Institution: Edinburgh Research Partnership in Engineering

(ERPE: Edinburgh and Heriot-Watt Universities joint submission)

Unit of Assessment: UoA12 Engineering

Title of case study:

Technology, business and international policy innovation drives investment in offshore renewable energy

Period when the underpinning research was undertaken: 2004 to 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:
Prof. D. M. Ingram	Professor of Computational Fluid Dynamics	April 2006 – present
Dr Anup Nambiar	Research Assistant	Jan 2009 - present
Prof. M. A. Mueller	Professor of Electrical Generation Systems	Jan 2004 – present
Dr. B Sellar	Chancellor's Fellow in Marine Renewable Energy	Nov 2010 – present
H. F. Jeffrey	Senior Lecturer	Feb 2006 - present

Period when the claimed impact occurred: August 2013 – December 2020

Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact

ERPE researchers at the University of Edinburgh have supported the development of technologies, strategic growth of capacity, and critical policy interventions to advance the offshore renewable energy (ORE) sector. This has been delivered through inter-disciplinary research ranging from hydrodynamic to economic, and from the laboratory to the open sea. Working with industry across the ORE sectors has resulted in multi-million investments and a significant portfolio of impacts (A-D) including:

(A) Developing key open-source design tools utilised for international ORE asset and infrastructure design and supporting company new technologies such as Nortek and Sabella.
(B) Formation of new spin-out companies, accessing new business markets leading to CO_2 reductions – including MOCEAN Energy and REOptimise Systems.
(C) Establishment of strategic international government-industry-academia partnerships, driving investment in R&D infrastructure for the ORE sector – including in Chile and China.
(D) Influencing low carbon policy and offshore strategies – including the Ecuadorian Government launching 'Galapagos Vision 2040' at COP25 in Madrid in 2019.

2. Underpinning research

The UK and many other countries have ambitious targets to develop offshore renewable energy (ORE) from wind, tidal and wave resources. To develop and grow an industry sector such as ORE, a portfolio of underpinning research is required for critically interconnected advances including new technologies to enable array-deployment, ensure electricity network integration, optimise energy and economic performance, and to establish international marine test facilities and support policies. ERPE researchers at the University of Edinburgh have led flagship UKRI, Innovate UK and EU collaborations addressing these needs since 2004, including hosting the Supergen UK Centre for Marine Energy Research (UKCMER) and the Industrial Doctoral Centre for Offshore Renewable Energy (IDCORE). Key examples of underpinning research follow.

Array deployment is essential to up-scale ORE projects from single to multiple machine investments. Investor and regulatory confidence relies on understanding and reducing the techno-economic-environmental risks of the new energy infrastructure on or below the sea. A standardised electrical architecture of the offshore delivery network and its sub-systems is

essential to underpin design for affordable reliability and to exploit economies of scale across the supply chain. Jeffrey led DTOcean [P1], one of the largest marine energy projects funded in the EU FP7 era, with 18 partners (14 industry) from 11 countries, which developed a series of open-source design tools to inform and assist the design of the array infrastructure connecting generators and optimising their performance and energy production. [3.1] reported the results of the first systematic techno-economic appraisal of the applicability and fitness-for-purpose of the main cost-critical and reliability-defining assets in the offshore delivery infrastructure, including subsea connectors, dynamic cabling, sub-stations and converter equipment.

Tidal current turbine blade-systems, power-take-offs and support structures are subjected to varying mechanical and fatigue loadings arising from the combination of forces from tidal flows, random and structured turbulence and cyclic modulation of velocity by surface waves. ReDAPT [P2] characterised the spatial and temporal knowledge of the incoming energy flux that is essential to quantify energy yield and quality and product-critical to inform blade design and real-time control of machines for durability. Working in the laboratory and at sea with partners Nortek, ERPE researchers Sellar et al [P3] developed new sensors and novel sensor-configurations including a convergent-beam Acoustic Doppler Current Profiler (ADCP) to create the first field-scale 3D velocimeter [3.2].

These sensor systems were deployed in one of the world's most dynamic marine environments in a tidal channel at the European Marine Energy Centre (EMEC) at Orkney, capturing yearly descriptions of the conditions to which an operating 1MW turbine was exposed. [3.3] reported summary data analysis and results from the research, which remains the most comprehensive tidal field measurement campaign conducted. Through exposing the magnitude of local (sub-100 metre) spatial variation, it identified the criticality of making full array-scale models to the sector, validated by enhanced array-wide measurements.

Generator design tools and optimisation are critical to develop generators that can operate in the marine environment, absorbing high oscillatory drive forces, without gearboxes to increase the speed of rotation. Mueller pioneered the C-GEN family of air-cored, low-speed, direct-drive rotary and linear generators and improved their thermal performance. Research funded through [P4] demonstrated C-GEN's suitability to wave energy conversion, as reported in [3.4]. This leveraged further funding from Wave Energy Scotland (WES) that enabled Mueller to develop the design tools and enable the integration of electromagnetic, thermal and structural design techniques, providing the first opportunity for full optimisation.

The integrated electrical-thermal design method was extended in [3.5] to include computational fluid dynamic (CFD) predictions of airflow in an air-cooled axial-flux permanent-magnet (AFPM) machine and validated predicted temperature rises with those measured in service. Using new algorithmic approaches Mueller improved inlet designs to significantly reduce stator temperature rises and thermal losses.

International strategic support and collaboration is essential to bring tidal, wave and floating offshore renewable energy technologies to market, to help realise ambitions for a lower-carbon future. Since 2004 ERPE researchers Ingram, Jeffrey and Mueller [3.6], worked within UKCMER, in collaboration with UK and international institutions, to help establish government-funded mirror ORE test centres in Mexico, Canada, USA and Ireland. Strategically this consolidated UK and international partnerships and helped to position the UK as world-leaders in research, translation and deployment of ORE energy technology. [3.6] stimulated further interest and support partnerships with Chile (2013-19), China (2017-18) and Ecuador (2018-20).

ERPE researchers have worked closely with, often on secondment to, UK and overseas governments and industry to produce sectoral strategy and roadmaps for ORE. Jeffrey leads the European Energy Research Alliance Ocean Energy Joint Programme, chairs the IEA Ocean Energy Systems initiative and is Head of Strategy and Internationalisation at WES. Between 2010 and 2016, phase 2 of UKCMER developed a (then unique) collaborative approach to training PhD students in partnership with ORE industry and wider stakeholders. Since then IDCORE [P5] has trained and delivered, in partnership with 20 industry companies (multi-nationals and SMEs), around 60 EngD students to be key post-doctoral contributors to the impact arising from and within industry partnerships.

3. References to the research

[3.1] **Journal**. Collin, A, Nambiar, A, Bould, D, Whitby, B, Moonem, M, Schenkman, B, Atcitty, S, Chainho, P, & Kiprakis, A, (2017) 'Electrical Components for Marine Renewable Energy Arrays: A Techno-Economic Review', Energies, Vol. 10, 12, https://doi.org/10.3390/en10121973
[3.2] **Journal**. Sellar, B., Harding, S. & Richmond, M., (2015) 'High-resolution velocimetry in energetic tidal currents using a convergent-beam acoustic Doppler profiler', J. Meas. Sci. & Tech. 26, 8, https://iopscience.iop.org/article/10.1088/0957-0233/26/8/085801
[3.3] **Journal**. Sellar, B., Venugopal V., Ingram D., & Wakelam, G., (2018) 'Characterisation of Tidal Flows at the European Marine Energy Centre in the Absence of Ocean Waves', Energies 11, https://www.research.ed.ac.uk/en/publications/characterisation-of-tidal-flows-at-the-european-marine-energy-cen
[3.4] **Journal**. N. Hodgins, O. Keysan, A. S. McDonald & M. A. Mueller, (2012) 'Design and Testing of a Linear Generator for Wave-Energy Applications,' IEEE Trans Ind Electronics, 59, 2094-2103, https://doi.org/10.1109/TIE.2011.2141103
[3.5] **Journal**. Y. C. Chong, E. J. P. Echenique Subiabre, M. A. Mueller, J. Chick, D. A. Staton and A. S. McDonald, (2014) 'The Ventilation Effect on Stator Convective Heat Transfer of an Axial-Flux Permanent-Magnet Machine," IEEE Trans Ind Electronics, 61, 4392-4403, https://doi.org/10.1109/TIE.2013.2284151
[3.6] **Journal**. Mueller, M.A., Jeffrey, H.F., Wallace A.R., von Jouanne, A., (2015) 'Centers for Marine Renewable Energy in Europe and North America', Oceanography, 23(2):42–52, https://doi.org/10.5670/oceanog.2010.42

Related Research Project Funding

[P1] – EU FP7 'DTOcean project'. EUR4,000,000. PI Jeffrey, H. (2013-2016).
[P2] – ETI ReDAPT: GBP12,600,000. Co-PI Ingram, D (2013-2015)
[P3] – RealTide: H2020, No.727689; EUR4,974,990 Co-PI Sellar, B (2018-2020)
[P4] – Carbon Trust Marine Energy Accelerator; GBP3,500,000 Co-PI Mueller, M, (2009-2011)
[P5] – EPSRC EP/J500847/1: Industrial Doctoral Centre for ORE, (IDCORE) GBP 6,531,437

4. Details of the impact

ERPE research, based at the University of Edinburgh's Institute for Energy Systems, has underpinned a portfolio of key strategic measures and impacts to help drive progress in offshore renewable energies (ORE) in the UK and internationally in three continents. The ERPE research resulted in multi-million pound investments from ORE sector companies and government agencies to develop next generation technologies. The impacts include the following:

(A) International open-access tools to assist offshore renewables array deployment

The DTOcean project [P1] (led by ERPE) resulted in a EUR8,000,000 investment [5.1] by the EU Commission in DTOcean+ (led by Tecnalia based in Spain, with UoE as a leading partner) to support European countries and companies to accelerate the commercialisation, deployment and network integration of ORE technologies [5.1]. Building on [3.1] DTOcean+ has developed an extensive series of open-source engineering design tools [5.2] for the ORE sector. Two years into a three-year programme [5.2] ERPE researchers have led the development or co-produced 9 of the 12 online DTOcean+ tools now being used across the ORE sector worldwide [5.2], including: *design and stage gate tools, machine characterisation, energy capture, energy transformation, energy delivery module* and *station keeping, marine logistics, energy yield and system reliability* [5.2].

The underpinning ERPE research reported in [3.2] enabled industry partner **Nortek,** headquartered in Norway, to develop new products (CADP) and features to service the instrumentation needs of the ORE sector as it moves to array-scale deployments [5.3]. Nortek's product portfolio includes wave, current and turbulence measurement systems for coastal and ocean use. The CADP system has been further developed, extending capability to allow the previously unachievable volumetric mapping of 3D turbulent flow fields in the field. This was successfully demonstrated on the west coast of the USA. Integrating data from the Nortek single-beam system [P2] into an acquired Met-ocean conditions database increased measurement resolution of velocity and turbulence, improving the ORE sector's understanding

of the operational environment. **Nortek's** new products including their interfaces, software and re-configurability stem from the ERPE research and '*enable faster and finer current measurements over greater distances*' [5.3].

Sabella is a French SME and developer of tidal turbines. Since 2018, through participation in the EUR4,974,990 EU RealTide Project [P3] and in collaboration with Sellar, they have built upon the underpinning research in [P2], reported in [3.3]. In addition to using the ERPE research findings to refine the design of their blading systems [5.4a], the ERPE modelling of tidal energy sites was described by Sabella as "*an important enabling contribution…supporting strategic commercial goals…delivering global improvements to advanced sensor systems… and including the realisation of significant risk reductions*" [5.4b].

They have implemented both within RealTide and in the 'game-changing' EUR45,000,000 industry TIGER project. Datasets obtained using this ERPE-led methodology has enabled the optimisation of the next generation of Sabella turbines reducing blade fabrication costs by 30% [5.4a].

In 2020 the Head of Innovation at SABELLA, said: "*This blade is the achievement of two years of engineering effort and [represents technical progress] in comparison with the previous design. In collaboration with the RealTide project partners, the shape and structure of the blade has been optimised to improve the performance and reduce the cost of fabrication*" [5.4a].

(B) Formation of new spin-out companies, business markets and CO_2 reductions

The underpinning research and proof of concept work reported in [3.4] established the innovative C-GEN technology that is incorporated by the UK spin out company **MOCEAN Energy** into their state-of-the-art wave machines. They have launched two new wave technologies [5.5]: 'Blue Star wave energy converter', which powers off-grid subsea applications, such as propulsion and control system for to ROVs and autonomous underwater vehicles; and 'Blue Horizon larger hinged-raft wave energy converter', which connects to the onshore electricity network. **MOCEAN Energy** has secured GBP4,000,000 [5.5] to manufacture and deploy both devices in Orkney, also enabling new UK and international industry partnerships [5.6] with Blackfish Engineering, Industrial Systems and Controls, TechX and Sequentec.

The ERPE research [3.5] investigating the loss minimisation in electrical machines and its application to optimise the output from wind and tidal energy converters, led to the establishment of **REOptimize Systems** in 2018, based in the UK [5.7]. REOptimize is a novel system for optimisation of wind, tidal and hydro turbine control parameters. It uses machine learning techniques [3.5] combined with accurate component models, to find the control settings which globally optimise performance of the generation system at all operating points. In April 2019 the '*research formed the basis of the company winning Shell Springboard Regional Award*'" [5.7].

The original research algorithms led to a further new software product called Autonomous Continuous Turbine Optimisation System (ACTOS). The ACTOS software platform can control the turbines to reduce emissions by as much as 135 tons of CO_2 per year per turbine (e.g. 2MW) [5.7], and could prevent the release of 2,700 tons of carbon over the 20 year turbine lifetime, doubling the net profit for a wind farm operator, while also reducing maintenance costs and turbine downtime [5.7]. This can make a critical difference to the commercial viability of individual wind farm developments [5.7].

ACTOS has been successfully deployed on turbines from 20kW to 250kW and is also being piloted for the utility-sized 2.3MW Siemens turbine [5.7]. The market sector ACTOS is targeting in the existing deployed (onshore and offshore) wind turbines is worth around GBP1,300,000,000 per annum. The ERPE underpinned impact has enabled the company to secure international commercial contracts in Italy and Germany [5.7].

(C) Establishment of strategic international investment in ORE R&D infrastructure

ERPE's previous research appraisal of the need for, support necessary and development of international marine testing facilities [3.6] resulted in Ingram and Jeffrey becoming advisors to the Chilean government, enterprise bodies and academic institutions. Chile has 6,000km of coastline, facing some of the best wave energy resources. As a result of ERPE's collaboration

with CORFO, the **Chilean economic development agency**, a new USD20,000,000 Marine Energy Research and Innovation Centre (MERIC) was opened in Chile in June 2016. The Executive Director of MERIC described the impact of the ERPE research and support as being "*instrumental in supporting the formation and research agenda of the Chilean Marine Energy Research and Innovation Centre (MERIC)"* [5.8]. Additionally, the ERPE/University of Edinburgh research has "*informed the shape and direction of MERIC's research programme and supported the development of the Open Sea Lab and associated laboratory scale test programmes for the assessment of offshore renewable energy devices*" [5.8].

In May 2017 the China-UK Low Carbon College (LCC) was established by Shanghai Jiao Tong University (SJTU) and the **Shanghai Lin-gang Government** [5.9], in partnership with the University of Edinburgh. ERPE researchers with colleagues in the Edinburgh Climate Change Institute (ECCI) advised on the formation of LCC research, training and test centres, including renewable energy and storage, carbon capture and low carbon technologies, and continue to help shape the research and training at the LCC. The LCC became China's first dedicated centre [5.9] for expertise on carbon reduction and innovation, with 20,000m^2 of laboratories and training space, enabling international co-operation in research, policy support and innovation.

(D) Influencing low carbon policy and strategies.

As a result of the ERPE research on ORE and hybrid energy systems, and a strong collaborative interdisciplinary approach with ECCI and the UoE Centre for Contemporary Latin American Studies, in 2018 the **Ecuadorian government** requested support to develop an energy, transport and infrastructure strategy for the Galapagos Islands archipelago, a UNESCO 'World Heritage Site'.

This interdisciplinary advisory project (2018-19) involving ERPE was cited by the Minister-President of the Galapagos region as a "*significant contributor to the development of the Galapagos 2040 Vision*" [5.10] and was launched by the Vice President of Ecuador at COP25 in Madrid [5.10].

5. Sources to corroborate the impact

[5.1] DTOcean+ EUR8 Million investment led by Tecnalia, follow on from ERPE led DTOcean (2018). https://www.dtoceanplus.eu/About-DTOceanPlus/Description
[5.2] DTOcean+ open access design tools (published 2020). 9 of the 12 online tools led or co-led by ERPE/UoE. https://www.dtoceanplus.eu/News/alpha-version-of-the-tools-implemented
[5.3] Nortek Group – Article stating significance of UoE research in the development of their new 'Signature' series products. https://www.nortekgroup.com/knowledge-center/userstory/how-can-we-improve-the-feasibility-of-renewable-tidal-stream-energy-production-1-1
[5.4a] Sabella unveils now tidal turbine blade developed with UoE (2020) https://www.offshore-energy.biz/sabella-unveils-new-generation-tidal-turbine-blade/
[5.4b] Sabella – letter stating the new technologies impact of the ReDAPT & RealTide projects.
[5.5] MOCEAN Energy spin out company (web site 2020) detailing company, products and investments https://www.mocean.energy/
[5.6] MOCEAN Energy – and their industry UK supply chain partnerships formed (2020) https://www.mocean.energy/mocean-energy-partners/
[5.7] REOptimise Systems – Chief Technology Officer (CTO) letter on the underpinning research led impacts – products, award, international markets, CO_2 reductions.
[5.8] MERIC – letter from Executive Director (MERIC, Chile) confirming UoE research and support impacts in establishing the national government ORE research and test facility (2016).
[5.9] China's first Low Carbon College (LCC), supported by UoE/ERPE for the China-UK LCC. http://europe.chinadaily.com.cn/a/201809/26/WS5baa6447a310c4cc775e80a6.html
[5.10] Ecuador Government – letter from the Minister-President for the Special Region of the Galapagos – confirming UoE contribution to 'Galapagos 2040 vision' launched COP25 (2019).