Institution:
Bangor University, 10007857

Unit of Assessment:
UoA 12 - Engineering

Title of case study:
Ocean Renewable Energy: Improved resource assessment and characterisation drives development of second-generation tidal energy technology

Period when the underpinning research was undertaken:
2009 - 2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Professor Simon Neill	Professor in Physical Oceanography	October 2001 – present
Dr Peter Robins	Senior Lecturer in Physical Oceanography	October 2007 – present
Dr Matthew Lewis	Research Fellow	October 2012 – present

Period when the claimed impact occurred:
2013 – 31 July 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Research led by Bangor University's ocean energy research group (2009 - 2020) has pioneered understanding of the opportunities and challenges faced by the international tidal energy industry, of less energetic 'second-generation' tidal energy sites. Bangor-led research has directly informed the development of new wave-tide interaction engineering models, the design of state-of-the-art laboratory facilities (to quantify/model the forces of asymmetric tides/waves on scale-models of tidal turbine structures), the selection of second-generation tidal energy sites and tidal turbine design. Bangor's wave/current interaction research informed the International Electrotechnical Commission (IEC) Technical Specification for tidal resource assessment and characterisation (2020), significantly changing the landscape of tidal energy project assessment.

2. Underpinning research

Context

The ocean contains vast reserves of wave and tidal energy – approximately 2TW of each (average global demand for electricity is approximately 3TW). Since tides are predictable, and because the majority of tidal dissipation occurs in shelf seas, i.e. within range of grid connections, it is a highly attractive form of energy conversion. The first generation of tidal energy convertors focussed exclusively on high energy sites, requiring costly turbines working under extreme conditions, and so progress over the last decade has been modest. In contrast, modelling approaches developed at Bangor University (led by Professor Simon Neill in collaboration with the University of Rhode Island (URI)) have pioneered research into understanding the opportunities and challenges associated with less energetic tidal energy sites **[3.1]**, including the influence of waves on the tidal energy resource **[3.2]**, and the potential for concurrent development of sites to minimise variability in aggregated power output **[3.3]**.

Building on previous research into the influence of waves on tidal processes, Bangor researchers (in collaboration with URI and Cardiff University via an Engineering and Physical Sciences Research Council (EPSRC)-funded project **[3.a]**) investigated the influence of waves on tidal energy resource characterisation in situations where strong vertical shear in the water column co-exists with energetic wave conditions, and helped inform resilient design and a new topic within tidal-stream energy research. Bangor's studies of phase diversity between tidal sites have highlighted the need to develop less energetic tidal energy sites. Bangor's application of optimisation algorithms to inform site selection for tidal energy projects **[3.3]** has led the way for uptake of these methods by industry.

Main innovations of the research

Research at Bangor **[3.1]** has identified a unique set of challenges and opportunities relating to less energetic tidal energy sites. The loadings on turbines at these sites allow for lower-cost devices (e.g. due to lower susceptibility to material fatigue). There is increased sea space available for lower energy sites compared with high energy "hot spots", and more opportunities for grid connectivity. However, less energetic sites are generally in deeper, more exposed environments, and so the resource is influenced by wave processes.

a. Wave/current interaction. Whereas previous research (including Bangor's) focused on how tides modulate the wave climate (for example within the context of coastal flood risk), recent Bangor research has focussed on how waves influence the tidal energy resource. Bangor-developed dynamically-coupled models and observations of wave/current interaction demonstrate that waves influence the tidal energy resource by around 10% per metre wave height **[3.4]**. Further, Bangor-led research has demonstrated that waves primarily influence the tidal energy resource through combined bed shear stress **[3.2]**, particularly for power output at deeper, more wave-exposed, second-generation tidal energy sites.

b. Tidal asymmetry and misalignment of waves and tides. Bangor-led research analysed the challenges associated with tidal energy sites that exhibit varying degrees of (magnitude and direction) asymmetry throughout the tidal cycle **[3.5]**, and conditions where waves and currents are not aligned (in-line conditions are generally assumed in most flume experiments and previous modelling studies of wave/current interaction **[3.2, 3.4]**). Bangor demonstrated that the majority of first- and particularly second-generation tidal energy sites will have a high degree of tidal asymmetry, as will the resulting power output. In most tidal energy sites, the waves and tides exceed 20 degrees out-of-line, with implications for turbine blade design and requirement for devices to yaw.

c. Temporal variability and phase diversity. Previous research, for limited sites, had shown that highly energetic 'first generation' tidal energy sites in the UK are in phase (i.e. occurring at the same time) with one-another, hence the resulting (aggregated) electricity signal would be strongly semi-diurnal, and so characterised by four periods per day of low/zero electricity generation – a problem for the integration of tidal energy into electricity grids. Bangor research has demonstrated, through optimisation, the increased phase diversity offered by including less energetic tidal sites in the energy mix **[3.3]**. Further, Bangor-led research has shown the value of tidal energy due to temporal variability at much shorter time scales **[3.6]**.

3. References to the research

Research Outputs

3.1 **Lewis, M. J., Neill, S. P., Robins, P. E.** and Hashemi, M. R. (2015) Resource assessment for future generations of tidal-stream energy arrays. *Energy*, **83**, 403–415. DOI (Peer-reviewed journal article) Submitted to REF2021 (REF identifier UoA12_02)

3.2 Hashemi, M. R., **Neill, S. P., Robins, P. E.**, Davies, A. G. and **Lewis, M. J.** (2015) Effect of waves on the tidal energy resource at a planned tidal stream array. *Renewable Energy*, **75**, 626–639. DOI (Peer-reviewed journal article)

3.3 **Neill, S. P., Lewis, M. J.** and Hashemi, M. R. (2014) Optimal phasing of the European tidal stream resource using the greedy algorithm with penalty function. *Energy*, **73**, 997–1006. DOI (Peer-reviewed journal article)

3.4 **Lewis, M. J., Neill, S. P.** and Hashemi, M. R. (2014) Realistic wave conditions and their influence on quantifying the tidal stream energy resource. *Applied Energy*, **136**, 495–508. DOI (Peer-reviewed journal article) Submitted to REF2021 (REF identifier UoA12_38)

3.5 **Neill, S. P.**, Hashemi, M. R. and **Lewis, M. J.** (2014) The role of tidal asymmetry in characterizing the tidal energy resource of Orkney. *Renewable Energy*, **68**, 337–350. DOI (Peer-reviewed journal article)

3.6 **Lewis, M. J.**, McNaughton, J., Márquez-Dominguez, C., Todeschini, G., Togneri, M., Masters, I., Allmark, M., Stallard, T., **Neill, S. P.**, Goward Brown, A. and **Robins, P. E.** (2019) Power variability of tidal-stream energy and implications for electricity supply. *Energy*, **183**, 1061–1074. DOI (Peer-reviewed journal article) Submitted to REF2021 (REF identifier UoA12_22)

Grants

3.a **Co-PI Neill, S.P.** (2012–2015) *The Effects of Realistic Tidal Flows on the Performance and Structural Integrity of Tidal Stream Turbines*. Engineering and Physical Sciences Research Council (EPSRC) EP/J010200/1 GBP246,625 (Bangor University R28R11) (led by Cardiff University: full award GBP1,389,372)

3.b **Lewis, M.** (2018–2021) *Improving Methods of Characterising Resource, Interactions and Conditions (METRIC)*. Engineering and Physical Sciences Research Council (EPSRC) EP/R034664/1 GBP287,382 (Bangor University: R28R33)

4. Details of the impact

Challenges and developments in the tidal energy industry

The tidal energy industry traditionally relied on the development of overly ambitious (e.g. 400MW) tidal arrays in highly energetic rectilinear tidal environments. However, these high-energy environment devices suffered many failures and financial setbacks for two main reasons: i) severity of the environment, leading to structural failures and a need for heavily over-engineered and expensive turbines; ii) competition from offshore wind. Bangor's research has re-focussed the tidal energy industry, towards development of less energetic tidal sites that are complementary in terms of the timing of power output.

The wind industry took 40 years to transition from low-power (100kW), to the much greater-power devices of today (10MW or more), which now account for approximately 15% of UK electricity generation. As a direct result of Bangor's research, the tidal energy industry has: i) evolved to follow a realistic but contrasting path by developing smaller tidal devices (second-generation models) (100-200kW) that are now competitive in the UK; and ii) created a pathway for international development via reassessment of the tidal energy resource of countries previously considered below the threshold of financial viability (using the high-resolution modelling approach developed at Bangor) to significantly expand the global market.

Development of second-generation tidal device technology

In the UK, Bangor research has guided the research agenda of the UKRI Offshore Renewable Energy (ORE) Supergen research hub (including 10 universities), and the ORE Catapult **[5.1]**, identifying common issues between offshore wind and tidal energy, the most important of which is development of floating technologies that can be used (and in some instances directly shared) between both forms of offshore energy conversion. Bangor-led research into tidal asymmetry and misalignment of waves and tides (making energy more challenging to exploit, and putting tidal turbine structures under stress) has: i) led to the development of new wave-tide interaction engineering models; ii) informed the design of state-of-the-art laboratory facilities (by ORE Supergen) to directly quantify/model the forces acting on scale models of tidal turbine structures when tides and waves are out of line (FloWave ocean energy research facility, University of Edinburgh **[5.2]**); and iii) directly informed tidal turbine design.

Bangor-led research findings have been used to address challenges facing second-generation tidal device technology globally, informing Australian researchers from CSIRO working on the GBP3,000,000 AUSTeN project, via the use of Bangor-developed methodologies, to further advance coupled wave-tide models for tidal energy resource assessment **[5.3]**.

Importance of wave/current interaction on tidal energy resource assessment

Research on wave/current interaction at Bangor informed the International Electrotechnical Commission (IEC) Technical Specification for tidal resource assessment and characterisation **[5.4]**, with Bangor research directly cited in recommendations that explicitly state that the role of waves in influencing the tidal energy resource needs to be assessed for tidal energy projects. It has informed developers about a unique set of challenges faced by second-generation tidal energy sites **[5.1]**. Bangor's research (into the influence of coastal currents on wave propagation) has directly informed large-scale wave energy modelling projects conducted by the Commonwealth Scientific and Industrial Research Organisation (CSIRO-Australia) **[5.3]**, and the US Department of Energy **[5.5]**. This has significantly changed the landscape of tidal energy project assessment.

Maximising power supply to the national grid: the quality of tidal energy and UK tidal energy site diversification

Bangor research has demonstrated the value of tidal energy electricity to the UK grid system, highlighted in UK Government POST NOTE 625 **[5.6]**. This research, combined with our research into the development of lower energy tidal sites and the benefits of phase diversity, has led to European consortia **[5.7]** and the Isle of Man Government **[5.8]** recommending less energetic tidal sites as an important component of the future electricity mix.

Tidal energy site selection by industry

Bangor's phase diversity research has also directly informed the selection of second-generation tidal energy sites by private industry (e.g. Minesto, Repetitive Energy Ltd.). Minesto, as the global leader in second-generation tidal energy device technology, has developed tidal energy sites in the UK, including Holyhead Deep to the west of Anglesey, Wales. The GBP184,000,000 Australian Cooperative Research Centre, working closely with Dr Matt Lewis on his EPSRC fellowship **[3.b]**, has made extensive use of Bangor's research into tidal asymmetry and the challenges of second-generation sites in their Blue Economy drive **[5.9]**.

5. Sources to corroborate the impact

5.1 **Offshore Renewable Energy (ORE) Catapult (2015)** cites **[3.4]** in its report "Wave and Tidal Energy Yield Uncertainty". https://ore.catapult.org.uk/app/uploads/2018/01/Wave-and-Tidal-Energy-Yield-Uncertainty-Literature-Review.pdf

5.2 **Wave-current interactions at the FloWave Ocean Energy Research Facility** cites **[3.4]** on misalignment between tidal currents and waves at tidal energy sites. https://ui.adsabs.harvard.edu/abs/2015EGUGA..17.4821N/abstract

5.3. **Testimonial from Principal Research Scientist of Commonwealth Scientific and Industrial Research Organisation (CSIRO-Australia)** (reporter on impact delivery) outlining the role of Bangor-led research on wave/current interactions in coastal hazard and large-scale modelling projects.

5.4. **International Electrotechnical Commission (IEC) Technical Specification 201 (2020)** "Marine energy – Wave, tidal and other water current converters – Part 201: Tidal energy resource assessment and characterization" for the industry directly cites **[3.2]** and **[3.4]** as the evidence that the role of waves must now be assessed when siting tidal energy projects. (Copy of specification available on request)

5.5 **Testimonial from Chief Scientist for Coastal Ocean Modelling at PNNL (US Department of Energy)** (reporter on impact deliver) demonstrates that Bangor research has directly informed large-scale ocean energy resource assessment conducted by the US Department of Energy.

5.6 **UK Government POST NOTE 625, June 2020, Marine Renewables** outlines energy system benefits of tidal energy, directly citing **[3.6]**. https://post.parliament.uk/research-briefings/post-pn-0625/

5.7 **Pro-Tide Work Package 2 Final Report (2015)** (funded by Interreg, European Regional Development Funding). Bangor research **[3.1]** is cited on page 34 of the online document, outlining the importance of lower-energy tidal sites in broadening Europe's tidal energy resource. https://nerc.ukri.org/innovation/activities/energy/offshore/pro-tide/

5.8 **Isle of Man Programme for Achievement of Climate Targets (2019)** cites Bangor research on the tidal energy resource of the Irish Sea, with a focus on generation of tidal energy resource **[3.1]**. https://www.gov.im/media/1368070/appendix-17-tidal-power.pdf
5.9 **Testimonial from Research Director, Blue Economy CRC and Professor in Marine Renewable Energy, University of Tasmania** highlights the importance of Bangor University research on wave-tide interaction, tidal phasing, and tidal asymmetry.