Institution: University of Plymouth		
Unit of Assessment: UoA12		
Title of case study: Enabling the growth of the emerging Offshore and Marine Renewable Energy industry in the UK through increased technological understanding		
Period when the underpinning research was undertaken: October 2007 to 31 December 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 Deborah Greaves	Professor of Ocean Engineering	October 2007 – present
Period when the claimed impact occurred: 1 August 2013 and 31 July 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Professor Deborah Greaves, the COAST Engineering Research Group and the Coastal, Ocean And Sediment Transport (COAST) Laboratory have enabled significant advancement of the marine (MRE) & offshore renewable energy (ORE) sectors at a regional (SW and Wales), national (across the UK) and international (partners have offices in numerous countries across all continents except Antarctica) level through contributions to research and development, collaboration and leadership. The impact has been enabled by multiple interwoven elements: commercial access and supported use of the COAST Laboratory, leadership (Greaves' directorship of the academic/industry Supergen ORE Hub), other collaborative research and education/public/policy contributions. Impact reported in this case study takes the form of policy and economic impacts. Commercial impact in the REF period, exceeds the £36million in saved costs and additional external investment across identified by the 8 companies cited in this case study. There are also non-numerical impacts on improved business knowledge, perception of UK based business and increased knowledge from outreach activities.

2. Underpinning research

There is an urgent need to develop marine and offshore renewables as an alternative to hydrocarbon-based energy, to help achieve netZero by 2050 and to mitigate climate change. The ORE theme, led by Professor Deborah Greaves, within the COAST Engineering Research Group at the University of Plymouth (UoP) has made an outstanding contribution to the advancement of marine and offshore renewable energy. The team have delivered high-impact research projects, and, through the establishment of the COAST laboratory, have provided a facility that benefits UK and international industry.

Since 2008, the group's research on the development and application of numerical models to predict wave-structure interaction has led to better understanding of the performance and response of wave energy devices, and also of the influence of the numerical models utilised on the quality of results [3.1]. This work demonstrated the need for physical model tests to be carried out in combination with numerical modelling and the requirement for a facility to enable experimentation at realistic scales combined with numerical simulations to provide further insight [3.2]. All of the research know-how produced between 2008 and 2012 went into the design of the COAST Laboratory [3.3]; since 2012 ongoing research results and collaboration with the research group continue to provide experimental and facility upgrade design protocols and support for partners using the COAST Laboratory. The build was supported by European and UK Government funding.

The internationally leading facility was designed to support research and development of MRE and ORE systems, working closely with the sector to identify needs and inform enhancement of the facility. It comprises an ocean and a coastal wave basin and two flumes, each combining waves and currents. A recent addition in 2020 was the wind generation and measurement

system for studies relating to the growing Floating Offshore Wind sector. Since opening in October 2012, the laboratory has supported 69 industrial projects for 41 businesses [3.4 & 3.5], 379 student dissertations (inc 30 collaborations with industry projects), and hosted more than 496 outreach/PR/external visitor or facility demonstration events.

The COAST Laboratory and research group have become an integral component in the UK MRE and ORE community through involvement in, and leadership of, various research consortia: leadership (Greaves) of the Supergen ORE Hub, Partnership for Research In Marine Renewable Energy (PRIMaRE) and the Collaborative Computational Project for Wave Structure Interaction (CCP-WSI). These consortia and the group's involvement in them has been a key part of the development pathway for ORE through collaboration with WaveHub (a company, which during the REF impact period was focused on managing testing and test facilities for offshore energy technologies) and FabTest (a 2.8km^2 area within Falmouth Bay where device developers can test prototypes and/or components in a moderate wave climate without the need to have first gained full planning, marine, safety, etc. consents for their devices) and the Offshore Renewable Energy Catapult.

The Laboratory has won over £41 million in new research grants since 2012, including UKRI-funded research to investigate new concepts in wave energy [3.4] and tidal energy [5], extreme loads [1], and novel developments in Computational Fluid Dynamics (CFD). EU funding was used to investigate impact assessment in MRE, technology breakthroughs and to collaborate in transnational access consortia, collaborative research projects with industry [3.4 & 3.5] and enhance structural reliability through recommendations for design [3.6].

Since 2015, Greaves leadership of the CCP-WSI has drawn together academics and industry experts, computational scientists and experimentalists from both the UK and overseas. Building on CFD research [3.1], recent achievements include advancing understanding of the applicability and reliability of WSI through internationally recognised Blind Tests (50 participants); published through dedicated sessions at 3 international conferences, and 25 papers in 3 special issue journals. The collaborative nature of these activities underpinned the development and transfer of new techniques into new and existing commercial codes, methodologies and prototypes, as described in section 4.

In July 2017, Greaves was appointed to lead the £9m, 4 year Supergen ORE Hub, and to develop the strategy and consortium. The new ORE Hub provides research leadership and brings together the Offshore Wind with Marine Energy sectors connecting cutting-edge research, partners and shared strategy with policy makers to further enhance development of the new and growing ORE and MRE industries.

3. References to the research (indicative maximum of six references)

3.1 Westphalen, J., **Greaves**, D.M., Williams, C.J.K, **Hunt-Raby**, A.C., Zang, J. (2012) Focused waves and wave-structure interaction in a numerical wave tank, Ocean Engineering, Volume 45, May 2012, Pages 9–21. http://dx.doi.org/10.1016/j.oceaneng.2011.12.016

3.2 **Greaves**, D.M, Smith, G, Attrill, M., Belmont, M., Chadwick, A., Conley, D., Eccleston, A., Godley, B., Harrington, N., Hor, C.L., Hosegood, P., Johanning, L., Millar, D., Pan, S., Reeve, D., Williams, J., Wolfram, J., Xu, J., Zobaa, A., Zou, Q. (2009) Development of Marine Renewable Energy – research, design, installation, Proceedings of the Institution of Civil Engineers, Maritime Engineering, Special Issue on Offshore Renewable Energy, 2009, Vol. 162; Issue MA4, pp. 187 – 196. https://doi.org/10.1680/maen.2009.162.4.187

3.3 Collins, K. M., Stripling, S., Simmonds, D. J., & **Greaves**, D. M. (2018). Quantitative metrics for evaluation of wave fields in basins. Ocean Engineering, 169, 300-314. https://doi.org/10.1016/j.oceaneng.2018.09.010

3.4 Faraggiana, E., Whitlam, C., Chapman, J., Hillis, A.,Roesner, J.,Hann, M., **Greaves**, D., Yu, J-H., Ruehl, K., Masters, I., Foster, G. and Stockman, G. 2019 Computational

modelling and experimental tank testing of the multi float WaveSub under regular wave forcing, Renewable Energy, https://doi.org/10.1016/j.renene.2019.12.146. (with MPS Ltd.)

3.5 S.A. Brown, E.J. Ransley, N. Xie, K. Monk, G.M. De Angelis, R. Nicholls-Lee, E. Guerrini, D.M. **Greaves.** 2020 On the impact of motion-thrust coupling in floating tidal energy applications, Ocean Engineering, Volume 282, 116246, https://doi.org/10.1016/j.apenergy.2020.116246. (with MTG Ltd.)

3.6 Mai, T., Mai, C., **Raby**, A. and **Greaves**, D.M. 2019 Aeration effects on water-structure impacts: part 2. Wave impacts on a truncated vertical wall, Ocean Engineering, Vol. 186, https://doi.org/10.1016/j.oceaneng.2019.05.035

4. Details of the impact

The two most significant impacts within the REF period have been via commercial partners and inclusion in policy discussions/decisions. Commercial impact takes the form of costs saved and investment attracted as a direct result of interaction with UoP. Costs were saved because testing within the COAST Laboratory is much more tightly controlled than would be at sea. Furthermore, smaller scale models could be used, fewer personnel were needed, and because partners subjected their prototypes to far more rigorous testing than could be achieved via full scale at-sea tests, designs were improved beyond that which would have previously been possible. The examples given here, which are a small subset of all projects carried out within the COAST facility, are estimated by the companies involved to be worth approximately £36million in saved costs and additional investment received. The testimonials received during preparation of this case study also refer to increased know-how and reputational enhancements; which are impossible to quantify but are reported to have very likely led to increases in sales and income for individual businesses. Policy impact has occurred via authorship of sector strategies, leadership of collaborative research efforts and increasing awareness amongst decision makers. This has led to a more joined up approach between academia, industry and regulators which testimonials credit with enabling investment and speeding the growth of the sector.

The COAST Laboratory

At-sea tests of wave energy devices are very expensive and the ORE/MRE sectors are emerging sectors; characterised by many innovative, small, start-up companies and relatively few early stage investors. The unique adaptability of the COAST Laboratory facility means partners can subject their prototypes to all the conditions which could be encountered at sea, including for example, freak waves which are very likely to occur whilst a device is in use but are very unlikely to occur during a test phase of an early prototype. Partners are extremely positive about the support they received and the commercial benefits working with the COAST team has created [5.1-5.6]. In total, users reported saving over £7million through the avoidance of expensive sea trials alongside the ability to subject their prototypes to more extreme oceanic conditions and therefore to optimise their designs. The partnership with COAST has enabled 41 companies to move their devices through technology readiness much more rapidly and successfully than would have otherwise been possible. A programme of at-sea testing typically takes 12 months to complete and requires 1:3 and full scale models, whereas testing within the COAST facility might only take approximately two weeks and results can be achieved with a much smaller scale model, enabling material cost savings as well as savings from reduced need for support vessels, personnel, etc.

For example in 2019 AMOG [5.4] tested a 1:12 scale WEC (Wave Energy Converter) model and tow bridle design to define real world tow condition parameters, to increase safety and prove the capability of their technology demonstrator. This work enabled AMOG to attract external investment and move on to sea trials of a 1:3 scale technology demonstrator. MTG [5.6] conducted tank testing and numerical modelling of a novel floating tidal energy concept, which secured £1.4m investment and start-up capital: *"without the collaborative research we undertook together we would not have been able to contemplate building our scale model"*. Large leaps forward with 3 products were enabled for Marine Power Systems [5.1]; the increased knowledge and understanding supported the company in securing £24M in new investment, saved

£200,000 in estimated at-sea trial costs, enabled recruitment of specialist staff and increased the likelihood of market success by facilitating interaction with policy makers: *"…to place MPS and the UK at the forefront of a potentially very important sector of the future. In getting to this point the partnership with the COAST Laboratory has been vital to MPS".* For Griffon Hoverwork Ltd. [5.6] COAST Lab enabled existing specialist expertise to be utilised on a brand new concept for which: "*the company expects to develop new methods and skills, initially through R&D programmes, continuing through prototyping and eventually on to production*". For Corpower Ocean [5.6], '*The successful tank testing at the Ocean Basin has allowed CorPower to unlock multi-million euro funding releases from key project funders and investors as we were able to pass and prove key design and project milestones'*.

Collaborative Numerical Methods development

The physical COAST facility is not the only route through which Plymouth's research has been applied for positive benefit. The CCP-WSI Blind Test Series was cited by all those involved in the tests and named in the testimonials associated with this case study as being particularly influential in terms of their own in-house code refinement, reputations for technical excellence and ability to offer their own customers numerical/computation assessment methods. CCP-WSI work with ARUP [5.5] enabled them to save costs estimated (savings were not tracked so they cannot be more specific) to be of the order of hundreds of thousands and time when significant design iteration was required on wave slam pressures/loading simulation of a £2bn offshore platform project. ARUP cited *"enabling new know-how and code which has enhanced the in-house wave-slam and hydrodynamics elements of a key piece of engineering consultancy software as a result of the CCP-WSI blind test series"*. Furthermore, the company noted the importance of such collaborative projects to the reputation of UK businesses and thus their ability to win external business. The world's largest design validation organisation, DNV-GL [5.2] also collaborated within the CCP-WSI to improve their in-house wave energy impact code. The testimonial author reports his belief from conservations with customers and colleagues that this work greatly enhanced their reputation as a technology leader, increasing the likelihood of winning new business, and increased satisfaction amongst technical staff thanks to the intellectually fulfilling project. Overall the company credits the collaboration as having contributed approximately £100,000 p.a.

Supergen ORE

The ORE/MRE sector contains multiple small, start-up firms, many of which are growing rapidly within this young and dynamic sector. Greaves' role in providing research leadership, connecting the sector and advocacy is frequently highlighted by partners. For CWE [5.3], the impact of COAST is *"in the order of £5 million in cost savings and deferrals, because at sea tests of prototypes are de-risked and we are able to bring a more thoroughly tested device with far more design iterations to market. Other than the direct impact on our device, interaction with the COAST team, particularly through Prof Greaves' role in leading Supergen ORE, has also exposed our business to a much wider network of similar businesses and has enabled us to participate in developing shared research goals to move the UK sector on and enhance its place in the world market."* For CWE strengthening connections within the sector and enabling it to agree shared messages to policy makers and technical goals has been particularly helpful.

Policy impact has also been generated:

Following workshops in Aug '19, Jan '20 and a series of structured interviews with academics, policy-makers, funding bodies and industry professionals, Prof Greaves authored a comprehensive review of the UK wave energy sector reporting on progress, achievement and international position to UK Government and industry. The report demonstrated the potential for decarbonisation of UK industry through utility scale and niche markets in wave energy; recommendations were made to develop the sector. Subsequently, the Wave Energy Innovation Position Paper and Wave Energy Road Map were published by Supergen ORE Hub in May 2020 [5.7], resulting in the EPSRC launch of the £4.5 million Marine Wave Energy Call for proposals. Outputs from this work also contributed to the BEIS consultation on contracts for Difference for Low Carbon Electricity Generation (May 2020) which caused a splitting of funds into separate fixed and floating offshore wind categories. Furthermore, the outputs of Prof

Greaves' roadmap and innovation report were also carried forward into the September 2020 call for evidence on the potential of marine energy projects in Great Britain [5.8] and in turn into the Energy white paper [5.9].

Policy impact has also occurred across the EU; where Greaves' research, as part of the SOWFIA project, provided: an increased understanding of the marine environment, guided funding for the development of wave energy technologies, made recommendations to enable earlier stage local and stakeholder engagement, ensured better communication and a smoother consenting process and informed the European Maritime and Fisheries Fund strategy for commissioning future research [5.10].

Lastly, Greaves' expertise has contributed to policy/public engagement activities with the offshore/marine energy debate via:

- the POST Parliamentary Briefing on Marine Energy, June 2020, which led to the BEIS Marine energy call for evidence in September 2020 and was recommended by POST's Energy Adviser to MPs preparing to engage in: a forthcoming EAC inquiry into tidal power and a 30-minute adjournment debate in Westminster Hall on marine renewables that took place in December 2020.
- The Economist Intelligence Unit study on marine energy and the blue economy for US DoE, June 2020. The Economist's most viewed & engaged Twitter post published on November 6th 2020 reaching 27.9k Twitter users.
- October 2019 issue New Power magazine interview on Marine Energy, contribution to Lloyds Register Technology Radar – Renewable Energy 2017 'Towards the Tipping Point'
- Tortoise Media ThinkIn (expert panel) Southampton 27 Feb 2020 - Can we invent our way to net zero, or is it too late? Live streamed climate change debate.
- Times Radio Mariella Frostrop (expert panel) discussion programme, October 2020
- RAEng Ingenia Magazine article, June 2020.

Research and industrial collaboration, led by Prof Greaves and the team at the University of Plymouth's COAST Laboratory, has played a fundamental and pivotal role in the development of the marine and offshore renewable energy sectors across the UK, connecting businesses with each other and with policy makers, having commercial impact via saved costs, unlocked investment and increased know-how; and guided UK national and EU level marine policy. Without these efforts it is unlikely that the sector would be where it is today.

5. Sources to corroborate the impact (indicative maximum of 10 references)

5.1 Dr Gareth Stockman, MPS
5.2 Benjamin Childs, DNV-GL
5.3 Jack Jorgenson (Carnegie Wave Energy, CWE)
5.4 Peter Mazurenko (AMOG)
5.5 Steve Downie (ARUP)
5.6 https://www.plymouth.ac.uk/schools/school-of-engineering-computing-and-mathematics/coast-laboratory/coast-laboratory-commercial-case-studies
5.7 Roadmap and innovation position paper: https://supergen-ore.net/impact
5.8 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/937634/cfd-proposed-amendments-scheme-2020-ar4-government-response.pdf
5.9 Energy white paper – 14th December 2020, https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future
5.10 Study on impacts of EU actions supporting the development of renewable energy technologies - study commissioned by DG RTD and carried out by Trinomics http://trinomics.eu/wp-content/uploads/2019/03/Trinomics-et-al.-2019-Study-on-impacts-of-EU-actions-supporting-the-development-of-RE-technologies.pdf