stream capacity connected to the UK electricity network (roughly equivalent to the capacity of the largest modern offshore wind turbine), and no tidal range.[12] The amount of electricity generated by wave and tidal stream energy globally has increased from 5 gigawatt-hours (GWh) in 2009 to 45GWh in 2019.[13]

Box 1: Proposed tidal range projects in the UK
The Severn Estuary has the second highest tidal range in the world,[14] leading to numerous proposals for tidal energy projects. In 2010, the UK Government published the Severn Tidal Power Feasibility Study following several proposals to construct tidal barrages on the Severn.[15] Due to environmental and economic concerns (POSTnote 435), none of the projects were developed. However, it was suggested that the use of lagoons could avoid these risks.[16]

In 2011, the company Tidal Lagoon Power proposed a series of lagoons, beginning with a 'pathfinder' in Swansea Bay (CBP-7940). Swansea Bay would have capacity to generate 320MW of power and upfront construction costs would be £1bn–£1.3bn.[17,18] It obtained planning permission in 2015.[19] Due to cost concerns, the UK Government commissioned the Hendry Review to examine the role of tidal lagoons in May 2016. In 2017 it recommended the Swansea project go ahead, highlighting the learning opportunity to reduce the cost of future lagoons, as well as other potential benefits for economic regeneration and long-term low-carbon electricity generation. However, it suggested that lagoons' export potential was unclear, and emphasised the importance of cost reduction for subsequent projects. The UK Government chose not to financially support the Swansea Bay project.[20] Tidal Lagoon Power is currently seeking private funding and plans to begin on-site works in 2020.[21]

Wave energy
Unlike conventional power generation (which uses steam to drive a turbine), wave energy converters (WECs) require a novel, often complex, approach to converting wave motion into power. This can present unique engineering challenges. Various designs have been proposed. Pelamis-like devices have hinged sections,[22] and a hydraulic power take-off system, which converts wave motion into pressure in a fluid, driving a generator.[23] Bombora's devices use pressure differences due to the height of the waves.[24] There is no agreement on the optimal approach.[25] Different devices are better suited to different conditions, such as near-shore versus offshore.[26]

Marine renewables in the UK
The Energy Technologies Institute (ETI, a public-private partnership) estimated in 2015 that, if developed to its full technical potential, wave energy could supply 10–70TWh of UK electricity demand (currently totalling around 300TWh).[27] It also estimated that tidal stream could supply 20–100TWh.[28] A proposed fleet of lagoons (Box 1) were estimated to have the potential to generate around 30TWh annually.[29] National Grid's 2019 scenarios for future UK energy supply consider a range of economic and policy outcomes, as well as technical potential. They suggested, in the most optimistic scenario for renewables, that 4 gigawatts (GW) of total capacity of marine renewables could be deployed by 2050. This would supply up to 3% of UK demand.[30]

The UK is widely considered a world-leading R&D centre for marine renewables. Between 2000 and 2017, roughly £200m of public grants were awarded to marine energy research and development.[31] UK-based initiatives include:

- The European Marine Energy Centre (EMEC, Box 2), established in 2003 with an initial investment of £10m.[32]

Box 2. European Marine Energy Centre (EMEC)
EMEC is the world's largest marine renewables testing facility. It comprises several offshore mooring berths, connected to the electricity network, and port facilities in an area of Orkney with large waves and high tidal currents. With overall funding of around £40m, it has generated an estimated £250m of gross value to the UK economy by 2015, attracting rent from overseas developers to use its facilities.[33] The first grid-connected wave and tidal stream devices were tested in 2004[34] and 2008[35] at EMEC. By 2019, over 30 wave and tidal devices from 20 developers had been tested.[32] Currently two tidal developers are testing devices, and two wave prototypes are to be tested in 2020.

Connected energy systems on Orkney
EMEC is part of a series of trials of low-carbon, connected energy systems on Orkney. Renewables generate more than Orkney's total electricity demand.[36] Electricity storage (such as the batteries of the 200 electric vehicles on the island) can help balance renewable supply with demand. These are the focus of the £28.5m ReFLEX Orkney project.[37] The recent Surf-'n'-Turf project at EMEC generates hydrogen from tidal stream turbines.[38] The hydrogen is currently used to power ferries, and could be burned to provide low-carbon heat (POSTnote 565).

- The SuperGen UK Centre for Marine Energy Research, set up in 2003 with initial funding of £2.6m.[39] It encourages academic collaboration between 16 UK universities.[39]
- The Supergen Offshore Renewable Energy (ORE) Hub,[33] a £9m programme established in 2018 following multiple rounds of EPSRC Supergen funding. The ORE Hub conducts research across offshore wind, wave and tidal energy and published a Wave Energy Roadmap in June 2020.[40]
- The world's largest tidal stream project, MeyGen, in the Pentland Firth. It provided 13.8GWh of electricity to the grid in 2019, accounting for around a third of global marine renewable generation.[41] It currently has 6MW of capacity.[42]
- The Tidal Stream Industry Energiser (TIGER) project, which will invest €46m (with €28m from the European Regional Development Fund) into deploying 5 tidal stream turbines at different locations in the English Channel from 2020–2023.[43] It is led by the Offshore Renewable Energy Catapult.[44]
- Multiple UK Government-commissioned reviews into the potential for tidal range, such as a tidal lagoon 'fleet' in 2017 (Box 1) and the Severn Barrage in 2010.[15]

Devolved government initiatives
- Wave Energy Scotland was established by the Scottish Government in 2014 to support wave power. It aids the development of novel WECs and supporting technologies. It has allocated £40m to around 88 projects. Two winning devices are set to be tested at EMEC in summer 2020 following an innovation competition.[32]
- The Scottish Government's Saltire Tidal Energy Challenge Fund offers up to £10m to tidal stream projects.[45] In 2019, it awarded £3.4m to Orbital Marine Power for a 2MW turbine.[46]
- Marine Energy Wales has established demonstration zones for wave in Pembrokeshire and tidal in West Anglesey with support from the Welsh Government, Pembroke Dock and €100m of EU structural funding.[47]
- The Strangford Lough tidal turbine in Northern Ireland was the first commercial-scale tidal stream project. It was installed in 2008 and decommissioned in 2016.[48]

Potential benefits of marine renewables

Reducing emissions

Marine renewables could contribute to the 2050 net zero greenhouse gas target by reducing emissions from the power sector. Power sector CO_2 emissions decreased by 68% between 1990 and 2018, as coal power was replaced with natural gas and renewables, predominantly wind.[49] However, the Committee on Climate Change (CCC) advises that a greater proportion of energy for industry, heating and transport will need to be electric in future. Electricity demand may hence increase by two to four times between now and 2050, and total electricity-related emissions will need to be almost zero.[50] Although marine renewables are not included in the CCC's net zero modelling, some stakeholders, such as the Energy Systems Catapult, suggest that marine renewables could contribute.[51]

Industrial and economic opportunities

Developing a marine renewables industry could provide economic benefits, particularly in deprived port and coastal areas. Welsh Government-commissioned research estimated that marine renewables could provide £840m in gross value added to the UK economy, along with thousands of jobs, if 1GW were developed.[52] Sector advocates argue that much of the manufacturing supply chain and intellectual property (IP) for marine is within the UK, while other renewables rely on imports.[53] Wave energy may have greater export potential than tidal energy because there are more suitable sites and a greater overall resource for wave energy globally.[54]

Energy system benefits

Marine renewables can be a useful source of power for isolated areas such as islands, which often rely on expensive diesel generation. Small-scale energy generation, such as that used on Orkney (Box 2), can help develop a more flexible low-carbon electricity system (POSTnote 587). There is also interest in using marine renewables in the Channel.[55]

Although tidal power cannot be dispatched at will, it can be predicted accurately years in advance. This may be beneficial for operating grids with larger amounts of intermittent renewables (POSTnote 464).[56] This could help grid operators to plan more effectively, and eases the integration of tidal stream with energy storage. Some have suggested that tidal power stations at dispersed locations around the coast could help make total tidal power output vary less throughout the day.[57]

Engineering and environmental challenges

Wave Energy

Wave energy converters are intended for use in normal wave conditions but must also survive storms. There can be a trade-off between a device's resilience and its power conversion efficiency.[58] WECs can be built with steel shielding to survive these storms, but this increases device cost; research into different survival strategies for WECs is ongoing. Operating in calmer waters reduces storm risk but also the amount of energy available. Novel ideas for wave energy converters include flexible polymers that generate electricity when squeezed,[59] such as in the PolyWEC research project.[60] This could reduce material costs by reducing the need for steel and concrete.

Tidal stream

Some tidal stream devices, such as MeyGen, are mounted on the ocean floor. This reduces storm damage but raising the turbine for maintenance can lead to high operating costs and challenges during installation. Suitable maintenance vessels can be expensive to hire.[61] Some companies are developing 'floating tidal' turbines that are suspended beneath a moored platform.[62] This reduces maintenance costs, allowing more frequent interventions, but increases exposure to the weather.[63] Turbines can shut off to reduce mechanical stresses in storms.

It is unclear how large-scale marine renewable installations might influence marine life, although early evidence from EMEC suggests a low impact.[64] There were initial concerns that seals were at risk of colliding with tidal stream turbines at Strangford Lough, though evidence suggests that this has been avoided.[65]

Tidal range

Concerns around the environmental impact of tidal range devices include the loss of intertidal habitat for birds, fish and invertebrates, changes in water quality and collisions with turbines harming marine life, which led to opposition to proposals like the Severn Barrage (POSTnote 435). Proponents of tidal lagoons argue that they have a smaller environmental impact and do not interfere with river systems.[66]

Economic and technical challenges

As a less developed technology, the cost of installing and operating marine renewables is high, and projects remain small-scale. In the past decade, several marine renewables companies have failed or changed the focus of their operations. Wave Hub, a Cornish marine renewable testing facility commissioned in 2010, will now test floating offshore wind.[67]

There is scope for reducing the costs of marine renewables, particularly if subsidies support the sector's development. However, these costs will not fall to the level of other renewables during the next decade (Box 3).

Technological readiness

A 2017 report exploring the failure to commercialise wave energy (which now lags behind tidal stream) found contributing factors included premature emphasis on commercialisation, lack of knowledge sharing, inconsistent policy landscape, and failure to appreciate the engineering challenges of wave energy.[31] Since several leading companies collapsed in 2014–2015, investment has refocused on earlier stages of development.

Wave Energy Scotland licenses any IP developed with its help to facilitate knowledge sharing, as well as developing technologies like cabling and remote servicing.

There has been more consolidation and convergence in the tidal stream sector, both in turbine design and acquisitions of smaller companies. However, funding to develop prototypes has largely stopped, and the technology is not ready to compete against other energy generation technologies. Scaling the technology to arrays of turbines and commercialisation would require additional investment.

Box 3: Cost estimates of marine renewables
Different ways of generating electricity are often compared using the Levelized Cost of Electricity (LCOE), which combines the construction, operation, maintenance and fuel costs to determine an overall average cost per megawatt-hour (MWh) of electricity. Determining LCOE is difficult for new technologies where few projects exist. The LCOE for marine renewables has been estimated at around £200/MWh for tidal stream and over £300/MWh for wave.[25,26] Comparatively, nuclear energy had an LCOE of around £90/MWh in 2016.[69] Predictions are that the LCOE of marine renewables could reduce with increased deployment to £80–90/MWh for tidal stream and over £120/MWh for wave.

Access to subsidy
UK Government subsidy schemes for low-carbon electricity (Box 4) are intended to increase deployment and promote wider investment in technologies in early development, reducing costs of later projects. Access to a subsidy reduces the costs of financing by lowering interest rates on loans.

To date, no marine renewable project has been funded by a Contract for Difference (CfD, Box 4), currently the main subsidy mechanism. To win a CfD, they must compete in auction with offshore wind projects, a more established technology that has reduced substantially in price in recent years (POSTnote 602). The strike price awarded for a CfD is another metric for the cost of producing electricity with a technology. Recent strike prices for offshore wind are in the range of £40–85/MWh,[68] while tidal project MeyGen reportedly bid for a CfD at £150/MWh in 2019.[71] In March 2020, BEIS proposed a set of changes to the CfD scheme, including the possibility of separating offshore wind and marine renewables' funding.[72] Industry stakeholders have proposed alternative subsidy structures (Box 4).

In the absence of subsidy support, some projects are seeking investment from alternative sources such as crowdfunding.[73] Some projects have benefited from EU structural and research funding, such as Marine Energy Wales in Pembrokeshire.[74]

Reducing marine renewable costs
Increasing deployment
As energy industries grow, costs tend to reduce as companies become more efficient at manufacturing, operation and maintenance.[75] Investors also view projects as less risky, reducing the cost of finance. If deployment of marine renewables increased, these factors would reduce costs to some extent, as has occurred with wind power (POSTnote 602). However, marine renewables face some specific challenges. Wind turbines were made cheaper in part through convergence on a single design, which could then be scaled up in size. However, there are limits to the size of efficient wave devices and it is unclear if one design will be appropriate in all places.

Tidal stream devices are closer to being standardised and scaled up, but the global potential to deploy tidal capacity is smaller than wave, reducing the opportunity for economies of scale. Cost reduction in tidal range is less dependent on technological maturation, but instead on financing options and construction costs for large infrastructure projects.

Box 4: Subsidy and revenue sources
New and existing marine renewables technologies have two potential sources of subsidy available to them.

- **Renewables Obligations (ROs)** were established in 2002 to supplement the income that renewable electricity generators receive from selling electricity to the grid. It was closed to new projects from 2017. Under the RO, a marine renewables project would receive more support than other technologies, particularly in Scotland.[4]
- **Contracts for Difference (CfDs)** are the main subsidy for large-scale renewable projects. They are given to developers of eligible technologies who win a competitive auction. CfDs provide a guaranteed price for the electricity that generators sell into the wholesale market, known as a 'strike price'. When the wholesale price is below the strike price, generators are paid the difference. When it is higher, the generator pays the difference back.
- Developers can sell power directly to large consumers under a **Power Purchase Agreement** (**PPA**), which can also provide a guaranteed price for a fixed period.

Possible alternative schemes
There is consensus among stakeholder groups that a 'route to market' (revenue or subsidy support) would be needed for a marine renewables sector to develop, given that they cannot currently compete with established technologies in CfD auctions. Suggestions based on existing models include:

- **Innovation CfDs (iCfDs)**. These would allow proposed utility-scale projects in marine renewables and other less-developed technologies, such as floating offshore wind, to compete in a separate auction at higher prices.[76]
- **Innovation Power Purchase Agreements (IPPAs).** Companies would purchase electricity from a small-scale energy project, but any excess paid over the wholesale price would be returned as a tax break.

Niche markets
Specific applications may allow developers to sell technologies initially while learning and scaling up over time. For example, an initial market for solar panels on satellites helped solar to reduce its costs substantially.[77] Niche markets suggested for marine renewables include aquaculture,[78] offshore oil and gas decommissioning,[79] integration with breakwaters,[80] and remote island communities. However, a 2018 Crown Estate Scotland report suggested that there was limited scope for using marine renewables in several applications it assessed, given that cheaper and more mature options are usually available.[81]

Innovation for reducing cost
Technological and process innovations could reduce costs. For example, tidal stream devices can be positioned in arrays that focus the flow. These interactions could in theory increase energy generation by 20–30%.[82 83] Floating tidal turbines can reduce operating costs.[61] Co-location of offshore wind and marine allows shared grid connections and maintenance visits, if appropriate sites are identified.[84] New materials that replace steel and concrete can reduce capital expenditure; material improvements are a research focus for wave energy devices.[85]

For tidal range, new designs, such as a series of water wheels rather than a full concrete barrier, may have advantages through modular construction and lower material requirements. This could reduce capital cost and building time.[86] Many designs were proposed for the Severn Barrage (Box 1), some of which were rejected as too speculative.[87]

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