Rhwydwaith Ymchwil Cenedlaethol
i Ynni Carbon Isel a'r Amgylchedd Sêr Cymru

Sêr Cymru National Research Network
for Low Carbon, Energy and Environment

Science to Policy:

The role of marine renewable energy in a low carbon future

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Quotient was a Research Cluster that ran between 2013 and 2018 from the Sêr Cymru National Research Network for Low Carbon, Energy & Environment (see: www.nrn-lcee.ac.uk).

The aim of Quotient was to assess the role of marine renewable energy sources, namely tides and waves, in future energy markets.

This is a summary of the policy implications of both scientific review and original research undertaken by Quotient that fall within the remit of current and evolving Welsh policy.

Key recommendations

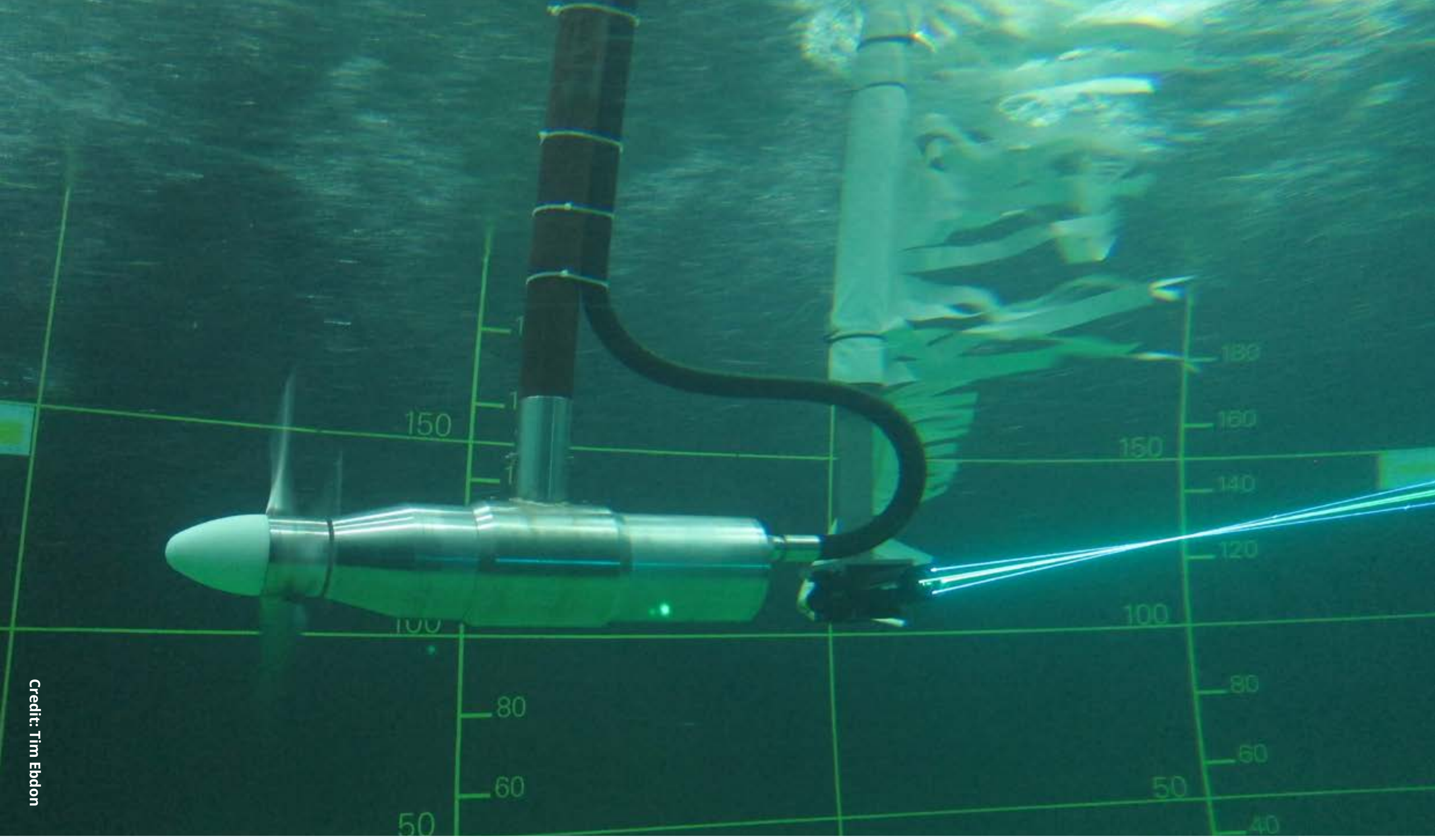
Marine renewables could provide a UK-based high-tech and globally exportable industry, with focal areas along the south and north Welsh coast where over 30% of the workforce are paid less than the voluntary Living Wage[1]. With low populations compared to the cities, the provision of skilled jobs in these peripheral regions can provide a significant social benefit. The following recommendations are made to develop UK marine renewables capacity:

- **The UK and devolved Governments need a top-down control on where and what size of projects to fund.** Schemes that are attractive to individual companies are frequently large. However, scientific evidence shows that tidal and wave power will need to be deployed at many sites with a combination of small and large schemes in order to attain a significant part of the UK's renewable mix and act as a baseload (offer continuous supply of energy without external storage requirements).

- **Start small.** The 'less attractive' small schemes may also be better value in the long run. Based on the history of wind power development, it seems likely that companies initially focusing on smaller sites and carrying those lessons to bigger sites will be the most successful.

- **A pricing structure that accounts for ancillary services is needed.** Competition between wind plus solar (which are at a more mature stage of implementation) and marine renewables needs to be reduced in order to enable marine renewable development. The UK Government's Contracts for Difference scheme for supporting low carbon electricity generation is based on simplistic cost- and price-based financial evaluations. Marine renewable electricity has unique qualities such as electricity quality/controllability alongside provision of flood defence and other ecosystem services.

- **Schemes could be tied in with tourism opportunities to support the local economy.** This has been done successfully e.g. in France (Rance Tidal Power Station) and Canada (Fundy Ocean Research Center for Energy), and a similar approach could be taken in Wales. The Holyhead Deep tidal stream project, for example, could be co-developed with recent financial injections to develop Holyhead.


Credit: Tim Ebdon

Background

The UK Government has pledged to obtain 15% of its energy from renewable sources by 2020, phase out carbon-based power sources by 2025, and by 2050 reduce its carbon dioxide emissions by 80% respective to 1990. While these targets are unlikely to be achieved based on predictions using existing trends, the power sector has performed laudably, achieving 75% of all UK emissions reductions since 2012[2]. Renewable energy sources currently account for ca. 25% of UK energy provision[3]. Wind and solar power account for most of this percentage and are projected to increase in the future.

Given the success of wind and solar, one may ask why there might be an urgency or importance in developing marine renewables. There are a few key reasons. Firstly, constantly increasing the proportion of wind and solar comes at a cost. Because they are both highly variable in time and challenging to predict across space and time (due to weather), more constant and/or accurately predictable combinations of fossil and nuclear energy are required to fill in gaps in provision. Secondly, strong peaks and troughs in energy provision due to the intermittency[1] of wind and solar also challenge the national grid's infrastructure in balancing under- and oversupply to demand. In addition, wind and solar do not contribute to system inertia, and so could cause grid stability issues[2].

Apart from storage technology, which can reduce fluctuation in energy provision, marine energy is one of the few alternatives that can provide energy during solar and wind lows, whilst also being renewable, low carbon, predictable, and popular among the public[4]. This is not to say that there is no variability in marine energy: UK tides undergo two highs and lows daily, with magnitudes that change cyclically through time, and wave power will vary with weather. Marine renewables have the potential to provide > £5.4 billion as Gross Value Added to UK GDP by 2040[5], with key areas in Wales such as along the Bristol Channel which has one of the largest tidal ranges in the world.

Over the past four years, Quotient has explored the fundamental research gaps in the marine renewable energy sector and made a considerable contribution to research and development in the industry.

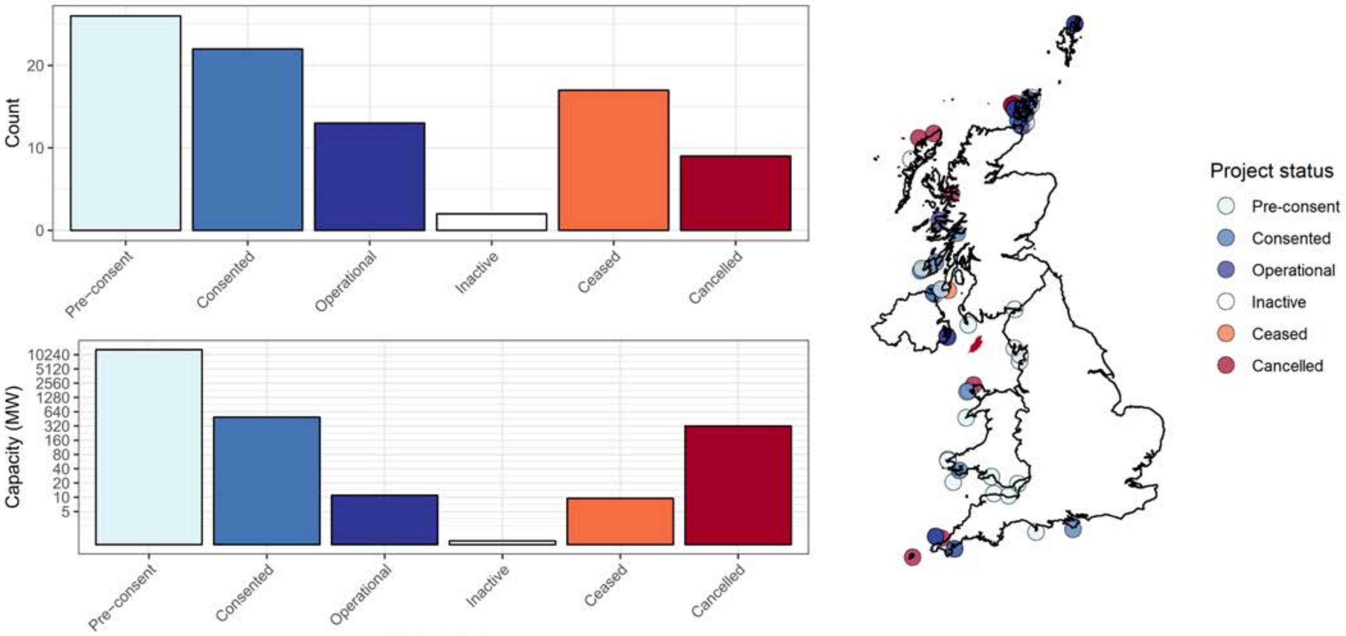


Figure 1
Status of wave and tidal projects in the UK and Isle of Man based on data from renewableuk.com. (Pre-consent = development and planning; Consented = Consent attained and construction stages; Operational = Working; Inactive = Exact status unknown due to lack of news; Ceased = Demonstration run completed; Cancelled = Planning permission rejected or financial failure).
Figure: Emma Wiik (NRN-LCEE)

Current policy

Marine renewables are presently in an uncertain position (Box 1). On the one hand, there are national targets for renewable energy provision including marine renewables, and consultations that strongly advocate supporting new marine renewable schemes for reasons such as the technical benefits of the energy itself but also its value to society (jobs, tourism, energy security). On the other hand, the UK Government's main mechanism for supporting low carbon electricity generation, the Contracts for Difference (CfD) scheme, in place since 2017, makes it much more likely for new wind and solar plans to be supported due to them being cheaper to start up than marine renewables. The future of EU funding, which many marine renewable initiatives such as the Holyhead Deep tidal development off the west coast of Anglesey (North Wales) have been reliant on, has become uncertain. There are also still research gaps leading to concerns about the effects of marine renewable energy developments on the environment, including marine mammals, sediment transport, and underwater noise.

Recent shifts in planned developments include schemes such as the Swansea Bay tidal lagoon which was cast into doubt due to high costs and lack of consistent investment. Plans to develop marine renewables around the Isle of Man, after being licensed in 2015, were cancelled in 2018, leading to the dissolution of Manx Tidal Energy.

The marine renewable sector has struggled to gain political backing and consequently has developed slowly (Fig. 1). The challenge going forward is to improve political confidence through rigorous research and development.

A recent review at EU level[11] (including an evaluation of Britain) stressed that 'investment has been identified as the biggest obstacle for ocean energy developers...when ocean technology developers finish the stage of full-scale prototyping, they usually encounter the hurdle of finding investors interested in taking the financial risk of the next step - the deployment of an array of devices - all of which leads to missing government deployment targets'.

- [1] Sources of electricity that exhibit uncontrolled increases or decreases in output are often referred to as intermittent.
- [2] Inertia is higher, the longer a system can keep producing energy after a stop in the source.

Box 1. Marine energy in policy literature

National Grid Future Energy Scenarios 2018
A National Grid report outlining energy strategies under four different future scenarios to 2050[6].

Welsh National Marine Plan
New policy document that sets to optimise sustainable exploitation of all marine sectors including renewable energy[7]. This includes mapping for multiple uses to facilitate development and planning and specifically supporting the development and demonstration of tidal stream and wave energy technologies over the next 5-10 years.

The Hendry review, 2017
Report to the UK Government making a case for tidal lagoons[8]. Despite this report having increased political momentum, it has not as yet spun lagoons into implementation.

Marine energy economic impact in Wales, 2013
Report to Welsh Government outlining Gross Value Added (what is left once bought-in goods and services have been paid for) to Welsh economy from three deployment scenarios (60 MW, 300 MW, 1 GW), ranging from £70m to £840m[9].

Contracts for Difference financing 2016
As part of the Electricity Market Reform, financing for low carbon energy technologies is set to a fixed proportion of development and initial operational costs[10]. This provides tidal and wave energy with more financial support than e.g. wind and solar, which is good as the technology is still more expensive, but ironically makes it less likely to win a contract.

Box 2. Marine energy types

Tidal stream energy
Harnesses the kinetic energy within tidal currents using a number of methods: horizontal and vertical axis (like under-water wind turbines), and tidal “kites” (that fly through the water, and use the apparent current speed to force a smaller horizontal-axis turbine). However, in all cases of design, strong currents (most likely at narrow channels) provide most energy potential because power is proportional to the cube of current speed.

Tidal range energy
Harnessed by physically damming either entire (barrage) or partial (lagoon) tide flows in a given location, creating an artificial low-high tide height difference. Involves more environmental alterations from infrastructure than tidal stream energy.

Wave energy
Relies on kinetic and potential energy from waves independent of tides. More unpredictable than the tidal resource, but also more ubiquitous.

Benefits of a marine strategy within renewable energy futures

The biggest challenge with solar and wind energies is matching supply with demand. Solar energy tracks the summer to winter, day to night cycles, and winds in the UK are often strongest in winter. The proportion of renewable energy in the UK grid tracks these availabilities, sinking as low as 0.1% in summer nights (Fig. 2). A second issue is predictability; for example, the occurrence of cloud cover. These issues lead to gaps in renewable energy provision and the requirement of predictable backup energy that currently is nuclear- or fossil-based (e.g. spinning reserve).

To reduce the dependence on non-renewable backup energy, the UK can either i. increase its storage capacity (to release stored energy when needed), ii. match the timing of energy use and provision (smart grids), iii. expand the energy portfolio (develop energies with complementary production peaks and/or high predictability), or combine the three to minimise risk.

Solar companies have recently invested in building a UK storage facility which will add to the ca. 33 GWh of estimated available national capacity[12]. Current capacity is modest compared with the 200 MW latent capacity from recently completed but not yet operational projects. As such, the UK can expect increasing storage as well as increasing use of smart grids, where car drivers or households, for example, can charge their domestic energy storage when energy is freely available and release it later, including back into the grid (consumers thereby being 'prosumers').

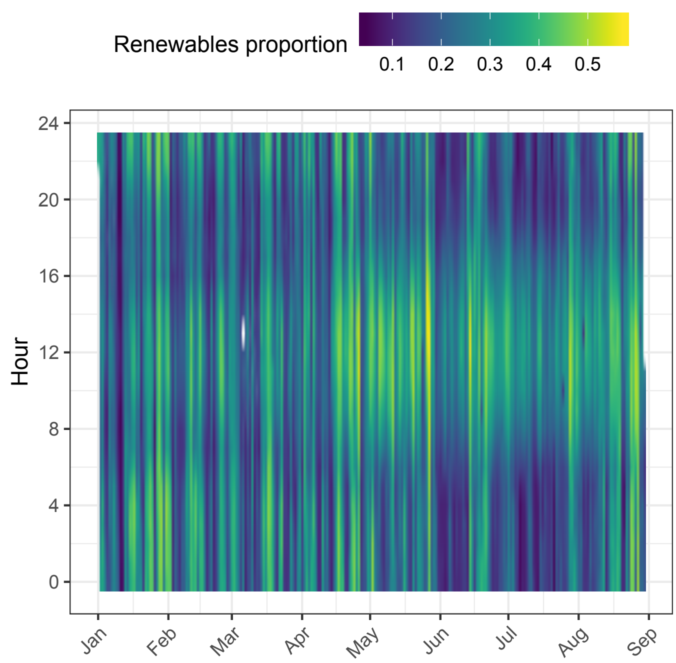


Figure 2
Day-night (vertical axis) and seasonal (horizontal axis) changes in the proportion of British renewable energy in the UK electricity grid in 2018 based on data from gridwatch. A government-level strategy is required to optimise the siting of marine renewables to best patch the existing gaps, as commercial interests as well as opportunities may not be thus aligned. Figure: Emma Wiik (NRN-LCEE)

Reasons to favour the parallel development of marine renewable resources alongside wind and solar include:

- **Marine energy is predictable:** e.g. incorporating tidal energy into the grid would provide a reliable source of energy that could provide ca 6-8% of the UK's energy demand, on a different pattern of generation from wind and solar. If the UK continues to increase the proportion of wind and solar as predicted, the National Grid will need to take measures to avoid network overload, such as curtailing renewable energy production on the one hand and control output from coal, gas and nuclear plants on the other.

- **Developing marine renewables reduces our reliance on storage:** If we reduce our dependence on non-renewable nuclear and fossil fuels by expanding on wind and solar renewable energy sources alone, we will create an ever-increasing demand on storage infrastructure.

- **Marine renewable energies can adapt to climate change:**
  - climate change may increase the energy available from tides and waves.
  - the installation of floating devices mitigates the challenges of sea level rise on resource management.
  - tidal energy generation can function as flood defence by reducing the peakiness of swell conditions.

- **Wales has high readiness for electricity connection:** There is already good grid connectivity and spare grid capacity at high-energy sites (particularly for tidal electricity generation), reducing the cost of setting up infrastructure.

Tidal and wave energy readiness and strategies

Marine renewable energy is now at a technological and implementation stage where the wind industry was around 30 years ago, and marine renewable energy is already extracted at commercial scale in a few UK locations. For example, Scotland's Orbital Marine (formerly Scotrenewables Tidal Power) has generated 7% of Orkney's electricity needs since the installation of its newest prototype in 2017. In Wales, Minesto's tidal energy kite is operational and has recently generated electricity at commercial scale. From a technical perspective, developing more accurate predictions of resource variability, optimal siting, resilient design and environmental interactions has been of primary concern to advance the industry. Quotient research has contributed substantially to this task.

Reducing uncertainties in resource assessment

Goward Brown *et al*.[13] combined complex tidal energy extraction models with regional ocean models and successfully reduced uncertainty in estimating energy available for extraction, with implications for sediment transport pathways (see Environmental interactions section).

Guillou *et al*.[14] combined wave and tidal circulation models to estimate the impact of waves on tidal energy extraction, and improved characterisations of tidal stream resources around France[15]. Conversely, Hashemi *et al*.[16] estimated the extent to which tides modulate the wave energy resource in the Bristol Channel among other areas. In general, model studies indicate that waves reduce the tidal resource by around 10% per metre increase in wave height, but further research is required using observations, particularly when waves propagate obliquely to tidal currents[17].

Realistic flow profiles for the Irish Sea have been generated to underpin resource assessment at a regional scale[18]. Lewis *et al*.[19] confirmed that storm surges, apart from instantaneous impacts on energy extraction, have negligible impacts on estimating energy extraction in tidal lagoons compared with uncertainties related to lagoon design decisions.

With these and other recent advances in technology as well as advances in computational modelling, Neill *et al.*[20] completed an up to date review of the tidal and wave resource in Scotland. This complements previous work that examined the Welsh marine energy sector within the context of environmental impacts (Roche *et al.* [21]).

Siting

Fairley *et al.*[22] show that four wave energy sites are sufficient to minimise idle time (when no energy is produced) at the UK scale. However, this requires conscious selection of areas with different wind direction profiles. Sites are required across Scotland and southwest UK (including Wales), and therefore a holistic vision (top down control) on where to develop the resource is essential. A similar situation applies to tidal lagoons where multiple smaller installations could be developed at strategic phase differences to ensure even production of electricity[24]. Micrositing may be required at detailed planning stages due to fine spatial variability of turbulence[25].

Piano *et al.*[26] evaluated the importance of flow asymmetries in impacting device siting optimisation, and Togneri *et al.*[27] developed a model which can estimate turbulence at a site in lieu of measurements, all of which reduces costs of site assessment. Evaluation of turbulence at individual sites is important for the development of proper standards. For example, the IEC standards ask for unrealistically difficult measurements for some aspects of a site (e.g. levels of detail for mean flow estimation) but ignore other important aspects completely (e.g. turbulence). Getting appropriate standards formalised will lower risk to developers and make it easier to attract investment.

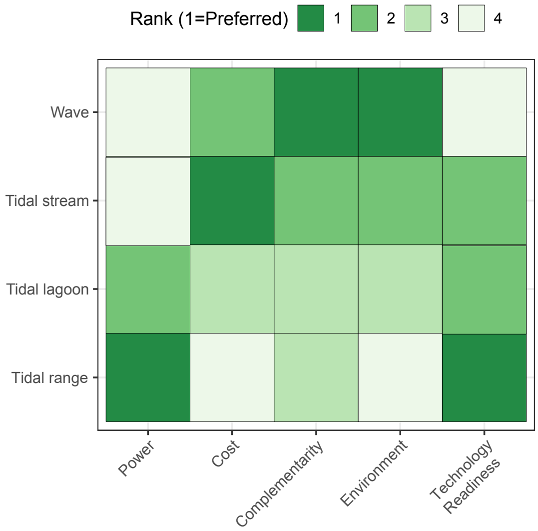


Figure 3:
Rankings of marine renewables in the UK in terms of the most important factors influencing decision-makers, based on available information. (Complementarity = how well the resource can reduce intermittency (e.g. providing energy during the night, or cloudy weather, when solar energy is not producing)).

Figure: Emma Wiik (NRN-LCEE)

Environmental interactions

The tools developed by Quotient provide high-quality understanding of flow around turbines at a number of scales. This enables investigation of some environmental parameters such as sediment transport.

Because both tidal and wave energy conversion remove energy from the water, they have the potential to alter tidal currents and sediment dynamics[3], in turn impacting on morphodynamics[28,29]. This may be a concern for large developments, but smaller developments are unlikely to have an impact to sediment transport above the range of natural variability[30]. Wave power, however, may intercept sediment delivery to beaches due to intercepting mean waves on the one hand, whilst allowing unhindered passage of storm waves, since wave energy convertors would enter safety shutdown mode during storm conditions.

Device power output modelling

Edmunds *et al.*[31] improved the accuracy of predicting power from horizontal axis turbines (those most commonly used by industry); and confidence in accounting for flow and turbulence has now been achieved, including the effects of the wake of one turbine on another. Piano *et al.*[32] estimated reductions in energy yield when moving from single-device to array-scale deployments given the interference between turbines.

Device resilience

Elasha *et al.*[33] developed a prognostic tool to estimate mechanical endurance of tidal turbine components so that maintenance costs can be minimised. In particular, array-averaged approaches account for momentum sinks in the models, but do not simulate the additional turbulence that the individual turbines would contribute to the flow field[34].

Advantages of different marine energy forms

The different types of marine renewable energies (Box 2) have different advantages across considerations such as output (how much electricity can it generate), cost (operations and maintenance), and environmental impact (Fig. 3).

Tidal range has the benefit of high electricity generation and capacity to act as energy storage. The ecological impacts of tidal range barrages, however, may potentially be higher than for other marine energy forms. Damming may incur a decrease in salinity upstream, combined with an increase in sedimentation due to decreased water flow. Downstream, scouring is increased as flow is higher, with ecological implications.

Tidal stream has the benefit of being predictable (tides are known throughout the UK), and is also technologically less challenging than wave energy. However, wave energy has the benefit of being ubiquitous in contrast to tides suitable for energy, which are in specific locations. The variability of the resource in space and time would also make wave energy a good fit in patching intermittency of wind and solar (e.g. waves generated by winds take longer to die off, meaning that wave energy can be harnessed when wind power plummets, and swell waves would be out of phase with local wind waves, adding to phase diversity). Suitable coastline for wave deployment is far more prevalent globally compared to tidal stream and so there would also be a bigger potential export market for wave devices than tidal stream technologies.

In practice, a matrix of developments, rather than focusing on one resource, is likely to be the best way forward.

Research needs that rely on commercial-scale deployment

Many estimates of the UK/Wales marine renewable energy capacity are independent of considerations such as conflicting resource use, environmental sensitivity, and technical limitations (e.g. design details that reduce maximum extractable energy). For example, a report arising from the Crown Estate[35] suggested 285 TWh/yr were available with the caveat that some extractions would be mutually exclusive[4]. The estimate includes barrages that have met with difficulties in gaining consent and excluded environmental constraints. Welsh Government developed maps for the UK that account for these considerations, with the aim to ease the planning of deployments[36].

Computational advances have given access to simulations that reflect reality, which reduces our reliance on on-site measurements. However, observational research is becoming increasingly necessary in order to reduce uncertainties, especially when estimating impacts of commercial-scale deployments. In particular (from the Quotient review by Roche *et al.*[21] an unaffiliated review by Segura *et al.*[11]; and other more subject-specific sources explicitly mentioned):

- Policy decisions on tidal lagoons have an insufficient scientific underpinning as lagoons are globally rare or absent.
- Levelised cost of energy (LCOE), operational expenditure (OPEX) and capital expenditure (CAPEX) estimates in their own right are uncertain owing to the lack of realised commercial undertakings[37].
- Cumulative impacts that arise at multi-array's or array-scale rather than device-scale deployment are unknown for multiple processes including:

  - Sediment transport: How will opposing forces such as scouring and sedimentation, interacting with impacts of installations/devices on tidal currents and waves, impact beach and saltmarsh profiles (erosion/sediment accretion/coastal defence)?
  - Tides and currents: How will currents change with the deployment of larger arrays, and how may this impact on water quality and biology?
  - Biodiversity, population sizes, behavioural responses and mortality of organisms: Models developed to predict behavioural and population-level responses to the changes in noise, infrastructure and/or water flow of larger deployments are inadequate if limited to information from single devices. For adequate environmental assessment, commercial deployments planned at acceptable pilot sites are crucial[38].

Many of these examples overlap with ‘key evidence needs’ outlined by the Welsh Government[7]; and as such Government facilitation of commercial-scale deployment could be seen as a crucial support mechanism.

- [3] Sediment transport is a function of velocity cubed, and so even small changes to velocity due to energy conversion could result in large changes to sediment transport.
- [4] UK electricity use was 320 TWh in 2017.

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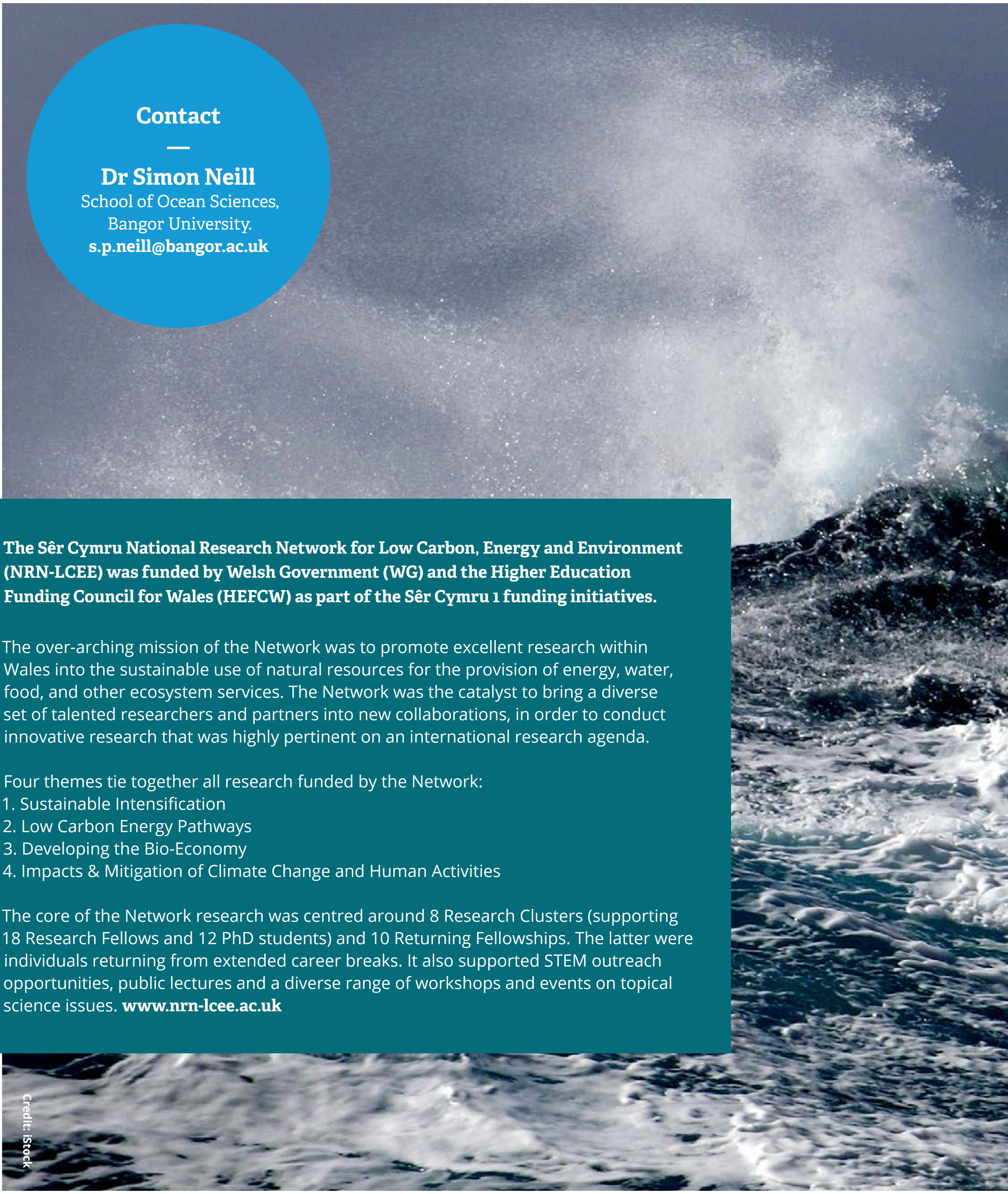

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The over-arching mission of the Network was to promote excellent research within Wales into the sustainable use of natural resources for the provision of energy, water, food, and other ecosystem services. The Network was the catalyst to bring a diverse set of talented researchers and partners into new collaborations, in order to conduct innovative research that was highly pertinent on an international research agenda.

Four themes tie together all research funded by the Network:

1. Sustainable Intensification
2. Low Carbon Energy Pathways
3. Developing the Bio-Economy
4. Impacts & Mitigation of Climate Change and Human Activities

The core of the Network research was centred around 8 Research Clusters (supporting 18 Research Fellows and 12 PhD students) and 10 Returning Fellowships. The latter were individuals returning from extended career breaks. It also supported STEM outreach opportunities, public lectures and a diverse range of workshops and events on topical science issues. **www.nrn-lcee.ac.uk**