Supergen Offshore Renewable Energy

Ocean Energy and Net Zero: Policy Support for the Cost Effective Delivery of 12GW Wave and Tidal Stream by 2050

A Supergen Offshore Renewable Energy Hub Policy Paper prepared by the Policy and Innovation Group at the University of Edinburgh.

July 2023

THE UNIVERSITY of EDINBURGH
School of Engineering
Policy and Innovation Group

UKRI Engineering and Physical Sciences Research Council

Policy and Innovation Group

The Policy and Innovation Research Group is part of the Institute for Energy Systems (IES), which is one of the six research institutes within the School of Engineering at the University of Edinburgh. The group combines expertise on technologies, energy system organisations and institutions, and the wider policy and regulatory context for energy. They apply a range of quantitative and qualitative research tools and methods including innovation systems, energy system modelling and scenarios, and transitions management. This leads to preparation of strategy and investment roadmaps for organisations' funding, public and private investment and government departments.

This report has been written by Pui Wah Wong, Kristofer Grattan and Henry Jeffrey from the Policy and Innovation Group.

Find out more about the Policy and Innovation Group at
http://www.policyandinnovationedinburgh.org/

Supergen Offshore Renewable Energy Hub

The Supergen ORE Hub is a £9 Million Engineering and Physical Sciences Research Council (EPSRC) funded programme which brings together academia, industry, policy makers and the general public to support and accelerate the development of offshore wind, wave and tidal technology for the benefit of society. The Hub is led by the University of Plymouth, and includes Co-Directors from the Universities of Aberdeen, Edinburgh, Exeter, Hull, Manchester, Oxford, Southampton, Strathclyde, and Warwick. The Supergen ORE Hub is one of three Supergen Hubs and two Supergen Network+ created by the EPSRC to deliver strategic and coordinated research on Sustainable Power Generation and supply.
https://www.supergen-ore.net/

Designed by Martin Budd Design Consultant

Cover image: Orkney supply chain vessels (Source: EMEC)

Acknowledgments:

The authors would like to thank all those who have supported this publication, provided underlying data and offered their insightful feedback and review, all of which has made the publication of this report possible. We would specifically like to thank Professor Ian Masters and Dr Michael Togneri, Swansea University; Professor Simon Neill, Bangor University; Matthew Finn and Donald Leaver, European Marine Energy Centre; James Murray, Orbital Marine Power; Ben Yeats, TTI Marine Renewables; Joanna Money, Scottish Enterprise; and Andrew Aveyard, Professor David Ingram, Dr Brian Sellar and Dr Donald Noble, University of Edinburgh.

We would like to give special thanks to Kasia Nikraszewicz at the Department of Energy Security and Net Zero and to Gordon Patterson at Scottish Government for their time and that of their respective teams in providing high-level feedback and input.

Finally, the views expressed in this report represent that of the Policy and Innovation Group and do not necessarily represent those of the organisations and individuals mentioned above.

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

CONTENTS

EXECUTIVE SUMMARY

This report outlines the policy support mechanisms and the associated costs that are required to accelerate the commercialisation of the wave and tidal stream energy sectors. One of the primary challenges facing these technologies is the need to drive down the overall cost of energy generation and achieve cost parity with the wholesale market price. This can be achieved in part through the targeted application of technology push and market pull policy support mechanisms, which can drive both sector innovation and market growth for wave and tidal stream energy devices.

This report will analyse the use of existing market pull and technology push policy support mechanisms and evaluate their success and impact to date. While this report will focus primarily on the future of the wave and tidal sectors within the UK, it will also look to compare levels of investment and success with comparable policy implementation in the European Union. This section will culminate in analysis of current funding levels in the sector to date and provide commentary regarding whether the levels of investment offered so far are compatible with the aims of growing the sector.

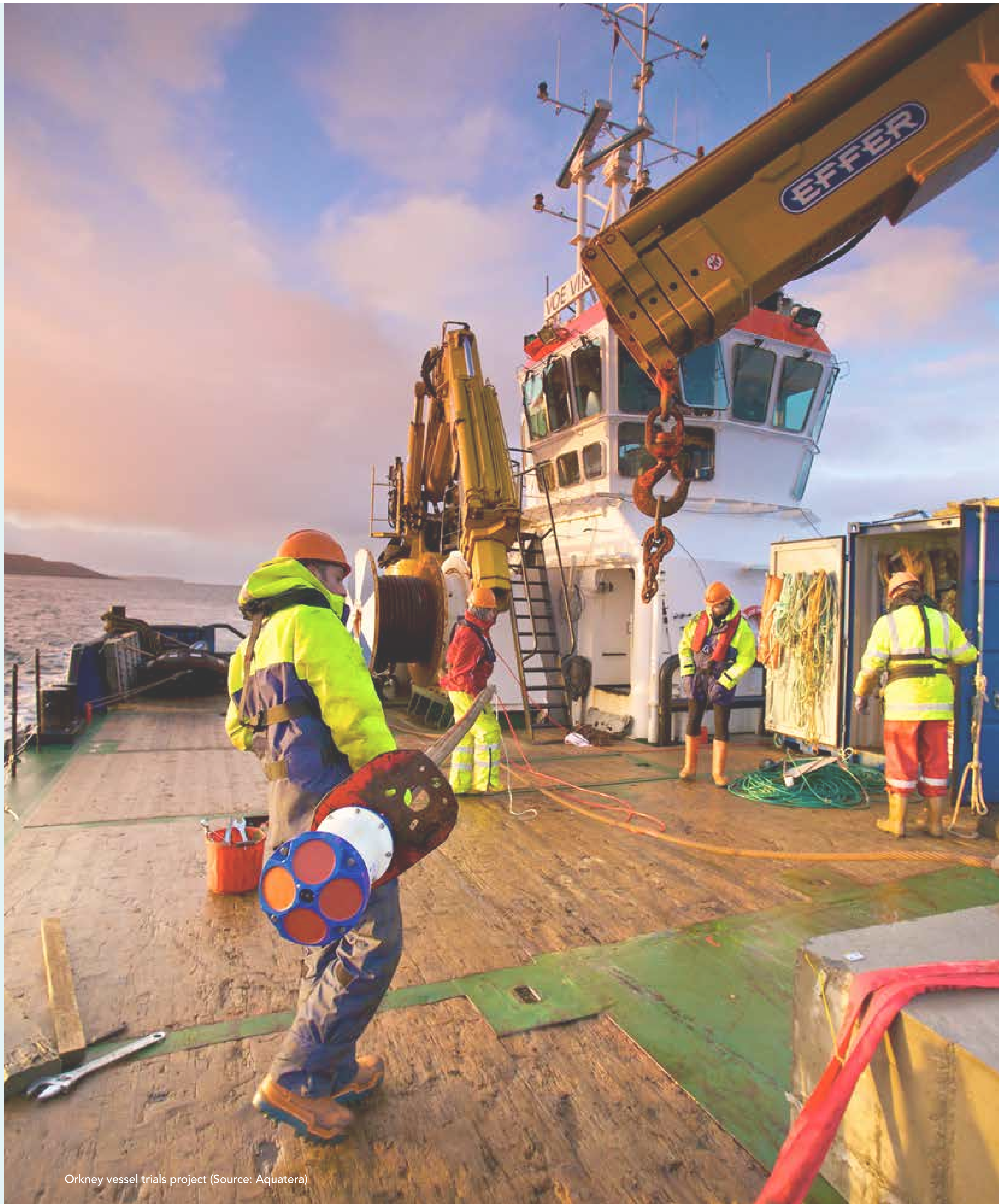
This report will then present a number of future evidence-based scenarios, evaluating the impact of both technology push and market pull policy support mechanisms, with a particular emphasis on the Contracts for Difference (CfD) scheme and the attainment of high technology learning rates. It will forecast the associated levels of investment required for the ocean energy sector to achieve parity with the wholesale market price of electricity and the requisite funding required at a national level to achieve the deployment of 6GW of wave energy and 6GW of tidal stream energy by 2050.

This report is the fourth in a series that outlines the policy mechanisms and innovations that will be required to unlock both the economic value and system benefits associated with commercial scale wave and tidal stream energy deployments. Previous publications have estimated the potential benefits of 6GW of wave and 6GW of tidal stream to the UK to be:

- **£11 billion - £41 billion** in gross value added (GVA) to the UK economy;
- **£1 billion per annum** reduction in dispatch cost.

This report has built on these results and delivered comprehensive analysis that aims to find the optimal balance between financial investment in both technology push and market pull policies and the delivery of 6GW of wave and 6GW of tidal stream at the best value for both the consumer and the taxpayer.

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050



Orkney vessel trials project (Source: Aquatera)

Results from this report are summarised in the following key messages:

Key Message 1 – Sector Benefits

The continued commercialisation of the wave and tidal stream sectors, aided by accelerated innovation, has the potential to **establish the UK as the world leading nation in ocean energy technology development and deployment**, delivering a range of accompanying Net Zero, socioeconomic and power system benefits. By achieving the forecasted deployment of 6GW of wave and 6GW of tidal stream, the following benefits can be realised:

- Between **£11billion to £41billion in GVA to the** UK economy by 2050 from both domestic and international deployment of wave and tidal stream technologies, relative to UK international market share;
- Approximately **£1 billion per annum** reduction in dispatch cost.

Key Message 2 – Existing Technology Push Support

Between 2017 and 2022 total funding to support technology push policies specific to the wave and tidal stream sectors in the UK amounted to **£315 million**. However, approximately only 23% **(£74 million)** of this came from domestic sources of funding, with **£44 million** coming directly from the Scottish Government initiatives (Wave Energy Scotland, EuropeWave and the Saltire Prize), concentrating predominantly on medium TRL status projects. The remaining **£28 million** of domestic funding is provided by the UK government, with the bulk of this coming in the form of EPSRC funding to the SuperGen programme.

There is a clear opportunity for the UK government to invest more heavily in technology push funding that focusses on early stage innovation (low TRL status) to drive technology innovation, ultimately helping to advance wave energy technology towards accessing market pull mechanisms and accelerating the cost reduction of tidal stream technology.

Key Message 3 – Existing Market Pull Policy Support

From 2002 until 2017, the implementation of the Renewables Obligation (RO) market pull mechanism has **successfully delivered 8.6MW of tidal stream capacity**. From 2014 to present day, the Contracts for Difference (CfD) market pull mechanism has provided targeted support to the tidal sector and has **contracted an initial 40.82MW of generative capacity** at a strike price of **£$_{2012}$178.54/MWh**. During the same period no wave energy devices have been deployed as a result of the same market pull policies.

In order to ensure that the wave and tidal stream sectors continue to play a significant role in achieving the UK governments ambitious net-zero target, long-term market pull policy support mechanisms, **such as the continuation of the CfD scheme**, are crucial.

Key Message 4 – Tidal Stream Sector Market Pull Funding Analysis

Our analysis has shown that technology push funding, which drives technology innovation, greatly affects the overall market pull funding required for tidal stream deployment in the following aspects:

- A higher learning rate (achieved through increased technology push funding) provides greater overall cost reductions and significantly reduces the total investment required to support market pull polices such as the CfD scheme. In our scenario, increasing the learning rate from 10% to 15% reduced the total investment required in the tidal stream sector from **£18.6 billion to £3.3 billion**; an increase from 15% to 20% further reduced the required investment in the tidal stream sector to **£1.9 billion**;
- The immediate application of technology innovation fueled by technology push funding allows the tidal stream sector to enable faster cost reductions and lower the strike prices offered in subsequent CfDs. This can lead to savings of approximately **£0.6 billion per year** of non-delay in the consistent cost reductions associated with the total funding required for market pull investments. This is a modest amount in comparison to the savings associated with the adoption of a 15% or 20% learning rate instead of a sub-optimal learning rate of 10%.

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

Key Message 5 – Wave Sector Market Pull Funding Analysis

Our analysis has shown that technology push funding, which in turn drives technology innovation, greatly affects market pull funding for wave deployment in the following aspects:

- A higher learning rate (achieved through increased technology push funding) provides greater overall cost reductions and significantly reduces the total required to support market pull polices such as the CfD scheme. In our scenario, increasing the learning rate from 10% to 15% reduced the total investment required in the wave sector from **£20.5 billion to £3.0 billion**; an increase from 15% to 20% further reduced the required investment in the wave sector to **£1.3 billion**;
- The immediate application of technology innovation fueled by technology push funding allows the wave sector to enable faster cost reductions and lower the strike prices offered in subsequent CfDs. This can lead to savings of approximately **£0.9 billion per year** of non-delay in the consistent cost reductions associated with the total funding required for market pull investments. This is a modest amount in comparison to the savings associated with the adoption of a 15% or 20% learning rate instead of a sub-optimal learning rate of 10%.

Key Message 6 – Future Technology Push Funding Analysis

Our analysis has outlined that funding for technology push policy mechanisms is a vital tool in ensuring that accelerated innovation continues to occur across the wave and tidal stream sectors. Targeting specific challenge areas, as outlined in the Strategic Research and Innovation Agenda (SRIA), will also help to deliver innovation in a cost-effective manner. By establishing two scenarios, **Maximum Collaboration** – where seven leading European wave energy countries and three leading European tidal stream countries, in collaboration with the European Commission, provide innovation funding – and **Partial Collaboration** – where three leading European wave energy countries and two leading European tidal stream countries, in collaboration with the European Commission, provide innovation funding – we have shown the following:

- Under the conditions of **Maximum Collaboration**, a total of **€370 million** (approximately **£325 million**) of tidal stream energy funding and **€207 million** (approximately **£180 million**) of wave energy funding, willl be required per country, supplemented by funding from the European Commission, to enable an accelerated learning rate that will reduce the overall market pull investment required between now and 2050;
- Under the conditions of **Partial Collaboration**, a total of **€555 million** (approximately **£488 million**) of tidal stream energy funding and **€483 million** (approximately **£420 million**) of wave energy funding, willl be required per country, supplemented by funding from the European Commission, to enable an accelerated learning rate that will reduce the overall market pull investment required between now and 2050.

The successful outcome of these technology push policy support mechanisms is highly contingent on two factors:

- Continued **collaboration between the leading European countries** in both the wave and tidal stream sectors;
- The **UK government providing adequate technology push funding** to support innovation across development and deployment in the ocean energy sector, encompassing all stages of technological maturity.

As outlined in these **six key messages**, should the forecasted 6GW of wave and 6GW of tidal stream deployment be achieved, at an optimum cost for both consumers and taxpayers relative to the total amount invested in both technology push and market pull policies, the UK will benefit from world-leading wave and tidal stream sectors in a number of ways:

First, the wave and tidal stream sectors have the potential to become a pivotal feature of our future Net-Zero energy system through the deployment of renewable technology, the generation of sustainable energy and the subsequent national energy system balancing benefits that can be expected.

Secondly, there is a clear opportunity for the UK to increase the GVA and associated socioeconomic benefits to the national economy, both domestically and from exports of UK expertise and supply chain capabilities to the global market. The wave and tidal stream sectors also have the potential to play a vital role in the Just Transition by providing well paid, high quality jobs in coastal and island communities.

HOW TO READ THIS REPORT

If the reader is already familiar with previous publications in this series, which cover GVA to the UK economy and overall energy system benefits associated with wave and tidal stream deployment, and has existing background knowledge of wave and tidal stream technologies, then Section 1 of this report can be overlooked.

This report also includes a series of Key Messages and Section Overviews that should be considered critical to understanding the analysis that follows.

INTRODUCTION

Wave and tidal stream energy technologies have a pivotal role to play in ensuring that the UK achieves its long-term and highly ambitious decarbonisation targets, helping to put us on the path towards a greener economy with the welfare of people and planet at the forefront. The wave and tidal stream sectors will also help to underpin the security of the national energy mix, cutting our reliance on imported fossil fuels, an objective that is becoming increasingly important as the invasion of Ukraine continues to threaten continuity of energy supply. The growth of the wave and tidal stream sectors will also allow the UK to utilise the still largely unrealised and untapped clean renewable resources in the waters that surround our nation, complementing and strengthening our ever-increasing renewable energy portfolio. Finally, the expansion of these sectors will also provide the opportunity for the UK to become an international leader in the research, design and deployment of wave and tidal stream technologies. Guided by timely and appropriate policy decisions, the UK has the chance to establish a strong domestic and international supply chain with the potential to deliver socioeconomic gains in the form of increased national income and job creation.

This report will look to provide clear evidence-based analysis of the learning investment that will be required to bring the wave and tidal stream sectors towards increased levels of deployment and will evaluate the impact that different learning rates and price trends have on the overall costs associated with commercialisation of ocean energy. This report will evaluate the costs associated with ensuring the commercial success of the wave and tidal stream sectors at different learning rates and price trends for both the wave and tidal sector. This report will also aim to quantify the amount of investment required to achieve 6GW of wave deployment and 6GW of tidal stream deployment by 2050, consistent with the deployment scenarios used in our previous three reports.

In achieving these ambitious deployment targets and positioning the UK as a world leader in wave and tidal stream technologies, there will also be an opportunity to develop a domestic supply chain that will allow socioeconomic gains to be retained within the UK. At the same time, the UK will also achieve a level of expertise in development and deployment, allowing the establishment of a strong exportable commodity and a level of technological expertise that will bolster the financial returns from domestic investment.

METHODOLOGY

This report focuses on highlighting the necessary policy decisions that should be undertaken to ensure that the socioeconomic and system benefits associated with the successful deployment of 6GW of wave and 6GW of tidal stream are realised. Establishing the optimal balance between technology push and market pull policy support mechanisms is a vital step in ensuring that these technologies achieve the accelerated innovation and cost reductions required to become commercially viable. This support will also help to guarantee that the UK leads internationally on both technology and supply chain development, locking in potential economic benefit for years to come.

Section 1 – Sector Benefits and Technological Overview

This section will begin with an overview of wave and tidal stream technologies, before providing a brief summary of the previous publications in this series and outline how their primary findings helped to guide the scope of this report.

Section 2 – Review of Existing Policy Support

This section will deliver a comprehensive overview of the previous and ongoing technology push and market pull policy support mechanisms offered to the wave and tidal stream sectors, summarising both scale and impact.

Section 3 – Market Pull Analysis

This section will then present an analysis of market pull policy and investigate a number of future scenarios where market pull mechanisms – the CfD scheme – are implemented with support from technology push driven innovations. These scenarios will look to establish how the deployment of 6GW of wave and 6GW of tidal stream by 2050 can be achieved in a cost effective manner, where the financial investment required to deliver the CfD scheme represents the best value for the consumer and taxpayer.

Section 4 – Technology Push Analysis

This section will then look more closely at technology push mechanisms and provide estimations on the amount of investment required between now and 2050, where scenarios modelling different levels of collaboration between leading ocean energy countries are used.

Section 5 – Discussion and Key Messages

Finally, this section will conclude the overall report with a discussion regarding the role of policy mechanisms and how they can be optimised to support the development and commercialisation of the ocean energy sector while at the same time unlocking the associated socioeconomic benefits. It will also provide a summary of the key messages listed throughout the report.

1 TECHNOLOGY OVERVIEW AND SECTOR BENEFITS

Power take off – hydraulic control pack Source: Wave Energy Scotland

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

OVERVIEW OF WAVE AND TIDAL STREAM ENERGY TECHNOLOGIES

This report focuses exclusively on wave and tidal stream energy converters, devices that still require significant levels of innovation and cost-reduction to become commercially competitive with more mature renewable technologies, such as wind and solar. However, their nascent technological status also means that there is great potential for the UK to become a world-leading nation with regards to technology, expertise and supply chain development in the coming years.

Tidal stream technologies have begun to reach maturity and design convergence, with the fixed and floating horizontal axis turbine starting to become established as the design of choice. This has helped to progress the sector, with both SAE Renewables and Nova Innovation array scale devices being deployed and connected to the grid at the MeyGen and Bluemull sound test sites respectively, since 2016/17. Additionally in 2022, three device developers, shown in Figure 1, were successful in gaining market support via the UK governments Contract for Difference (CfD) Allocation Round 4 scheme, locking in an additional 40.82MW of deployment slated for 2025-2027 at a number of sites across the UK [1]. This support will be vital in accelerating the progression of tidal stream from pre-commercial devices to array-scale levels of deployment.

Figure 1 - SAE Renewables, Orbital Marine Power, Magallanes Renovables (L-R)

Wave energy devices currently remain at a more nascent stage of development, with a number of prototypes currently undergoing tank testing and several developers conducting live-sea trials of single device demonstrations. There is still a diverse range of technology designs being considered as the innovation process continues to develop a number of promising technological solutions. The sector benefits from innovative R&D funding mechanisms such as the pre-commercial procurement (PCP) process pioneered by Wave Energy Scotland, which has been instrumental in bringing both the Archimedes Waveswing (AWS) and Mocean Energy technologies, Figure 2, to their present TRL status and supported their plans for open-water testing by 2025 [2].

Figure 2 - AWS Ocean Energy, Mocean Energy, CorPower Ocean (L-R)

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

Publication Series

This report is the fourth in a series of reports jointly published by the Supergen ORE Hub and the Policy and Innovation Group, University of Edinburgh, investigating the policy mechanisms and innovations that will be required to unlock both the economic value and system benefits associated with commercial scale wave and tidal stream energy deployments. Previous publications in this series, shown in Figure 3, have focused on showing how 6GW of wave and 6GW of tidal stream can be deployed in UK waters by 2050 and have outlined the potential gross value added (GVA) to the national economy and subsequent energy system balancing benefits that can be expected.

Figure 3 - Previous publications in this series

Our first report in this series, 'Delivering Net Zero: Achieving the Deployment of 12GW of Wave and Tidal Stream in UK Waters by 2050' [3], presents a scenario based modeling exercise, forecasting the future contribution of wave and tidal stream towards Net Zero targets under different Levelised Cost of Energy (LCOE) scenarios. The energy mixes outlined in these reports are founded on the Energy Systems Catapult's 96% Further Ambition (FA96) scenario [4], modelled using the Energy Systems Modelling Environment (ESME) tool, where the Strategic Energy Technology Implementation Plan (SET Plan) [5] cost targets for 2030 that have been input to ESME for wave are **€150/MWh** and for tidal stream are **€100/MWh**.

Moving beyond 2030, subsequent cost reductions and performance improvements for wave and tidal stream match with those laid out by the European Commission Joint Research Council modelling [6]. With these conditions in place, our first report estimated the following likely energy system mix by 2050, where the deployment of 6GW of wave energy and 6GW of tidal stream energy in the national energy system is achieved, as shown in Figure 4. This forecasted deployment of 12GW of ocean energy has since been used as the basis for each report in this publication series.

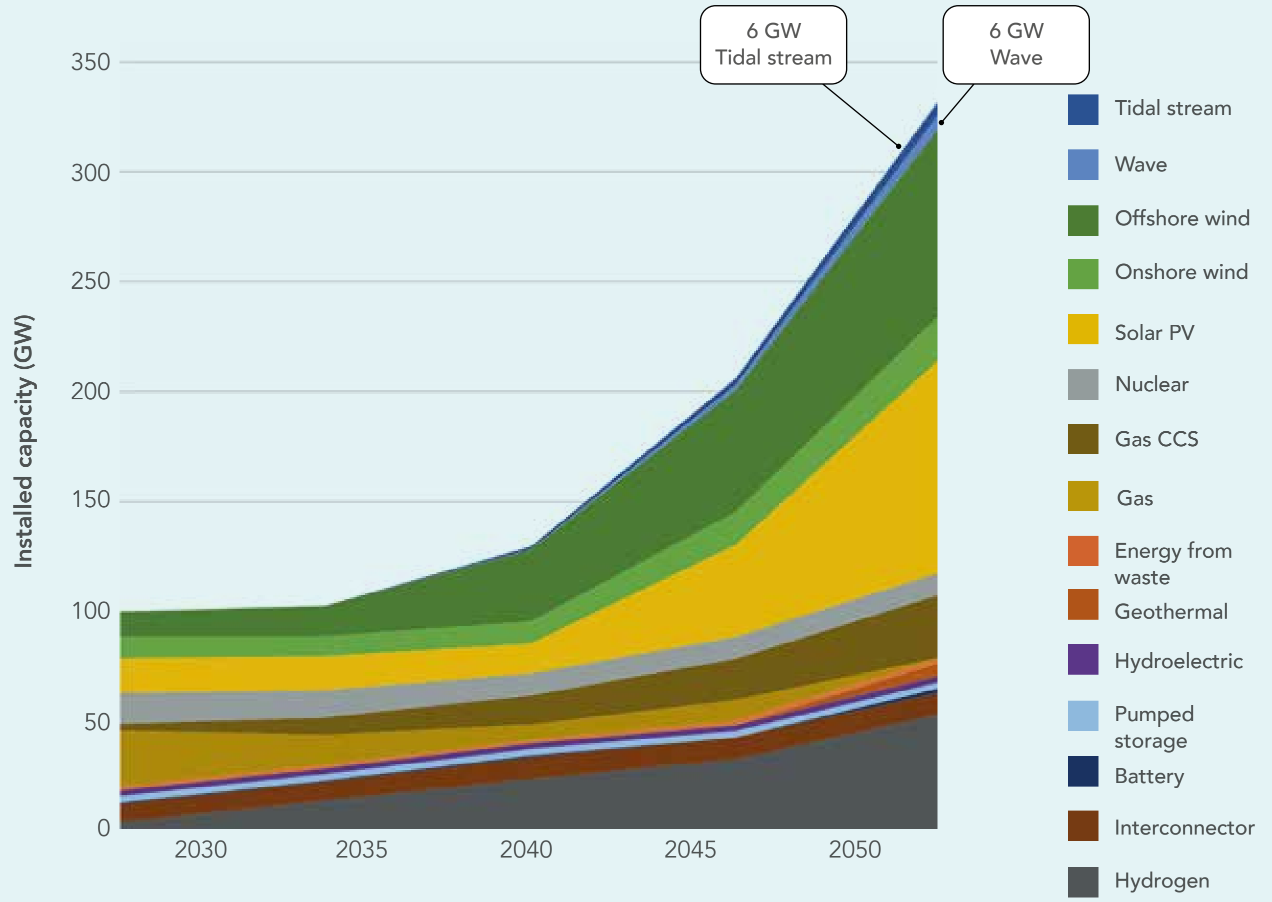


Figure 4 - Cumulative ESME model showing 2030 - 2050 UK energy mix, taken from 'Delivering Net Zero: Achieving the Deployment of 12GW of Wave and Tidal Stream in UK Waters by 2050'

In 2021, our second report, 'What is the value of innovative offshore renewable energy deployment to the UK economy?' focused on quantifying the potential socioeconomic benefit, in terms of GVA which the UK stands to gain through the deployment of wave and tidal stream energy technologies in domestic and international waters [7] . As Figure 5 demonstrates, this report established that the global deployment of wave and tidal stream technologies could produce:

- Between £4.9billion to £8.9billion in GVA to the UK economy from a domestic deployment and subsequent increases to overall supply chain competiveness;
- Between £11billion to £41billion in GVA to the UK economy by 2050 from both domestic and international deployment of wave and tidal stream technologies, relative to UK international market

These figures underline the significant potential value to the UK that can be gained if the UK government invests in developing the local supply chain ahead of these scaled deployments. However, this economic benefit will only be attained if the UK government continues to increase its levels of investment for the development and deployment of innovative wave and tidal stream energy technologies, thereby encouraging and enabling the reduction of energy generation cost through performance improvement, increased cost efficiencies and supply chain development.

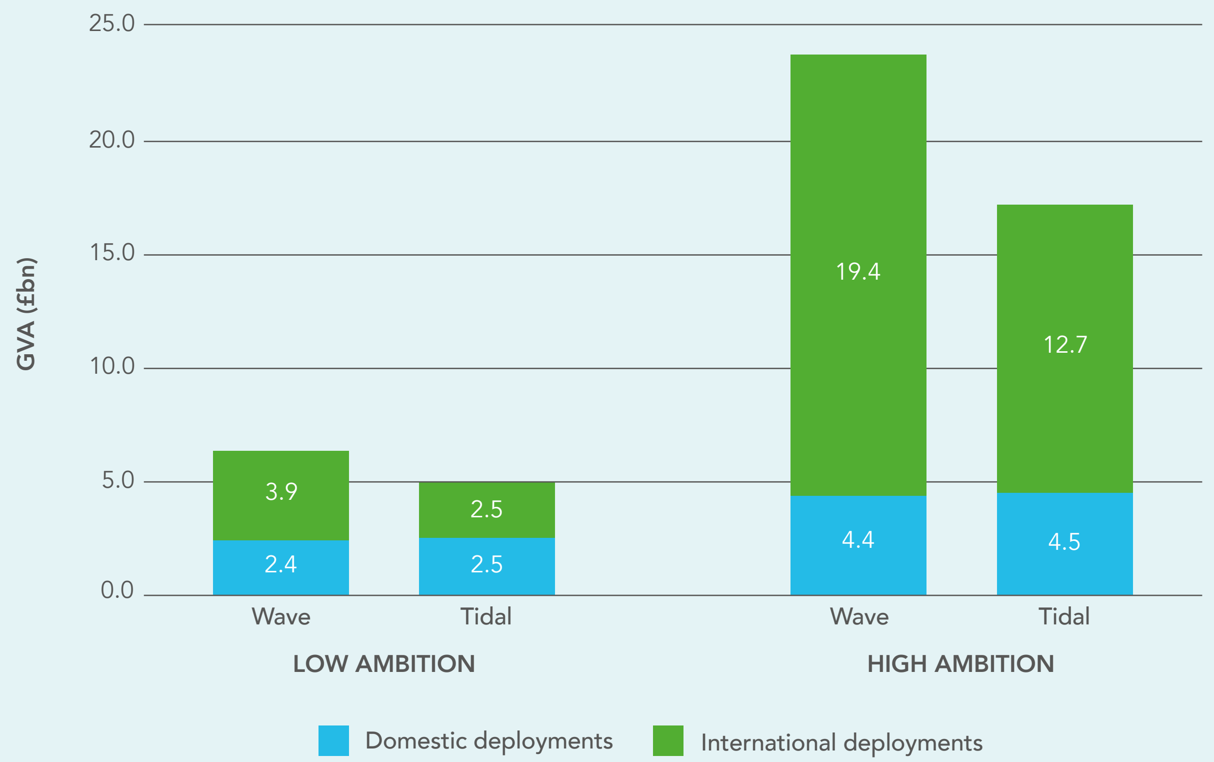


Figure 5 - GVA associated with domestic and international deployments, taken from 'What is the value of innovative offshore renewable energy deployment to the UK economy?'

The third report in this series, published in 2023, 'What are the UK power system benefits from deployments of wave and tidal stream generation?' focussed primarily on quantifying the potential power system benefits that the UK stands to gain through the deployment of wave and tidal stream energy technologies in domestic waters [8]. By forecasting a 2050 net-zero compliant energy mix, constructed using scenarios where this energy mix does and does not contain wave and tidal stream energy technologies, this report was able to illustrate how the temporal and spatial characteristics of wave and tidal stream energy resources can be appropriately exploited to complement the variability of more established renewable energy technologies, such as wind and solar.

Results from this work, shown in Figure 6, highlighted that should the estimated deployment of 6GW of tidal stream and 6GW of wave be achieved by 2050, together with other renewable sources, there is potential for:

- A £1 billion reduction in dispatch costs per annum, compared to a scenario using an energy mix without wave and tidal stream energy;
- An increase in renewable energy dispatch capability, estimated to be in the region of 27TWh, which will result in a reduction of approximately 24TWh (or 16%) of expensive peaking generation, when wave and tidal stream energy is included in the energy mix;
- A 5TWh reduction in the need for battery use;
- A 3GWh reduction in the need for energy imports over interconnectors.

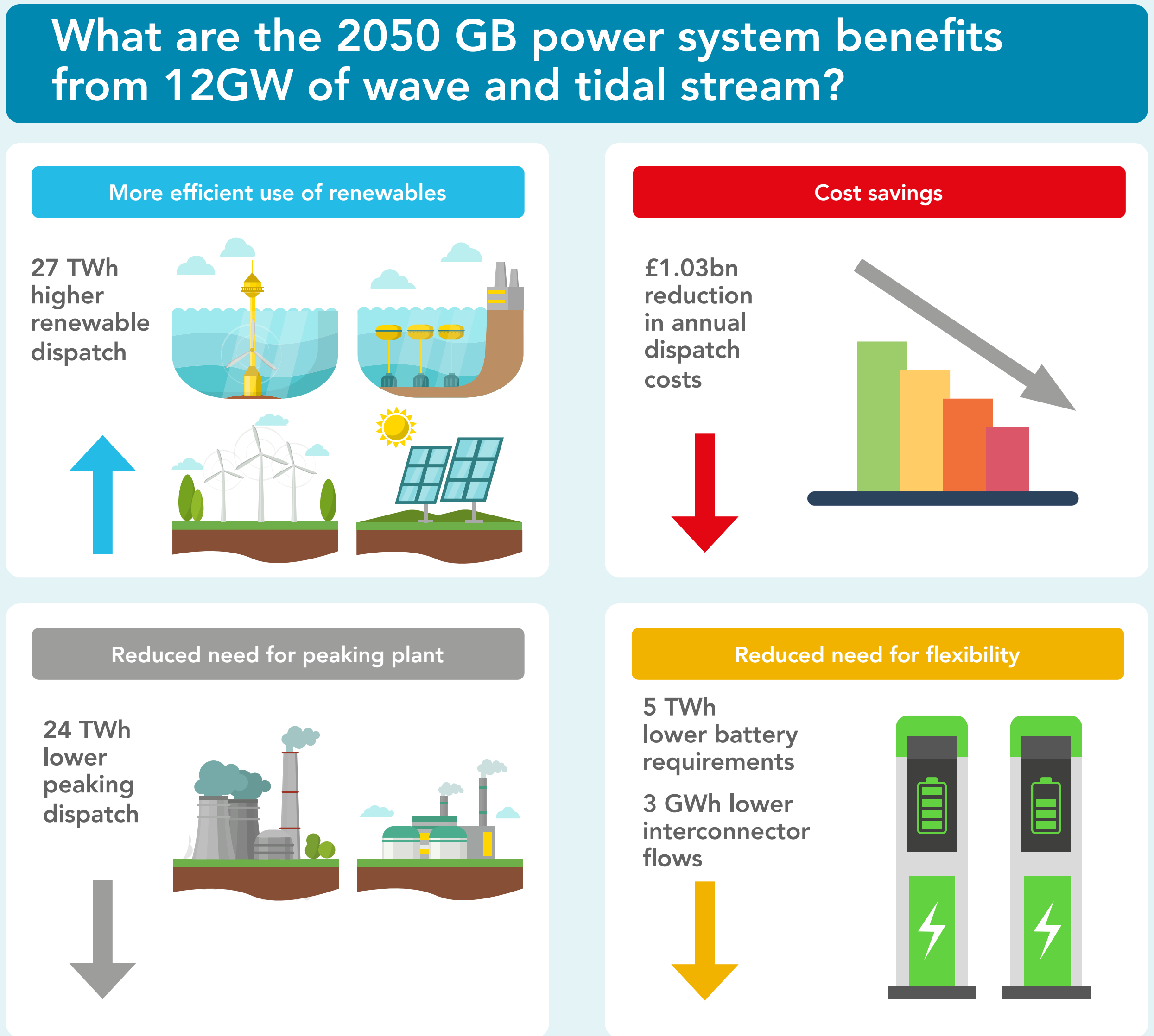


Figure 6 - Power system benefits related to deploying 12GW of wave and tidal stream by 2050, taken from 'What are the UK power system benefits from deployments of wave and tidal stream generation?'

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

This series of reports has illustrated the potential soci-oeconomic and power system benefits offered by the ocean energy sector and helped to quantify the role that it can play in overcoming the challenges posed by Net Zero, the Just Transition and domestic energy security.

However, these benefits can only be realised if there is concerted and focused policy support, designed to accelerate technology innovation and market deployment, both of which will ultimately be required to deliver a reduction in the cost of ocean energy generation.

Key Message 1 – Sector Benefits

The continued commercialisation of the wave and tidal stream sectors, aided by accelerated innovation, has the potential to **establish the UK as the world leading nation in ocean energy technology development and deployment**, delivering a range of accompanying Net Zero, socioeconomic and power system benefits. By achieving the forecasted deployment of 6GW of wave and 6GW of tidal stream, the following benefits can be realised:

- Between **£11billion to £41billion in GVA to the** UK economy by 2050 from both domestic and international deployment of wave and tidal stream technologies, relative to UK international market share;
- Approximately **£1 billion per annum** reduction in dispatch cost.

Mooring in tidal flow at EMEC tidal test site, Orkney (source: Colin Keldie / EMEC)

2 REVIEW OF EXISTING POLICY SUPPORT

Waverider buoy deployment at EMEC (source: Colin Keldie / EMEC)

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

Balancing Technology Push and Market Pull

In order for renewable energy technologies to replace existing forms of carbon-intensive energy production, there has been a need for bespoke policy support mechanisms that allow renewable energy technologies to compete with investment that has historically flowed to fossil-fuel based industries. For the wave and tidal sectors, this challenge is compounded by the fact that these technologies are also competing with mature and established, yet intermittent, renewable energy technologies, such as wind and solar. Therefore, for nascent renewable energy technologies, like wave and tidal stream, policy mechanisms that accelerate cost reductions are vital to ensuring that they reach a stage of commercial viability both in terms of costs and technology readiness levels (TRLs).

However, establishing the optimal combination of policy support mechanisms to bring a technology to this stage of TRL is a delicate balancing act between **technology push policies** – designed to support innovation at the early stage of technology development – and **market pull policies** – designed to accelerate the commercialisation of technologies by providing revenue support. This section will provide an overview of:

- Technology push policy mechanisms from 2017 – 2022;
- Market pull policy mechanisms, such as Contracts for Difference (CfDs) and Renewables Obligation (ROs), from 2002 to present day.

The combination of these policy support mechanisms effectively becomes a mixture of the cost to the taxpayer and the consumer of the commercialisation of any given technology. Striking the right balance between these commercialisation costs and benefits to society (i.e. the GVA to the economy or the overall impacts on both society and the environment), while still delivering a fair and cost-effective return on taxpayers investment, is a complex task, as shown in Figure 7.

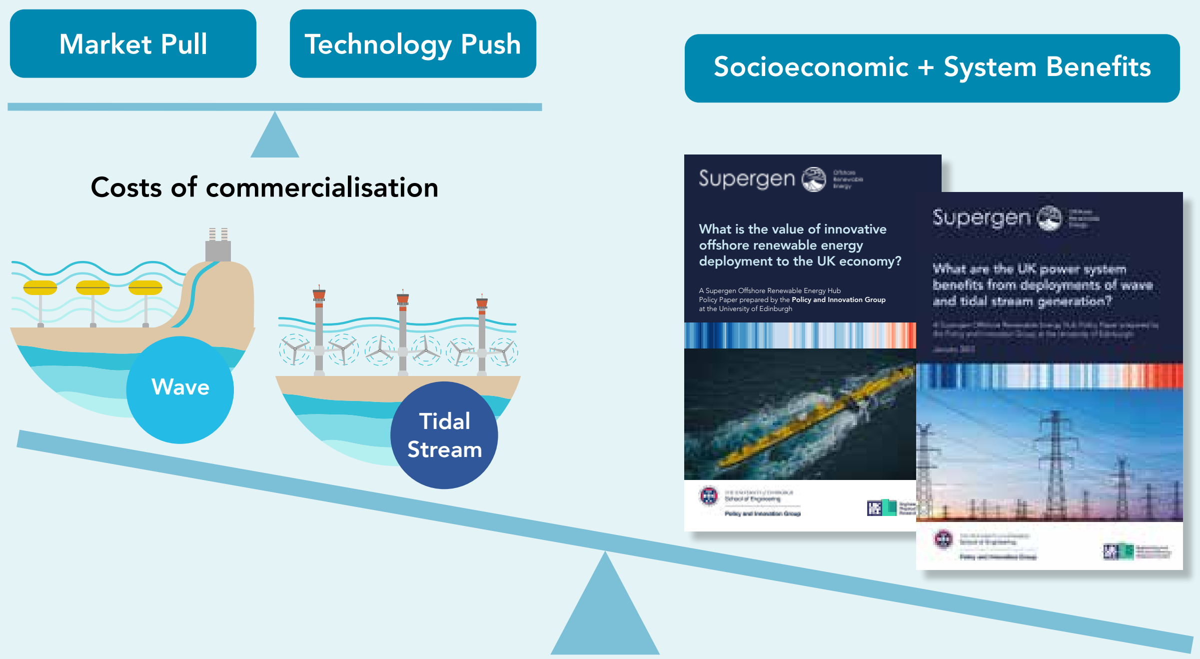


Figure 7 – Striking the balance between the costs of commercialisation and the benefits to society

The following section will evaluate the associated costs of policy implementation for both consumer and taxpayer, the overall effectiveness of existing policies in shaping the UK's wave and tidal sectors and how our level of national investment compares to the levels of wave and tidal stream sector funding in the EU.

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

Supergen Offshore Renewable Energy

Technology Push Policy Support: 2017–2022

Technology push mechanisms are designed to support innovation at the early stage of technology development. Technology push mechanisms exist mainly in the form of capital grants provided by public funding with the aim of driving down the energy generation cost through innovation. Many technology push policy levers are implemented with a direct goal of increasing the technological maturation of a given technology, described as its technology readiness level (TRL), at an accelerated rate. This can help to foster innovation, incentivising SMEs to grow, develop and refine their technology, ultimately driving it towards commercialisation. A lack of technology push policies at the nascent developmental stages is often cited as a reason for eventual over-spend on public investment in market pull policies.

The following section will look at how, in recent years, technology push policies have been used to support the wave and tidal stream sectors, with a comparison between the amounts of funding offered by the UK government and the amount of funding received from the EU.

Between 2017 and 2022, the total value of the support given to the wave and tidal sectors in the form of technology push funding in the UK amounted to £315 million, as shown in Table 1:

- £74 million is provided via domestic innovation funding, of which £44 million is provided by the Scottish government, primarily via Wave Energy Scotland;
- The remaining £241 million is provided by the EU through collaborative funding programmes, where the amount stated is the value received by UK organisations.

Table 1 – Breakdown of total funding across the wave and tidal stream sectors 2017-2022 [9], [10], [11], [12], [13], [14]

Funding Country	Main Funding Bodies and Programmes	Total funding (Wave and Tidal Stream)
UK	Innovate UK	**Total UK funding: £74 million** **Breakdown:** £57 million for wave £17 million for tidal stream
	EuropeWave	
	Wave Energy Scotland (WES)	
	Engineering and Physical Science Research Council (EPSRC)	
	Scottish Government	
	UK & Welsh Government	
	Welsh Government	
	British Council	
	Energy Entrepreneurs Fund	
EU[1]	Horizon 2020	**Total funding from EU to UK: £241 million** **Breakdown:** £107 million for wave £134 million for tidal stream
	European Regional Development Fund (ERDF)	
	European Social Fund (ESF)	
	European Maritime and Fisheries Fund (EMFF)	
	European Innovation Council (EIC)	
	Horizon Europe (HEU)	
UK & EU		**£315 million**

[1] Conversion rate (calculated as an average single value between 2017 and 2022) of €1.00 = £0.88 used in all European currency value conversions in Table 1

To provide some perspective to these figures, the £74 million invested by the UK government in technology push policy support is about 30% of the value received via EU funding (£241 million).

The breakdown of the total levels of technology push funding for both wave and tidal stream sectors can be seen in Figure 8 and Figure 9 below:

Wave

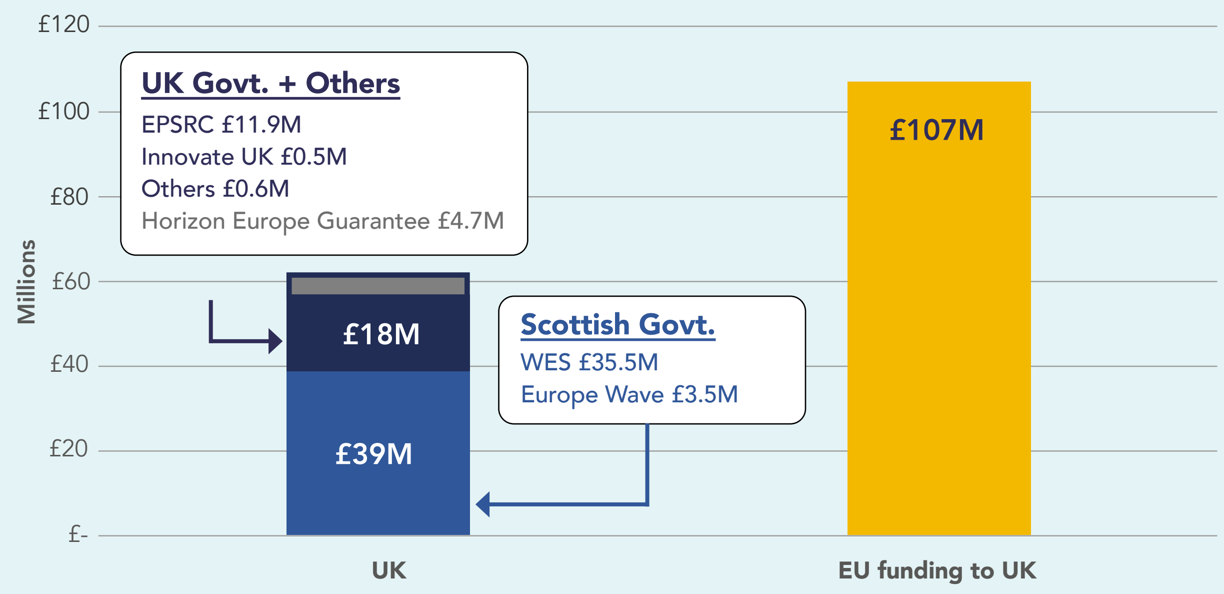


Figure 8 – Breakdown of funding for the wave sector

Tidal Stream

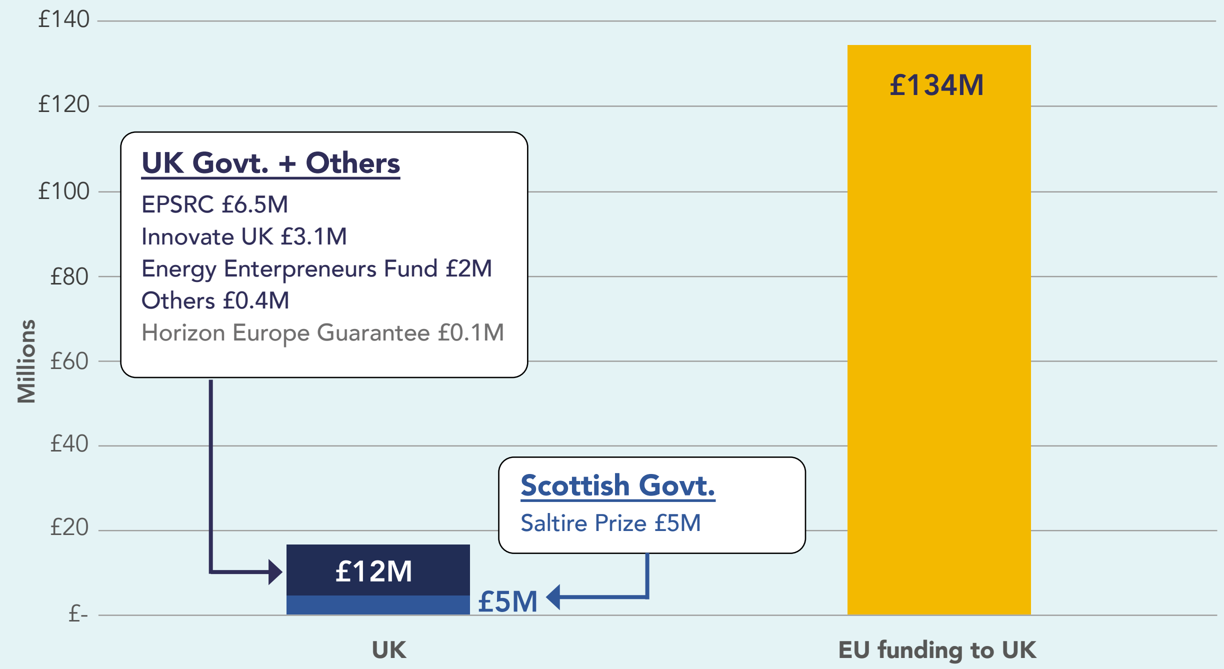


Figure 9 – Breakdown of funding for the tidal stream sector

It is also important to highlight that between 2017 and 2022, the majority of domestic funding for the wave and tidal stream sectors, around £53 million out of the £74 million that was being spent in the UK, was focussed primarily on projects at medium levels of TRL in areas such as testing and demonstration, as shown in Figure 10. It is also important to note that a huge proportion of this UK funding, around £44 million, came directly from the Scottish Government, primarily via Wave Energy Scotland. Of the remaining £28 million worth of funding provided by the UK government (mainly through EPSRC and Innovate UK), the majority is focussed on early stage innovation and underpinning science at low TRL, which may be insufficient in driving sustained technological innovation for both the wave and tidal stream sectors, shown in Figure 10.

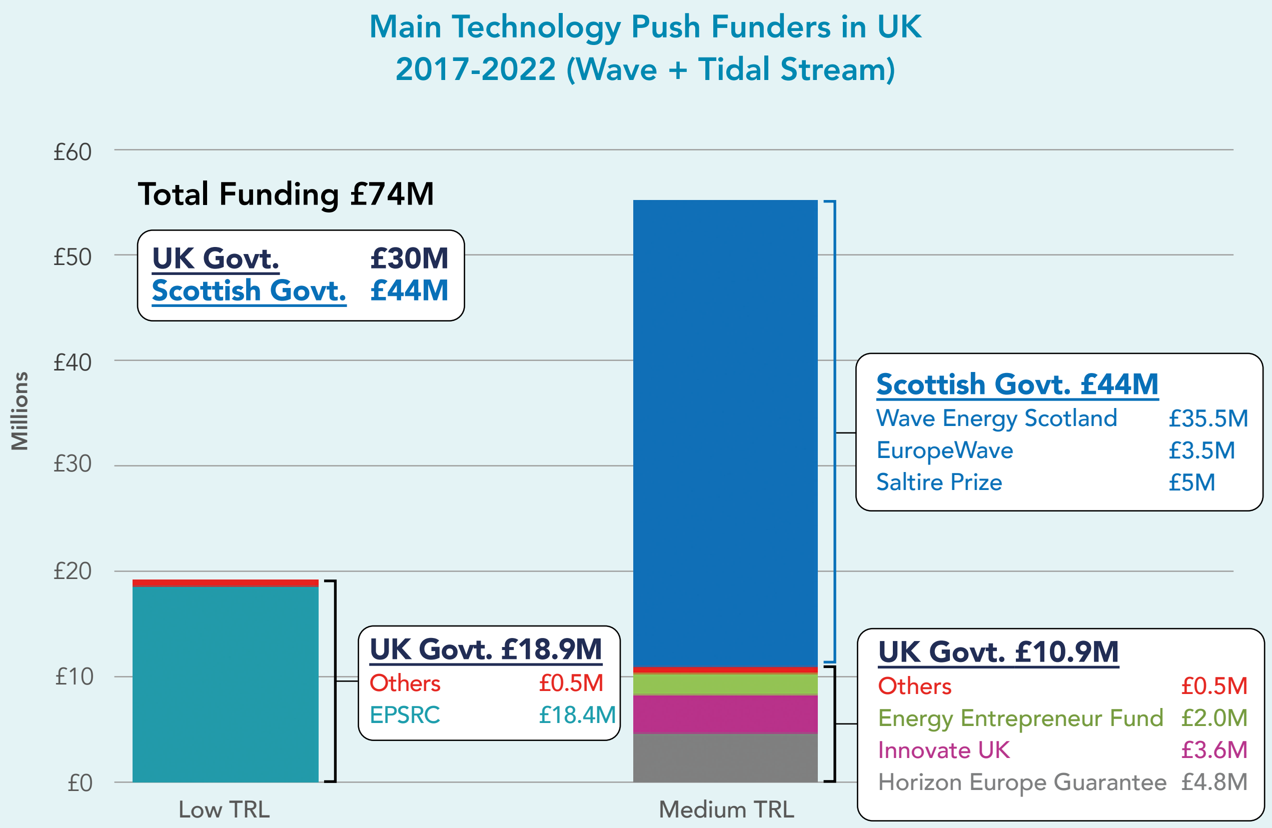


Figure 10 – Breakdown of funding allocation for both wave and tidal stream

Key Message 2 – Existing Technology Push Support

Between 2017 and 2022 total funding to support technology push policies specific to the wave and tidal stream sectors in the UK amounted to **£315 million**. However, approximately only 23% **(£74 million)** of this came from domestic sources of funding, with **£44 million** coming directly from the Scottish Government initiatives (Wave Energy Scotland, EuropeWave and the Saltire Prize), concentrating predominantly on medium TRL status projects. The remaining **£28 million** of domestic funding is provided by the UK government, with the bulk of this coming in the form of EPSRC funding to the SuperGen programme.

There is a clear opportunity for the UK government to invest more heavily in technology push funding that focusses on early stage innovation (low TRL status) to drive technology innovation, ultimately helping to advance wave energy technology towards accessing market pull mechanisms and accelerating the cost reduction of tidal stream technology.

Market Pull Policies: 2002 – Present

Market pull mechanisms are policies designed to accelerate the commercialisation of technologies by providing revenue support for renewable electricity generation projects. This steady stream of revenue, usually an agreed price to be paid to renewable electricity generators per unit of electricity generated (£/MWh) for an agreed period of time (e.g. 15-20 years), reduces financing costs and project risks, creating a more investor friendly market for emerging renewable energy technologies. Market pull policies are designed to reward successful innovation and provide consumer-led demand for technology or services, thus helping to create a market. For there to be marked progress in this area, there has to be strong collaboration between government bodies, technology developers and regulatory bodies. In instances where market pull policies are left unguided or without careful oversight, there can be price or even technological stagnation, where the incentive to develop radical new technology or continue cost reductions is reduced. There is also a key role for market interventions in ensuring that emerging renewable technologies, such as wave and tidal stream, are considered for commercial deployment and enabled to bring their anticipated system benefits into the energy mix.

There are a range of market pull policy support mechanisms that can be implemented in different ways to offer targeted support to specific areas of the wave and tidal stream sectors. Market pull mechanisms implemented within the UK in the past are listed below:

- Non-Fossil Fuel Obligation (NFFO): 1990-1998
- **Renewables Obligation (RO): 2002-2017**
- Marine Renewable Deployment Fund (MRDF): 2007-2011
- Wave and Tidal Energy Scheme (WATES, Scotland): 2006-2008
- Marine Supply Obligation (MSO, Scotland): 2007-2009
- **Contracts for Difference (CfD): 2014 - Present**

This section will provide an overview on Renewables Obligation and Contracts for Difference, two market pull policies that are currently ongoing in the UK, and examine the role they play in supporting the wave and tidal sectors domestically.

Renewables Obligation (RO)

The Renewables Obligation (RO) [15] ran from 2002 until 2017 and aimed to provide incentives for the deployment of large-scale renewable electricity generation in the UK under the Electricity Act 1989. The RO requires licensed UK electricity suppliers to source a specified proportion of the electricity they provide to customers from eligible renewable sources. Electricity suppliers purchase Renewables Obligation Certificates (ROCs) issued by Ofgem from eligible renewable electricity generators at a premium in addition to the wholesale electricity price. Suppliers then present the ROCs to Ofgem to demonstrate compliance. When suppliers fail to fulfil their obligation, they must pay the penalty known as 'buy-out-price', which will be redistributed on a pro-rata basis to suppliers who presented ROCs. Renewable electricity generators receive RO support for 20 years from the date of accreditation. The RO scheme was closed to new applications in March 2017.

In order to further promote the wave and tidal industry, the UK government introduced an enhanced RO banding to increase the number of wave and tidal stream projects supported by ROCs. Where typical renewable energy projects were offered a single ROC/MWh, wave and tidal stream were offered an enhanced 5 ROCs/MWh between 2013 and 2017 [16], [17]. As of October 2021, 14MW of tidal stream and 3MW of wave power had received accreditation under the RO scheme [18].

- In 2022, only three of the tidal stream projects, shown in Figure 11, are currently generating electricity, with a total capacity of 8.7MW
- As of 2022, none of the wave power projects are currently generating electricity

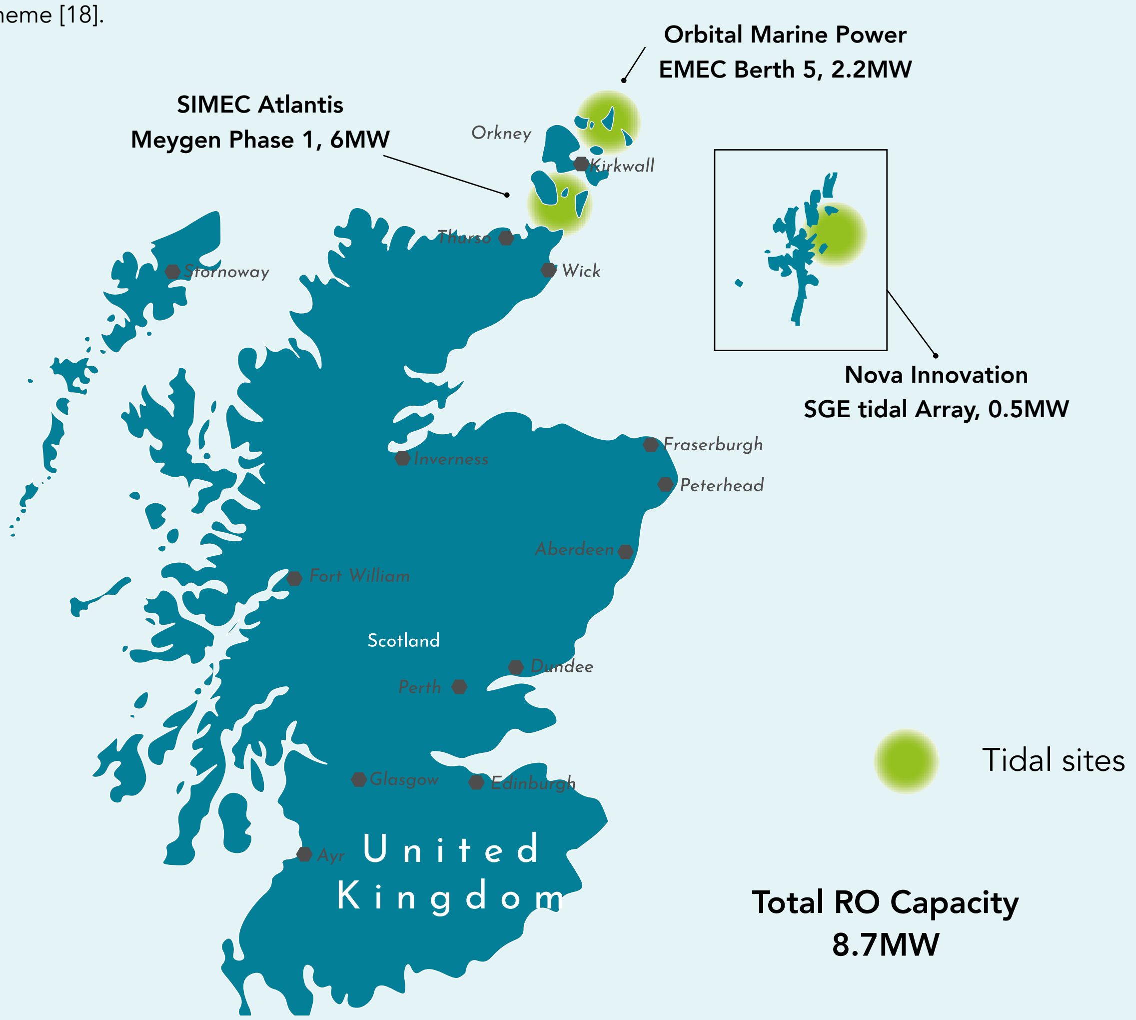


Figure 11 - Location and installation capacities of tidal stream projects supported by Renewables Obligations (RO)

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

Contracts for Difference (CfD)

The Contracts for Difference (CfD) [19] scheme, running from 2014 to present day, is the UK government's flagship programme for supporting the generation of low-carbon electricity. Based on top-up payments between a wholesale market reference price and a strike price, CfDs offer long-term price stabilisation and are awarded via competitive auctions. The CfD scheme incentivises investment in renewable energy by providing developers of renewable energy projects, normally projects with high upfront costs and long lifetimes, protection from volatile wholesale prices.

To date, there have been four Allocation Rounds (AR) which have seen a number of different renewable energy technologies compete in auctions for a contract. Historically ocean energy technologies have struggled to gain a CfD through the competitive auction process, primarily because they have been in the same CfD 'pot' as established, mature technologies such as offshore wind. However, following on from the government's decision in 2021 that there would be a separate £20 million ring-fenced fund available solely for the tidal stream sector, AR4 has delivered a major milestone, with four CfD contracts being awarded to tidal energy projects, shown in Figure 12.

In this most recent CfD auction round, a total capacity of **40.82MW** of tidal energy were granted CfDs at a strike price of $£_{2012}$178.54/MWh:

- Orbital Marine Power won two separate CfDs totalling 7.2MW for tidal energy deployments at EMEC's Fall of Warness site;
- SAE Renewables secured 28MW to further develop the MeyGen tidal array;
- Magallanes Renovables was awarded 5.62MW for a tidal energy project located at the Morlais Project in Wales

This report will provide an overview on Renewables Obligation and Contracts for Difference, two market pull policies that are currently ongoing in the UK, and examine the role they play in supporting the wave and tidal sectors domestically.

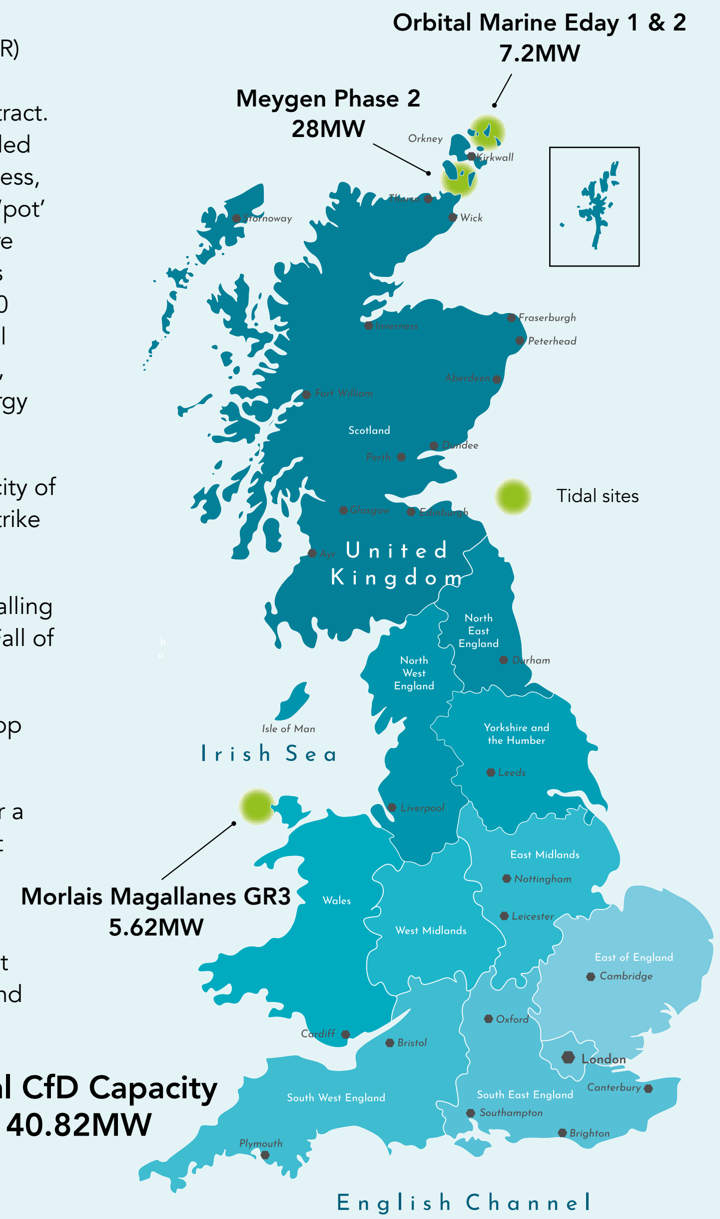


Figure 12 - Location and installation capacities of tidal stream projects supported by Contracts for Difference (CfD)

In December 2022, the parameters of AR5 were set with plans to move from three auction pots to two, reflecting the success of the CfD scheme in helping to bring down the cost of offshore wind, which was previously in its own auction pot (Pot 3). There will now be an auction pot reserved for established technologies (Pot 1), and a second auction pot reserved for less established technologies (Pot 2), such as wave and tidal stream. In AR5, the administrative strike price for tidal stream energy projects has been set at $£_{2012}$202/MWh, while wave energy projects have been given an administrative strike price of $£_{2012}$245/MWh [20].

Key Message 3 – Existing Market Pull Policy Support

From 2002 until 2017, the implementation of the Renewables Obligation (RO) market pull mechanism has **successfully delivered 8.6MW of tidal stream capacity**. From 2014 to present day, the Contracts for Difference (CfD) market pull mechanism has provided targeted support to the tidal sector and has **contracted an initial 40.82MW of generative capacity** at a strike price of **£$_{2012}$178.54/MWh**. During the same period no wave energy devices have been deployed as a result of the same market pull policies.

In order to ensure that the wave and tidal stream sectors continue to play a significant role in achieving the UK governments ambitious net-zero target, long-term market pull policy support mechanisms, **such as the continuation of the CfD scheme**, are crucial.

SECTION 2 OVERVIEW: REVIEW OF EXISTING POLICY SUPPORT

This section has outlined the Net Zero, socioeconomic and power system benefits that the UK could expect to experience as a result of the deployment of 12GW of ocean energy by 2050. With estimates of **£11 billion - £41 billion in GVA** to the UK economy and a **reduction of £1 billion per annum in dispatch costs,** the underlying economic arguments for these deployment targets are clear and unambiguous.

This report also highlights that clear, evidence-based policy interventions are a vital tool in ensuring that the UK fosters the conditions required for accelerated innovation in the ocean energy sector and delivers on deployment forecasts. As shown in the breakdown of the technology push policy figures, only £74 million of the total £315 million worth of money invested into innovation between 2017 and 2022, currently comes from domestic sources of funding. Across the technology push landscape, there **needs to be a rapid increase in the level of investment offered by UK government** to support innovation for developers at low and high TRL status ultimately helping to advance wave energy technology towards accessing market pull mechanisms and accelerating the cost reduction of tidal stream technology.

This is vital to ensure that innovation translates not only into the demonstration and improvement of sub-systems and prototype wave and tidal devices, but advances to full-scale deployment in real-sea conditions. Market pull mechanisms such as the CfD, will provide vital, long-term financial support to the wave and tidal stream sectors and it is essential that they continue to offer targeted and accessible funding. Finally, to ensure that the UK remains the leading nation in the development and deployment of wave and tidal stream technologies, **it is critical that policy funding scales at the required rate.**

To date, a combination of technology push and market pull mechanisms has ensured that by 2027, the UK will have deployed a total of 49.52MW of tidal stream capacity. If the UK is to **achieve the GVA and system benefits associated with the deployment of 6GW of wave and 6GW of tidal stream by 2050**, continued policy support will be required, where the cost of sector commercialisation is balanced against the socioeconomic benefit. Additionally, bold and decisive policy support strategies could also **result in the delivery of exceptional gains to the UK export economy** if inroads are made into both global supply chains and the international wave and tidal stream market.

The following sections aim to establish the optimum combination of technology push and market pull funding mechanisms required to deliver a proposed target of 6GW of wave and 6GW of tidal stream, while incurring minimum costs to the consumer and taxpayer.

3 MARKET PULL ANALYSIS

Orbital O2 operating at EMEC test site in Orkney (Source: Orbital Marine Power)

Introduction to Future Energy Scenarios

The second half of this report will present analysis on a series of future energy scenarios, outlining how the socio-economic benefits associated with an increased deployment of wave and tidal stream technologies can be realised, at minimum cost to the consumer and taxpayer. It will also examine the interactions between technology push and market pull policy mechanisms and whether a balance can be struck that allows the delivery of a cost effective policy programme that supports the accelerated expansion of the sector.

Future Energy Scenarios: Market Pull Policy Analysis

The following analysis will focus on the total market pull investment, achieved through the continued use of the CfD scheme, necessary to realise 6GW of wave and 6GW of tidal stream by 2050 where the future wave and tidal stream energy generation costs achieve eventual parity with wholesale market price[3]. As literature on the actual energy generation cost of both wave and tidal stream is scarce, primarily due to the lack of long term energy generation data for the sector, this report uses the strike price value of the CfD as a proxy for energy generation costs and the CfD award year as a reference of time. The following variables will be assessed:

- Cost reduction rate - the learning rate, generally defined as the percentage reduction in cost associated with a doubling of installed capacity [21];
- Delayed cost reduction – at what year, relative to the new CfD auction rounds, does consistent cost reduction occur?

The impact that these variables have on the cost-effective deployment of tidal stream and wave technologies will be assessed in the following scenarios:

Shetland tidal array deployment (Source: Nova Innovation)

[3] The electricity WMP uses 2023 – 2040 projections sourced from BEIS [22] and extrapolates from 2040 to 2050 based on trends outlined in the EU Energy Outlook 2060 article [23].

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

Future Tidal Stream Energy Scenario Analysis

Our analysis will initially look at how market pull policy mechanisms can drive down the generation cost of tidal stream and aid the sector in reaching the forecasted deployment capacity of 6GW by 2050 as a result of steady and supported cumulative deployment,[4] as shown in Figure 13.

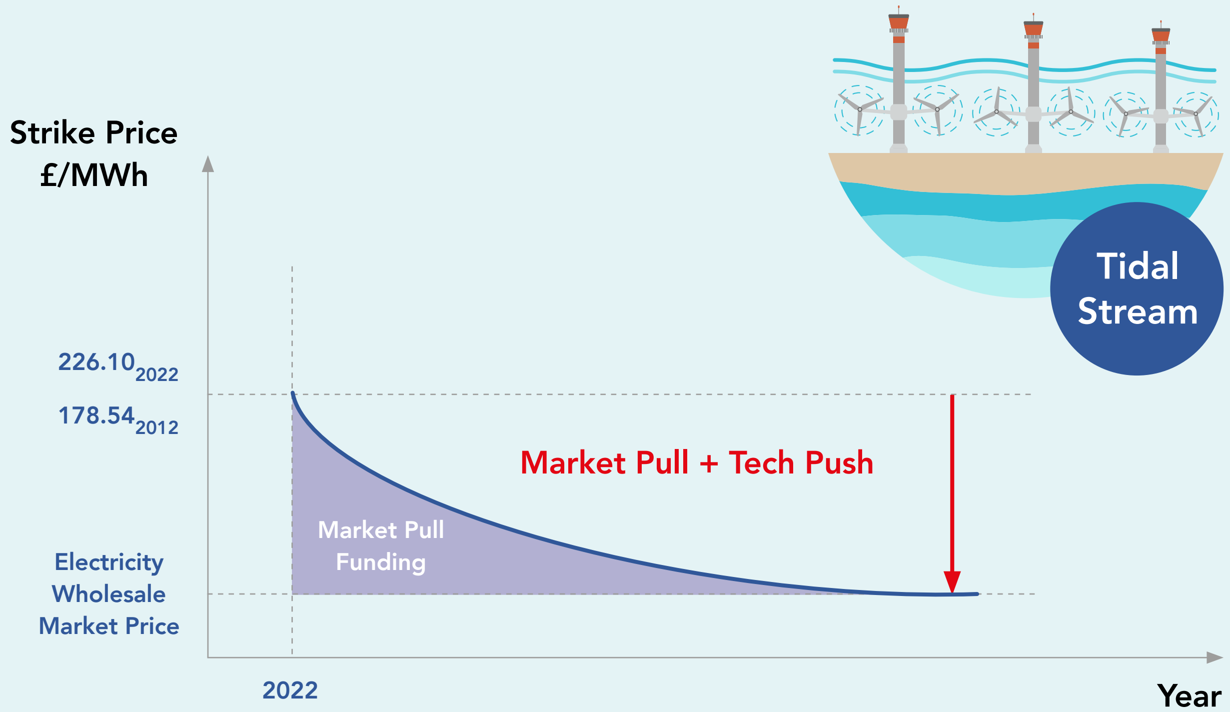


Figure 13 – Parameters for tidal stream analysis

Tidal Stream: Cost Reduction Rate Scenario Analysis

The first section of our future energy scenario for tidal stream examines the impact of learning rate on strike price reduction. The learning rate is considered to be a combination of technology push (learning by innovation) and market pull (learning by doing), that leads to an overall cost reduction. Three different learning rates were assumed in our scenario:

- 10% - a sub-optimal learning rate;
- 15% - a preferred and realistic learning rate;
- 20% - a highly ambitious learning rate.

The impact of these learning rates, quantified by how quickly they help to drive down the CfD strike price of the tidal stream sector to achieving parity with electricity wholesale market price (WMP), are shown in Figure 14. (overleaf).

[4] This analysis uses the strike price of tidal stream projects in CfD Allocation Round 4, $£_{2012}$178.54/MWh as a starting point as shown in Figure 13. This strike price is inflated to $£_{2022}$226.10/MWh using the Consumer Price Index [24], and this price is used throughout subsequent tidal stream analysis.

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050
Supergen Offshore Renewable Energy

Tidal Stream Strike Price Trend 6GW by 2050

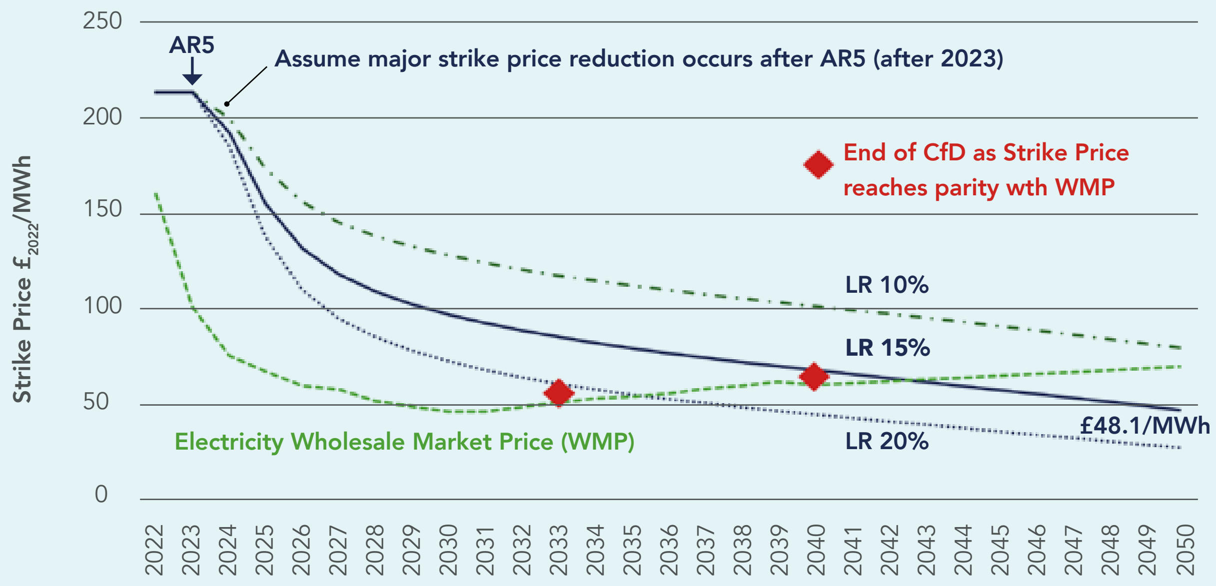


Figure 14 – Strike price trend associated with achieving 6GW of tidal stream by 2050

Total Market Pull Investment for Tidal Stream 6GW by 2050

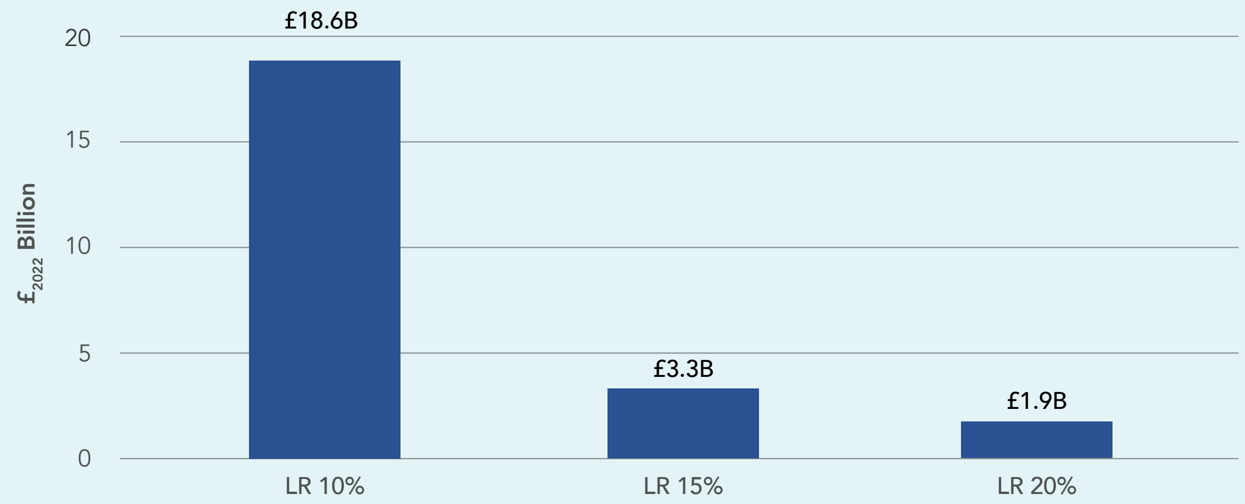


Figure 15 – Total cost of achieving 6GW of tidal stream deployment by 2050 at different learning rates

In this scenario the strike price remains the same for both AR4 and AR5, as shown in Figure 14, before experiencing major cost reductions in subsequent years. Our scenario analysis indicates:

- That a 20% learning rate will result in the tidal stream sector achieving market parity at around 2033, the earliest year under all three learning rate scenarios that analysis indicates this can be achieved;
- That at a 15% learning rate, market parity will be achieved at around 2040.

Both of these learning rates will result in continued reductions in the strike price of tidal stream, driving it below the WMP and most importantly showing that it is possible to achieve market parity before 2050, the current deadline set for the UK to achieve net-zero.

At a lower learning rate of 10% (i.e. the scenario with the most limited technology push funding equating to a slower rate of progress in technology innovation), the sector will be unable to achieve parity with WMP before 2050, prolonging the need for sustained financial support from market pull policy mechanisms such as the CfD, making this the most unattractive option.

As illustrated in Figure 15, the 6GW of tidal stream capacity projected by 2050 can be achieved with all three learning rate assumptions. However, this achievement comes at vastly different costs.

At a learning rate of 15%, considered to be a preferable and more realistic scenario, around £3.3 billion worth of CfD investment is required to achieve the forecasted 6GW of tidal stream deployment. At a higher learning rate of 20%, considered the most ambitious scenario in our analysis, the total investment is further reduced to around £2 billion.

A scenario with either of these learning rates will allow the CfD policy support mechanism to end when the strike price achieves parity with WMP, removing the need for continued CfD subsidy of tidal stream energy generation.

In comparison, a learning rate of 10% requires a total CfD investment of around £18.6 billion. In this scenario, it is likely that policy makers would realise the limited effectiveness of their intervention and withdraw financial support as it becomes clear that the sector would not be able to generate electricity at a cost effective rate.

This analysis underlines that technology push funding for innovation of tidal stream technology greatly impacts the total investment required via market pull funding.

Tidal Stream: Delayed Cost Reduction Scenario Analysis

The second section of our future energy scenario for tidal stream examines the implications of delaying the point at which cost reduction, achieved through a combination of learning by doing and technology innovation at a given learning rate, starts. In this scenario a learning rate of 15% is assumed and cost reduction occurs:

- After AR4 – immediate cost reduction;
- After AR5 – cost reduction delayed by one year;
- After AR6 – cost reduction delayed by two years;
- After AR7 – cost reduction delayed by three years.

Figure 16 shows how delaying the point at which the strike price starts to reduce, when associated with a given learning rate, can impact the point at which parity with the WMP is achieved and alter the total levels of required investment.

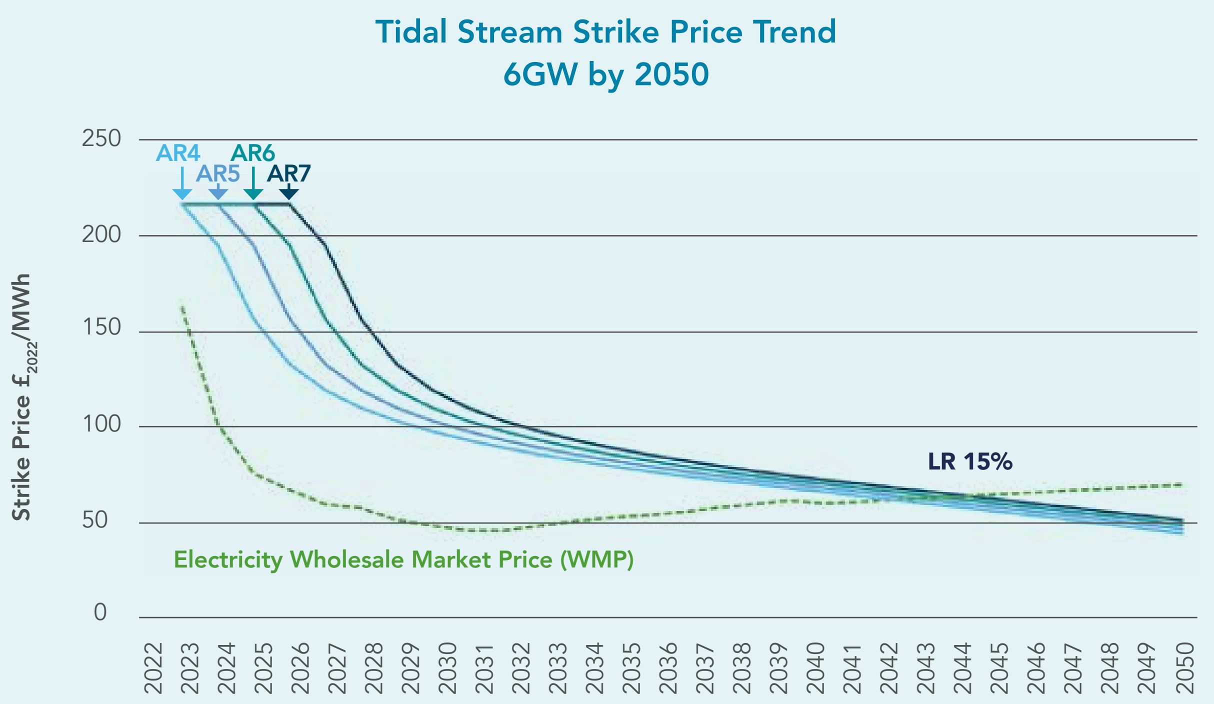


Figure 16 – Strike price trend associated with achieving 6GW of tidal stream by 2050 when there are delays to cost reduction at a 15% learning rate

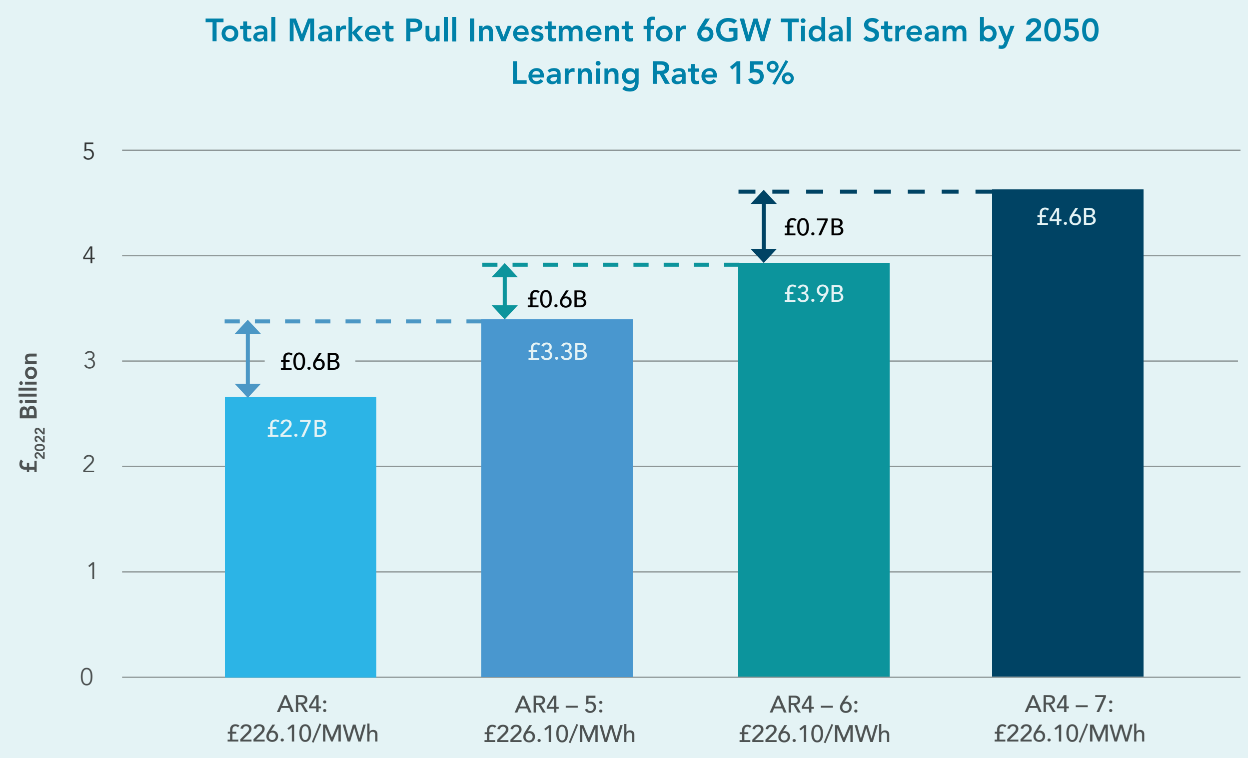


Figure 17 – Total additional market pull investment required for 6GW of tidal stream where cost reductions are delayed annually

The total market pull investment required to achieve 6GW of tidal stream energy capacity by 2050 at a learning rate of 15% is shown in Figure 17.

Figure 17 also demonstrates that when innovation is applied to the tidal stream sector at the earliest opportunity, in this case price reduction occurs immediately after AR4 (at AR5), the overall cost of CfD investment is at its lowest, £2.7 billion.

If this is delayed by one year i.e. the strike price remains the same for both AR4 and AR5 and so only reducing at AR6, the cost of CfD investment increases to £3.3billion. If it is again further delayed by a further year to AR7, the associated cost is £3.9 billion. Finally, if it is delayed an additional year, until AR8, the overall cost of CfD investment is £4.6 billion.

In this scenario, a delay in the strike price cost reduction will result in subsequent increased total investment at an average rate of approximately £0.6 billion per year of delayed cost reduction. As a result, the cost of inaction compounds over time and the associated socioeconomic benefits are offset by the greater cost to realising them.

However, this financial penalty is much smaller than that incurred by a reduced learning rate, as shown in the Tidal Stream: Cost Reduction Rate Scenario Analysis.

Key Message 4 – Tidal Stream Sector Market Pull Funding Analysis

Our analysis has shown that technology push funding, which drives technology innovation, greatly affects the overall market pull funding required for tidal stream deployment in the following aspects:

- A higher learning rate (achieved through increased technology push funding) provides greater overall cost reductions and significantly reduces the total investment required to support market pull polices such as the CfD scheme. In our scenario, increasing the learning rate from 10% to 15% reduced the total investment required in the tidal stream sector from **£18.6 billion to £3.3 billion**; an increase from 15% to 20% further reduced the required investment in the tidal stream sector to **£1.9 billion**;
- The immediate application of technology innovation fueled by technology push funding allows the tidal stream sector to enable faster cost reductions and lower the strike prices offered in subsequent CfDs. This can lead to savings of approximately **£0.6 billion per year** of non-delay in the consistent cost reductions associated with the total funding required for market pull investments. This is a modest amount in comparison to the savings associated with the adoption of a 15% or 20% learning rate instead of a sub-optimal learning rate of 10%.

Future Wave Energy Scenario Analysis

Our analysis will now look at how market pull policy mechanisms can drive down the generation cost of wave energy and aid the sector in reaching the forecasted deployment capacity of 6GW by 2050 as a result of steady and supported cumulative deployment. Our modelling assumes that the **technological maturity levels of the wave sector are five years behind that of the tidal stream sector[5].** Therefore, a further five years of innovation through technology push funding, achieved through a similar approach to the Wave Energy Scotland innovation programme, will be required from now until 2027 for the sector to reach comparable levels of technological maturity with the tidal stream sector. This should enable it to bid successfully into market pull mechanisms, such as the CfD, around 2027.

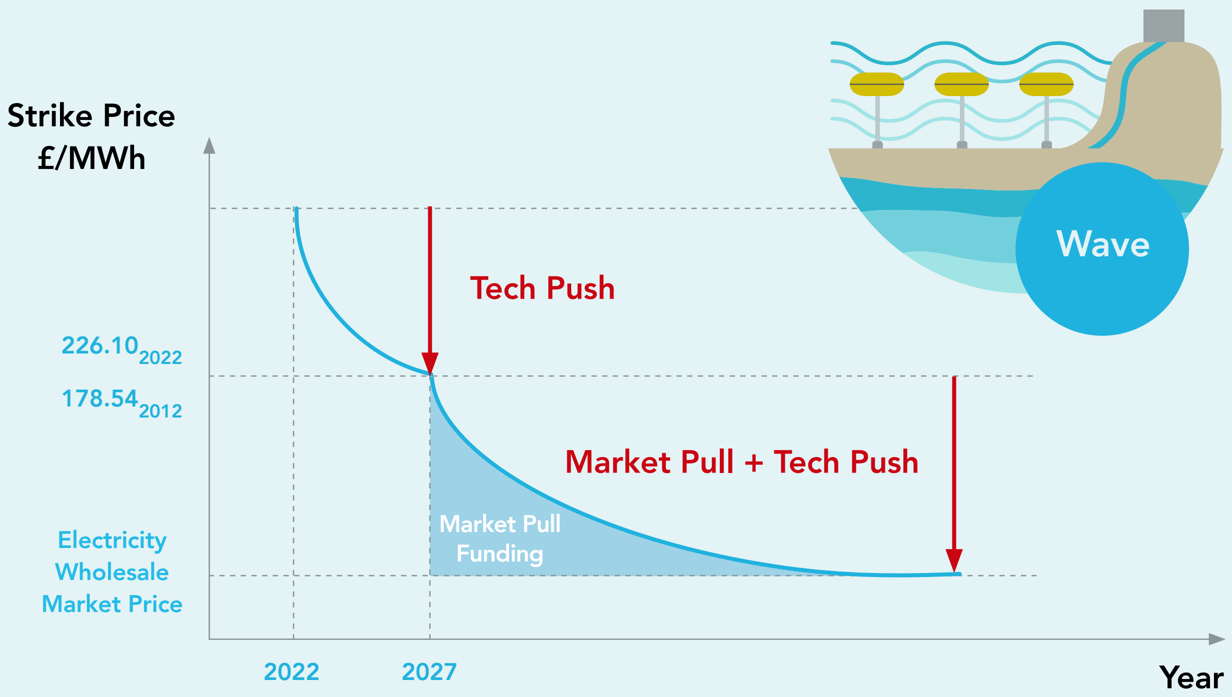


Figure 18 – Parameters for wave analysis

[5]This analysis uses a predicted strike price for wave projects in CfD Allocation Round 9 of £$_{2012}$178.54/MWh as a starting point, shown in Figure 18. This strike price is inflated to £$_{2022}$226.10/MWh using the Consumer Price Index. This price is used throughout subsequent wave analysis

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

Wave: Cost Reduction Rate Scenario Analysis

The first section of our future energy scenario for wave examines the impact of learning rate on strike price reduction. The learning rate is considered to be a combination of technology push (learning by innovation) and market pull (learning by doing), that leads to an overall cost reduction. Three different learning rates were applied to our scenario:

- 10% - a sub-optimal learning rate;
- 15% - a preferred and realistic learning rate;
- 20% - a highly ambitious learning rate.

The impact of these learning rates, quantified by how quickly they help to drive down the CfD strike price of the wave sector to achieving market parity with wholesale market prices (WMP), are shown in Figure 19.

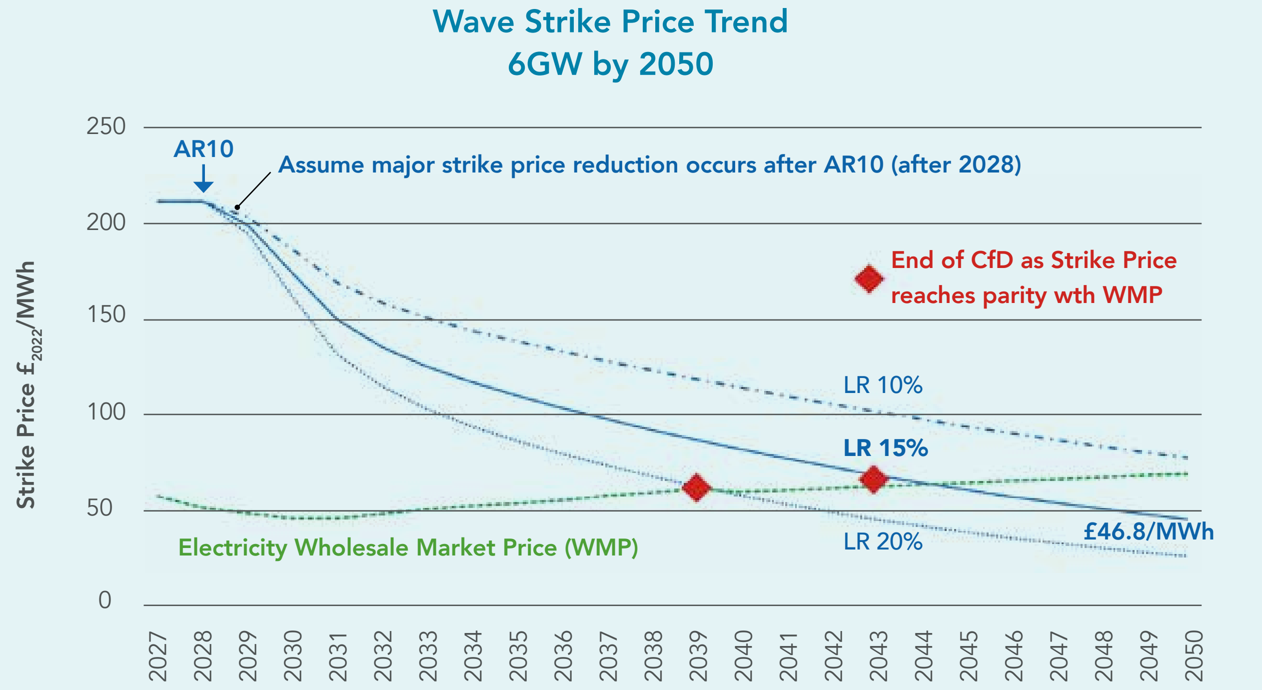


Figure 19 – Strike price trend associated with achieving 6GW of wave by 2050

In this scenario the strike price remains the same for both AR9 and AR10, before experiencing major cost reductions in subsequent years. Our scenario analysis indicates:

- That a 20% learning rate will result in the wave sector achieving market parity at around 2039, the earliest year under all three learning rate scenarios that analysis indicates this can be achieved;
- That at a 15% learning rate, market parity will be achieved at around 2043.

Both of these learning rates will result in continued reductions in the strike price of wave, driving it below the WMP and most importantly showing that it is possible to achieve market parity before 2050, the current deadline set for the UK to achieve net-zero.

At a lower learning rate of 10% (i.e. the scenario with the most limited technology push funding equating to a slower rate of progress in technology innovation) the sector will be unable to achieve parity with WMP before 2050, prolonging the need for sustained financial support from market pull policy mechanisms such as the CfD, making this the most unattractive option.

Total Market Pull Investment for Wave 6GW by 2050

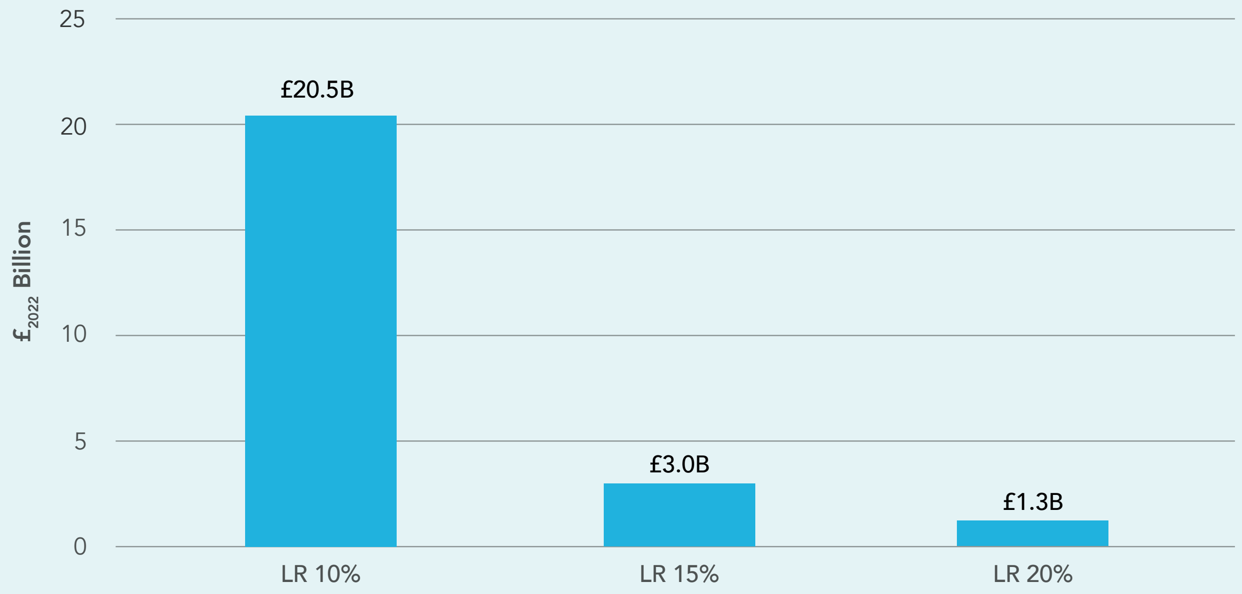


Figure 20 – Total cost of achieving 6GW of wave deployment by 2050 at different learning rates

As illustrated in Figure 20, the 6GW of wave capacity projected by 2050 can be achieved with all three learning rate assumptions. However, this achievement comes at vastly different costs.

At a learning rate of 15%, considered to be a preferable and more realistic scenario, around £3.0 billion worth of CfD investment is required to achieve the forecasted 6GW of wave deployment. At a higher learning rate of 20%, considered the most ambitious scenario in our analysis, the total investment is further reduced to around £1.3 billion.

A scenario with either of these learning rates will allow the CfD policy support mechanism to end when the strike price achieves parity with WMP, removing the need for continued CfD subsidy of wave energy generation.

In comparison, a learning rate of 10% requires a total investment of around £20.5 billion. In this scenario, it is likely that policy makers would realise the limited effectiveness of their intervention and withdraw financial support as it becomes clear that the sector would not be able to generate electricity at a cost effective rate.

This analysis underlines that technology push funding for innovation of wave technology greatly impacts the total investment required via market pull funding.

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

Wave: Delayed Cost Reduction Scenario Analysis

The second section of our future energy scenario for wave examines the implications of delaying the point at which cost reduction, achieved through a combination of learning by doing and technology innovation at a given learning rate, starts. In this scenario a learning rate of 15% is assumed and cost reduction occurs:

- After AR9 – immediate cost reduction;
- After AR10 – cost reduction delayed by one year;
- After AR11 – cost reduction delayed by two years;
- After AR12 – cost reduction delayed by three years.

Figure 21 shows how delaying the point at which the strike price starts to reduce, when associated with a given learning rate, can impact the point at which parity with the WMP is achieved and alter the total levels of required investment.

Wave Strike Price Trend 6GW by 2050

Figure 21 – Strike price trend associated with achieving 6GW of wave by 2050 when there are delays to cost reduction at a 15% learning rate

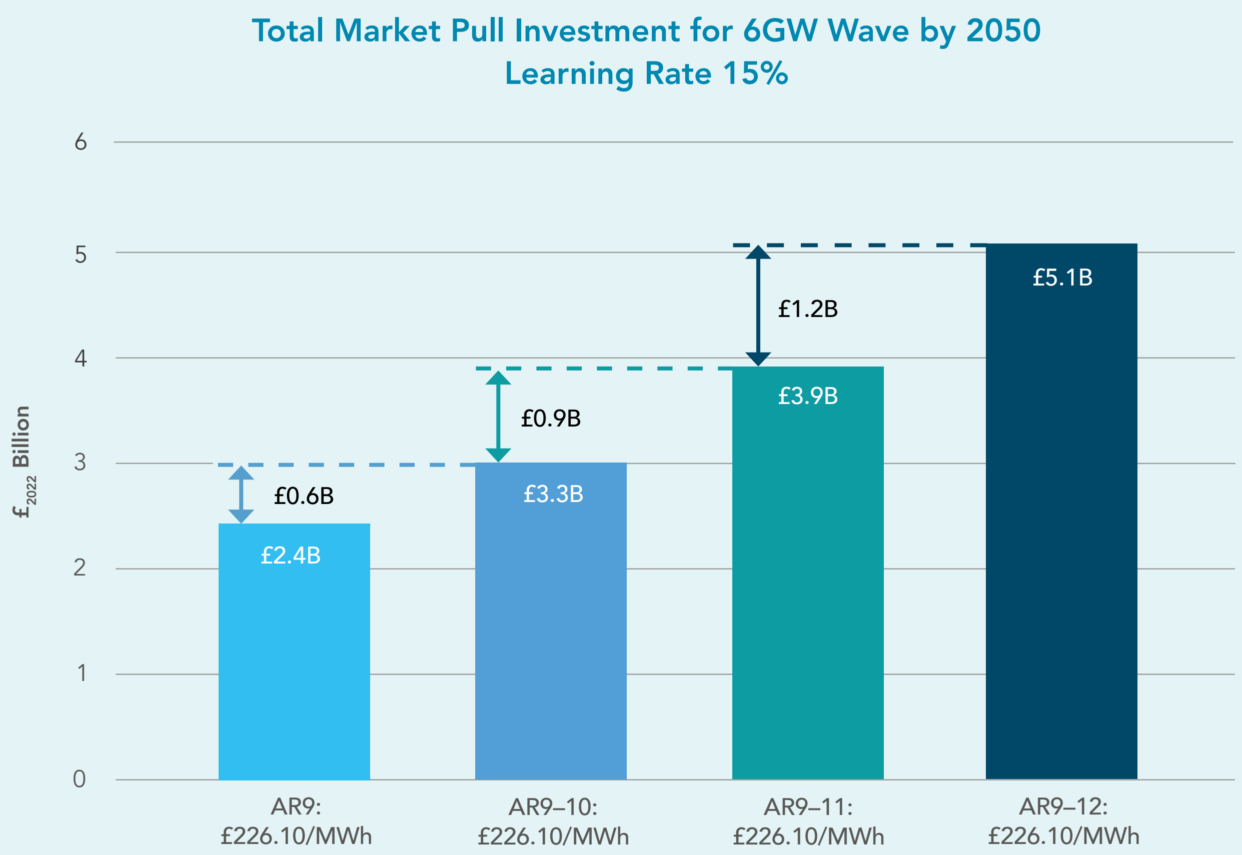


Figure 22 – Total additional market pull investment required for 6GW of wave where cost reductions are delayed annually

The total market pull investment required to achieve 6GW of wave energy capacity by 2050 at a learning rate of 15% is shown below in Figure 22.

Figure 22 also demonstrates that when innovation is applied to the wave sector at the earliest opportunity, in this case price reduction occurs immediately after AR9 (at AR10), the overall cost of CfD investment is at its lowest, £2.4 billion.

If this is delayed by one year i.e. the strike price remains the same for both AR9 and AR10 and so only reducing at AR11 the cost of CfD investment increases to £3.0 billion. If it is again further delayed by a further year to AR12, the associated cost is £3.9 billion. Finally, if it is delayed an additional year, until AR13, the overall cost of CfD investment is £5.1 billion.

In this scenario, a delay in the strike price cost reduction will result in subsequent increased total investment at an average rate of approximately £0.9 billion per year of delayed cost reduction. As a result, the cost of inaction compounds over time and the associated socioeconomic benefits are offset by the greater cost to realizing them.

However, this financial penalty is much smaller than that incurred by a reduced learning rate, as shown in the Wave: Cost Reduction Rate Scenario Analysis.

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

Key Message 5 – Wave Sector Market Pull Funding Analysis

Our analysis has shown that technology push funding, which in turn drives technology innovation, greatly affects market pull funding for wave deployment in the following aspects:

- A higher learning rate (achieved through increased technology push funding) provides greater overall cost reductions and significantly reduces the total required to support market pull polices such as the CfD scheme. In our scenario, increasing the learning rate from 10% to 15% reduced the total investment required in the wave sector from **£20.5 billion to £3.0 billion**; an increase from 15% to 20% further reduced the required investment in the wave sector to **£1.3 billion**;
- The immediate application of technology innovation fueled by technology push funding allows the wave sector to enable faster cost reductions and lower the strike prices offered in subsequent CfDs. This can lead to savings of approximately **£0.9 billion per year** of non-delay in the consistent cost reductions associated with the total funding required for market pull investments. This is a modest amount in comparison to the savings associated with the adoption of a 15% or 20% learning rate instead of a sub-optimal learning rate of 10%.

Mocean Energy Blue X wave energy converter in operation at EMEC Scapa Flow test site (Source: Mocean Energy)

SECTION 3 OVERVIEW: MARKET PULL ANALYSIS

Section three of this report has demonstrated the impact that sustained market pull policy support, particularly the continued bidding and successful awarding of CfDs, can have in ensuring that the forecasted deployment targets of 6GW for wave and 6GW for tidal stream are met. However, section three has also outlined that future market pull policy support has to be underpinned with effective and targeted support for sectoral innovation, where increased learning rates provide the impetus for cost reductions to be enabled at an accelerated rate, lowering the overall financial investment required to achieve the deployment targets.

Analysis of future energy scenarios have shown that the level of market pull investment required at a 10% learning rate across both the wave and tidal stream sectors is **£39.1 billion**. By increasing the learning rate from 10% to 15%, it has been shown that this value can be reduced down to a new total of **£6.4 billion**. When the learning rate is further increased from 15% to 20%, it has been shown that this value can be reduced down to a new total of **£3.2 billion**. This represents a remarkable saving on overall investment, while still enabling the deployment of 6GW of wave and 6GW of tidal stream, as shown in Figure 23.

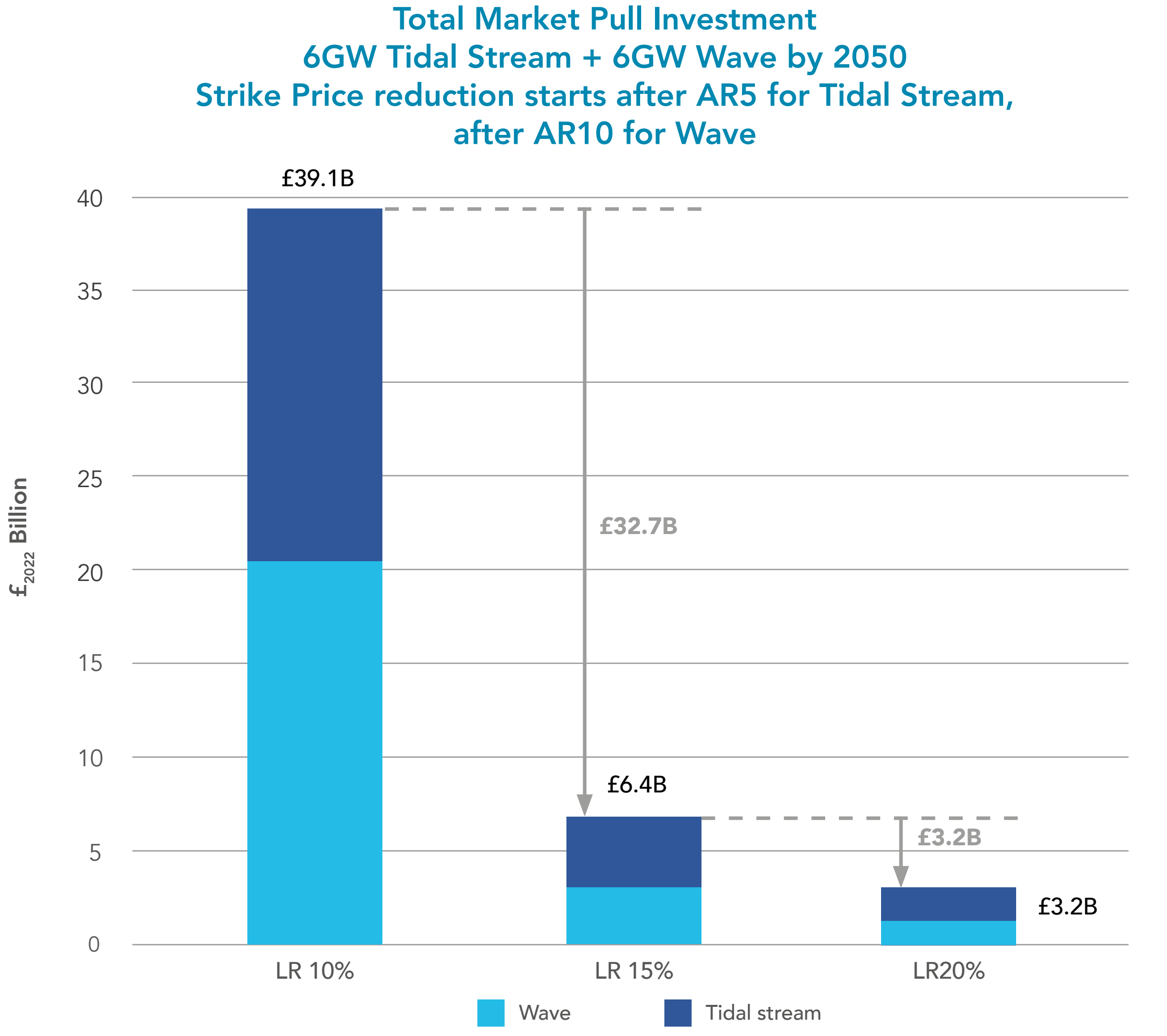


Figure 23 – Total market pull investment required at different learning rates

Additionally, our future scenario analysis has also highlighted the benefits of immediate cost reductions which amount to average savings of between **£0.6 billion** to **£0.9 billion** for each year where there is no delay to the cost reductions.

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

Section Three of this report has made clear that increasing overall cost reductions as a result of a higher learning rate through technology push funding is key to accelerating innovation and commercial deployment in both the wave and tidal stream sectors, at a minimal cost to the consumer and taxpayer. This outcome provides confidence that the cost of both wave and tidal stream energy can be reduced to a point of parity with that of the wholesale market price for electricity in the coming years and removes potential barriers preventing the sector form achieving commercialisation.

However, as has already been highlighted, the UK does not currently provide a comparable level of financial investment to support the technology push mechanisms required to deliver this innovation, in comparison to the funds received from the EU. Our analysis in section four will now look to provide an estimation of the total investment required in technology push policies if UK is to achieve deployment of 6GW of wave and 6GW of tidal stream at the least cost to consumer and taxpayer.

The AR1500 tidal turbine (Source: SAE Renewables)

4 TECHNOLOGY PUSH ANALYSIS

Fabrication Phase (Source: Orbital Marine Power)

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

Introduction to Technology Push Analysis

Section Four of this report will begin by providing a brief outline of technology push funding mechanisms, introducing a range of such documents that exist across the sector, identifying the key challenge areas that these documents seek to overcome. Section Four will then utilise two further scenarios for analysis:

- **Maximum Collaboration** – all the leading countries in the European wave and tidal stream sectors contribute to funding, as well as receiving collaborative funding from the European Commission;
- **Partial Collaboration** – a reduced number of leading countries in the European wave and tidal stream sectors contribute to funding, as well as receiving collaborative funding from the European Commission.

These scenarios will then provide estimations of the total investment required to underpin the technology push policy mechanisms required to deliver the deployment of 6GW of wave and 6GW of tidal stream at a learning rate of at least 15%.

Technology Push Development Areas

Technology push funding mechanisms are essential for the continued innovation of the ocean energy sector. Their implementation is predominantly financed through public funding and as such understanding the key areas for which technology development is required is key to ensuring that taxpayers' money is spent in a cost-effective manner. Technology push intervention, in the form of grants, programmes and funding of innovation organisations, is often required at a pre-commercial level to accelerate innovation in technological design and deployment. Many countries already have technology push mechanism for ocean energy and have provided guidance on the challenge areas that are considered critical to the future commercialisation of the sector. A selection of these challenge area reports are listed below:

- ETIPOcean (EU) – Strategic Research and Innovation Agenda for Ocean Energy;
- Maritime Energy Council (US) – Commercialisation Strategy for Marine Energy;
- IEA OES (Global) – An International Evaluation and Guidance Framework for Ocean Energy Technology.

Throughout these different publications, there is a great deal of consensus in identifying common challenge areas that must be targeted for further development, as shown in Figure 24.

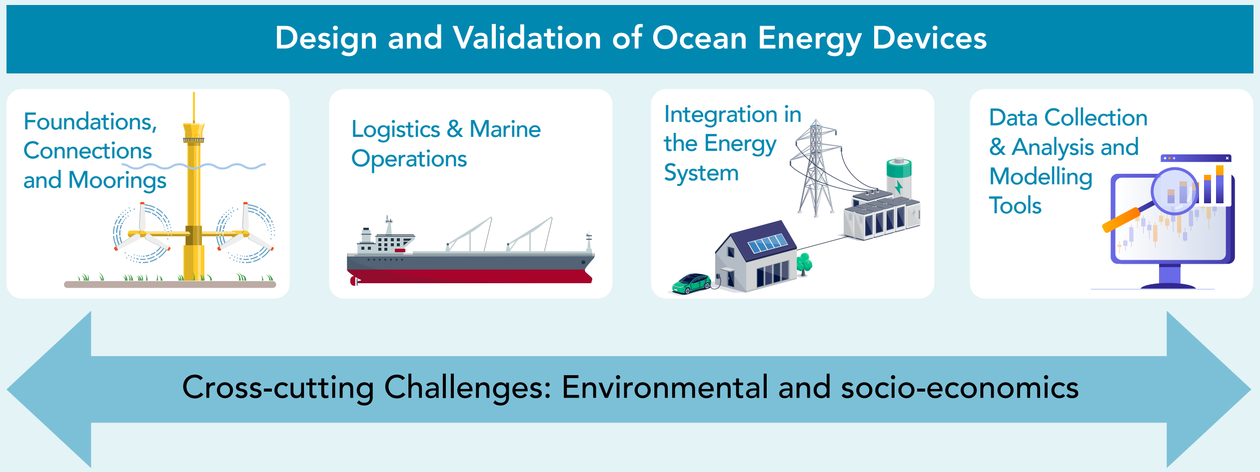


Figure 24 – Common challenge areas facing the wave and tidal stream sectors

In order to assess the total cost investment associated with overcoming the challenge areas identified in these reports, this report has decided to use the European Strategic Research and Innovation Agenda for Ocean Energy (SRIA) [25]. The SRIA details the six requisite challenge areas, shown in Table 2, in addition to identifying priority topics, the number and size of actions required and the overall budget allocation, mapped over a five year period, all of which allows for a greater degree of quantitative and qualitative analysis to be undertaken. An expanded version of this table can be found in Annex 1.

Table 2 Breakdown of the six challenge areas identified in the SRIA report

Challenge Area	Budget Required (€ millions)
1. Design and Validation of Ocean Energy Devices	685
2. Foundations, Connections and Mooring	85
3. Logistics and Marine Operations	80
4. Integration in the Energy System	86
5. Data Collection and Analysis and Modelling Tools	35
6. Cross-cutting Challenges	20
Total Cost of Investment	**991**

The SRIA outlines that from 2021 to 2025, a total of €1,006 million of funding will be required to address the key challenge areas facing the ocean energy sector, with the majority of funding directed to wave and tidal stream. However, this total also includes other ocean energy technologies such as ocean thermal energy conversion (OTEC) and salinity gradient. As our analysis focuses exclusively on wave and tidal stream, the funding that would be allocated to these other ocean energy technologies, amounting to €15 million, is removed. Therefore, our analysis is built on an SRIA budget of €991 million, where:

- €664 million comes from public finances (67% of total budget);
- €333 million is provided by the private sector (33% of total budget).

This section will focus primarily on the funding received from public finances. Of the €664 million that will be invested between 2021 and 2025, our analysis has calculated the following split:

- €315 million will be allocated to the tidal stream sector (47% of public finance budget);
- €349 million will be allocated to the wave sector (53% of public finance budget).

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

Supergen Offshore Renewable Energy

Technology Push Funding Scenarios

This section of the report will now detail the two scenarios, **Maximum Collaboration** and **Partial Collaboration**, to examine the funding required to overcome the challenge areas outlined in the SRIA report, between 2021 and 2025. The data modelling work conducted for this report extends to an estimation of the future costs associated with providing adequate funding to these challenge areas. This is critical to ensuring that the accelerated sectoral innovation that is required to drive down the costs of wave and tidal stream continues to happen. This section will then present a detailed estimation of the costs associated with future funding requirements for technology push mechanisms between 2023 and 2050. In order to deliver this analysis, Section Four will look at scenarios where the leading countries in both the European wave and tidal stream work collaboratively, with varying levels of engagement. This modelling work assumes that there are 7 European countries who can be considered to be leaders in the technological development of the wave energy sector and 3 European countries who can be considered to be leaders in the technological development of the tidal stream sector, as detailed below:

Scenario 1: Maximum Collaboration

Our first scenario, **Maximum Collaboration**, examines the cost breakdown if the maximum number of leading European countries in both the wave and tidal stream sectors contribute financially towards the challenge areas identified in the SRIA report:

- Wave – seven countries actively engaged;
- Tidal stream – three countries actively engaged.

Scenario 2: Partial Collaboration

Our second scenario, **Partial Collaboration**, examines the cost breakdown when there is more limited engagement and financial contribution between the leading European countries in both the wave and tidal stream sectors towards the SRIA challenge areas:

- Wave – three countries actively engaged;
- Tidal stream – two countries actively engaged.

The 'EUNICE' tidal turbine (Source: Nova Innovation)

Tidal Stream – Analysis of Funding Breakdown

The following section will present a breakdown of the funding required to deliver 6GW of tidal stream by 2050, where the conditions in both the **Maximum Collaboration** and **Partial Collaboration** scenarios are applied, as illustrated in the stage by stage progression shown in Figure 25.

Estimated Tidal Stream Technology Push Funding 2023-2050

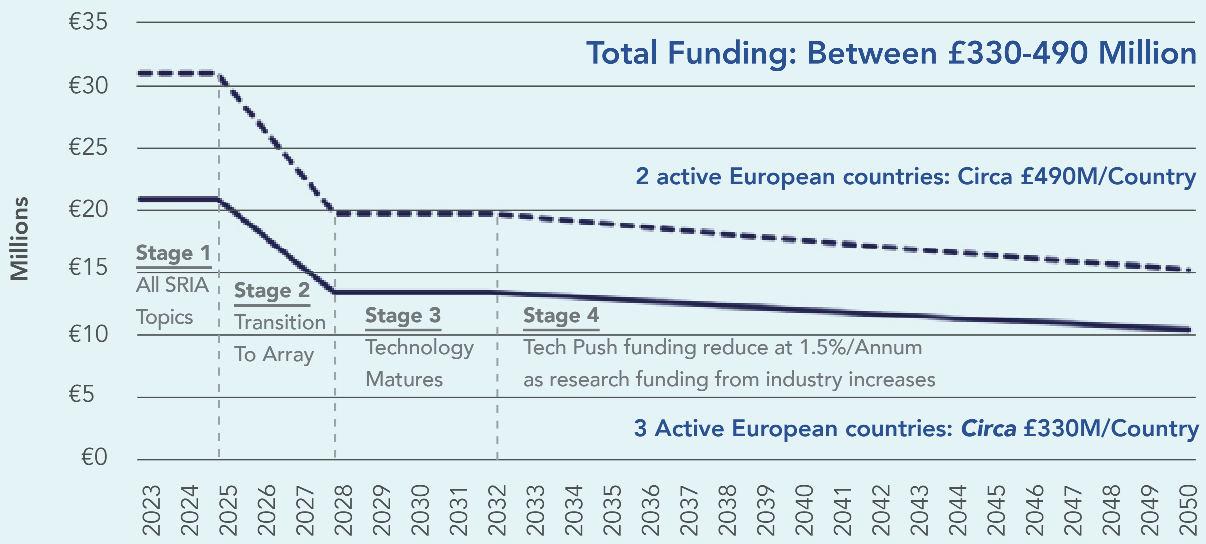


Figure 25 – Breakdown of technology push funding required to support the deployment of 6GW of tidal stream energy

Stage 1

Between 2023 and 2025, funding is applied uniformly to all the six challenge areas identified in the SRIA.

Under the conditions of **Maximum Collaboration**:

- **€21 million** per year will be contributed collaboratively, over the course of **three years**, by **three** leading European tidal stream countries and the European Commission.

Under the conditions of **Partial Collaboration**:

- **€31.5 million** per year will be contributed collaboratively, over the same **three year** period, by **two** leading European tidal stream countries and the European Commission.

Stage 2

Between 2025 and 2028, advancements in technology innovation will result in the successful deployment of tidal stream energy devices at array scale, gradually lowering the level of funding required for array scale demonstration. Demonstration of ocean energy technology at array scale constitutes the largest allocation of funds (€350 million) within Challenge Area 1, therefore achieving this significant milestone by 2028 greatly reduces the overall funding required moving forward.

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

Supergen Offshore Renewable Energy

Stage 3

Between 2028 and 2032, the technology underpinning the tidal stream sector continues to mature as a result of continued financial support and deployment at array-scale, therefore funding for array-scale demonstration is no longer required.

Under the conditions of **Maximum Collaboration**:

- **€13 million** per year will be contributed collaboratively, over the course of **five years**, by **three** leading European tidal stream countries and the European Commission.

Under the conditions of **Partial Collaboration**:

- **€20 million** per year will be contributed collaboratively, over the same **five year** period, by **two** leading European tidal stream countries and the European Commission.

Stage 4

Between 2032 and 2050, the financial investment required to support the tidal stream sector decreases at a rate of 1.5% per year as innovation funding from industry increases.

Under the conditions of **Maximum Collaboration**:

- Annual investment required from **three** leading European tidal stream countries and the European Commission will drop from **€13.2 million in 2037** to **€10.1 million in 2050**.

Under the conditions of **Partial Collaboration**:

- Annual investment required from **two** leading European tidal stream countries and the European Commission will drop from **€19.8 million in 2037** to **€15.1 million in 2050**.

Total Investment

To enable an accelerated learning rate that will reduce the overall market pull investment required between now and 2050, each European nation, in collaboration with the European Commission, will be required to contribute a total of:

- **Maximum Collaboration - €370 million** (approximately **£330 million**[6])
- **Partial Collaboration - €555 million** (approximately **£488 million**)

[6]Conversion rate, based on 2022 average, of €1.00 = £0.88 used in all European currency value conversions in Section 4

The O2 blade (Source: Orbital Marine Power)

Wave – Analysis of Funding Breakdown

The following section will present a breakdown of the funding required to deliver 6GW of wave by 2050, where the conditions in both the **Maximum Collaboration** and **Partial Collaboration** scenarios are applied, as illustrated in the stage by stage progression shown in Figure 26.

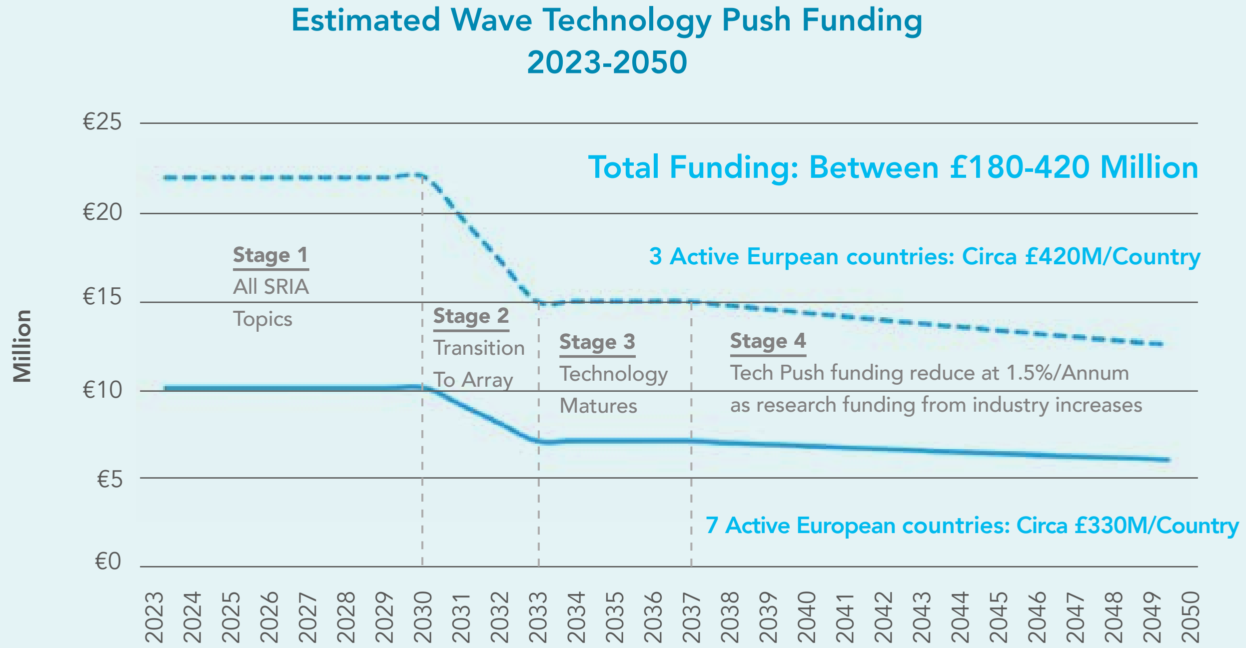


Figure 26 – Breakdown of technology push funding required to support the deployment of 6GW of wave energy

Stage 1

Between 2023 and 2030, funding is applied uniformly to all the six challenge areas identified in the SRIA.

Under the conditions of **Maximum Collaboration**:

- **€10 million** per year will be contributed collaboratively, over the course of **eight years**, by **seven** leading European tidal stream countries and the European Commission.

Under the conditions of **Partial Collaboration**:

- **€23 million** per year will be contributed collaboratively, over the same **eight year** period, by **three** leading European tidal stream countries and the European Commission.

Stage 2

Between 2030 and 2033, advancements in technology innovation will result in the successful deployment of wave energy devices at array scale, gradually lowering the level of funding required for array scale demonstration. Demonstration of ocean energy technology at array scale constitutes the largest allocation of funds (€350 million) within Challenge Area 1, therefore achieving this significant milestone by 2033 greatly reduces the overall funding required moving forward.

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

Stage 3

Between 2033 and 2037, the technology underpinning the wave sector continues to mature as a result of continued financial support and deployment at array-scale, therefore funding for array-scale demonstration is no longer required.

Under the conditions of **Maximum Collaboration**:

- **€6.6 million per year** will be contributed collaboratively, over the course of **five years**, by **seven** leading European tidal stream countries and the European Commission.
- **€15.4 million** per year will be contributed collaboratively, over the same **five year** period, by **three** leading European tidal stream countries and the European Commission.

Stage 4

Between 2037 and 2050, the financial investment required to support the wave sector decreases at a rate of 1.5% per year as innovation funding from industry increases.

Under the conditions of **Maximum Collaboration**:

- Annual investment required from **seven** leading European tidal stream countries and the European Commission will drop from **€6.6 million in 2037** to **€5.4 million in 2050**.

Under the conditions of **Partial Collaboration**:

- Annual investment required from **three** leading European tidal stream countries and the European Commission will drop from **€15.4 million in 2037** to **€12.7 million in 2050**.

Total Investment

To enable an accelerated learning rate that will reduce the overall market pull investment required between now and 2050, each European countries, in collaboration with the European Commission, will be required to contribute a total of:

- **Maximum Collaboration - €207 million** (approximately **£180 million**)
- **Partial Collaboration - €483 million** (approximately **£420 million**)

The Archimedes Wave Swing (Source: AWS Ocean Energy)

Key Message 6 – Future Technology Push Funding Analysis

Our analysis has outlined that funding for technology push policy mechanisms is a vital tool in ensuring that accelerated innovation continues to occur across the wave and tidal stream sectors. Targeting specific challenge areas, as outlined in the Strategic Research and Innovation Agenda (SRIA), will also help to deliver innovation in a cost-effective manner. By establishing two scenarios, **Maximum Collaboration** – where seven leading European wave energy countries and three leading European tidal stream countries, in collaboration with the European Commission, provide innovation funding – and **Partial Collaboration** – where three leading European wave energy countries and two leading European tidal stream countries, in collaboration with the European Commission, provide innovation funding – we have shown the following:

- Under the conditions of **Maximum Collaboration**, a total of **€370 million** (approximately **£325 million**) of tidal stream energy funding and **€207 million** (approximately **£180 million**) of wave energy funding, willl be required per country, supplemented by funding from the European Commission, to enable an accelerated learning rate that will reduce the overall market pull investment required between now and 2050;
- Under the conditions of **Partial Collaboration**, a total of **€555 million** (approximately **£488 million**) of tidal stream energy funding and **€483 million** (approximately **£420 million**) of wave energy funding, willl be required per country, supplemented by funding from the European Commission, to enable an accelerated learning rate that will reduce the overall market pull investment required between now and 2050.

The successful outcome of these technology push policy support mechanisms is highly contingent on two factors:

- Continued **collaboration between the leading European countries** in both the wave and tidal stream sectors;
- The **UK government providing adequate technology push funding** to support innovation across development and deployment in the ocean energy sector, encompassing all stages of technological maturity.

SECTION 4 OVERVIEW: TECHNOLOGY PUSH ANALYSIS

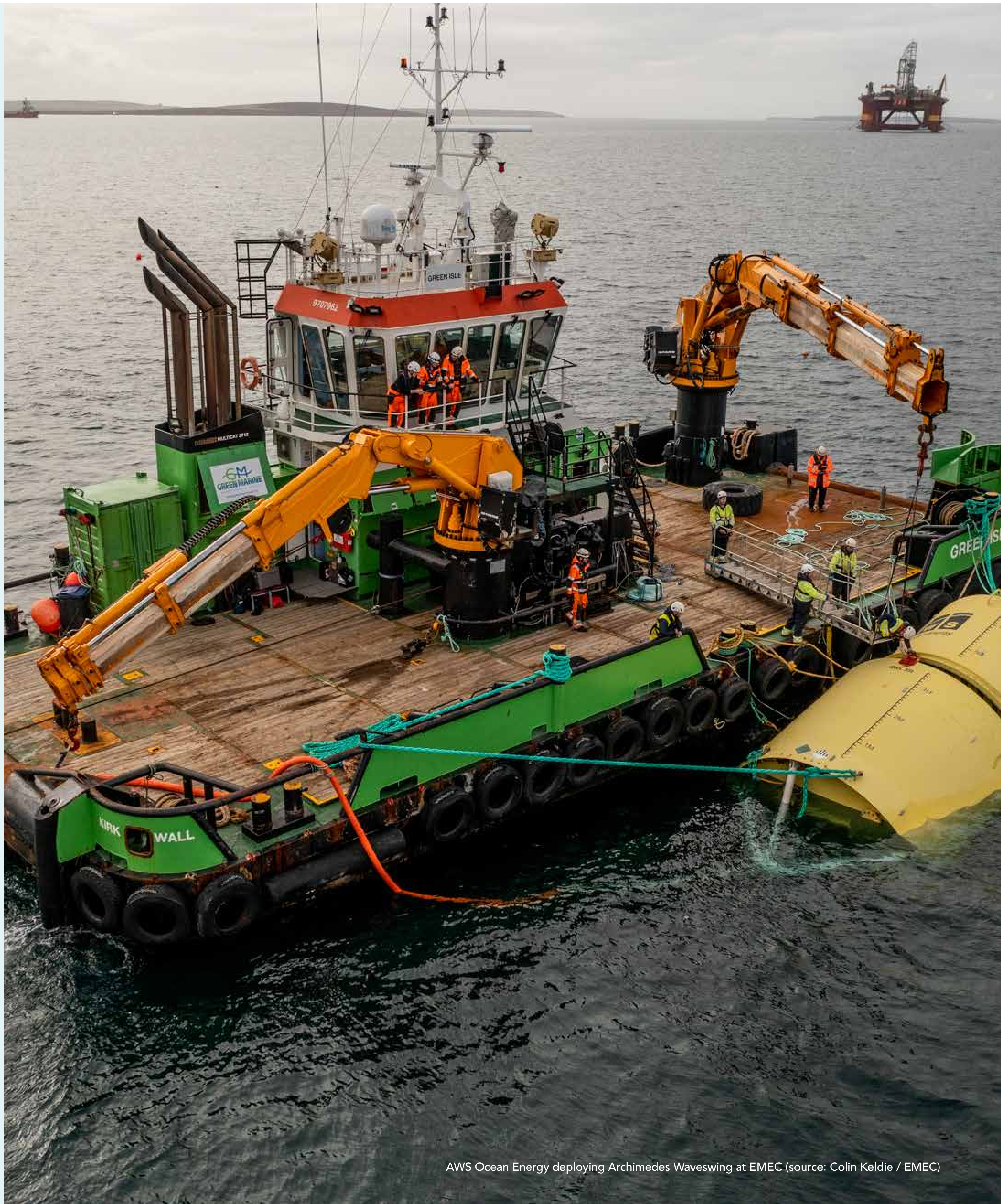
While the numbers associated with both scenarios may seem large compared to current technology push investments, this is a relatively modest contribution over a period of more than 20 years in comparison to the vast savings outlined in earlier sections of this report that can be achieved, should a high learning rate be attained. Providing adequate funding to technology push policy mechanisms that can accelerate the rate of innovation in the ocean energy sector is critical to ensuring the rapid commercialisation of wave and tidal stream technology.

Overcoming the challenge areas outlined in the SRIA report is an important first step in this journey. The speed and efficiency with which these challenge areas can be addressed is highly contingent on maintaining and increasing the collaborative innovation that is ongoing between European countries involved in the SRIA programme.

As shown earlier in this report, the UK has been highly reliant on access to EU funding to ensure that there was continued innovation occurring at all TRL stages in the domestic ocean energy sector. **It is crucial for the UK government to allocate adequate funding through a comprehensive technology push funding strategy to ensure sustained technology innovation and maintain the UK's leadership in the wave and tidal stream sectors.**

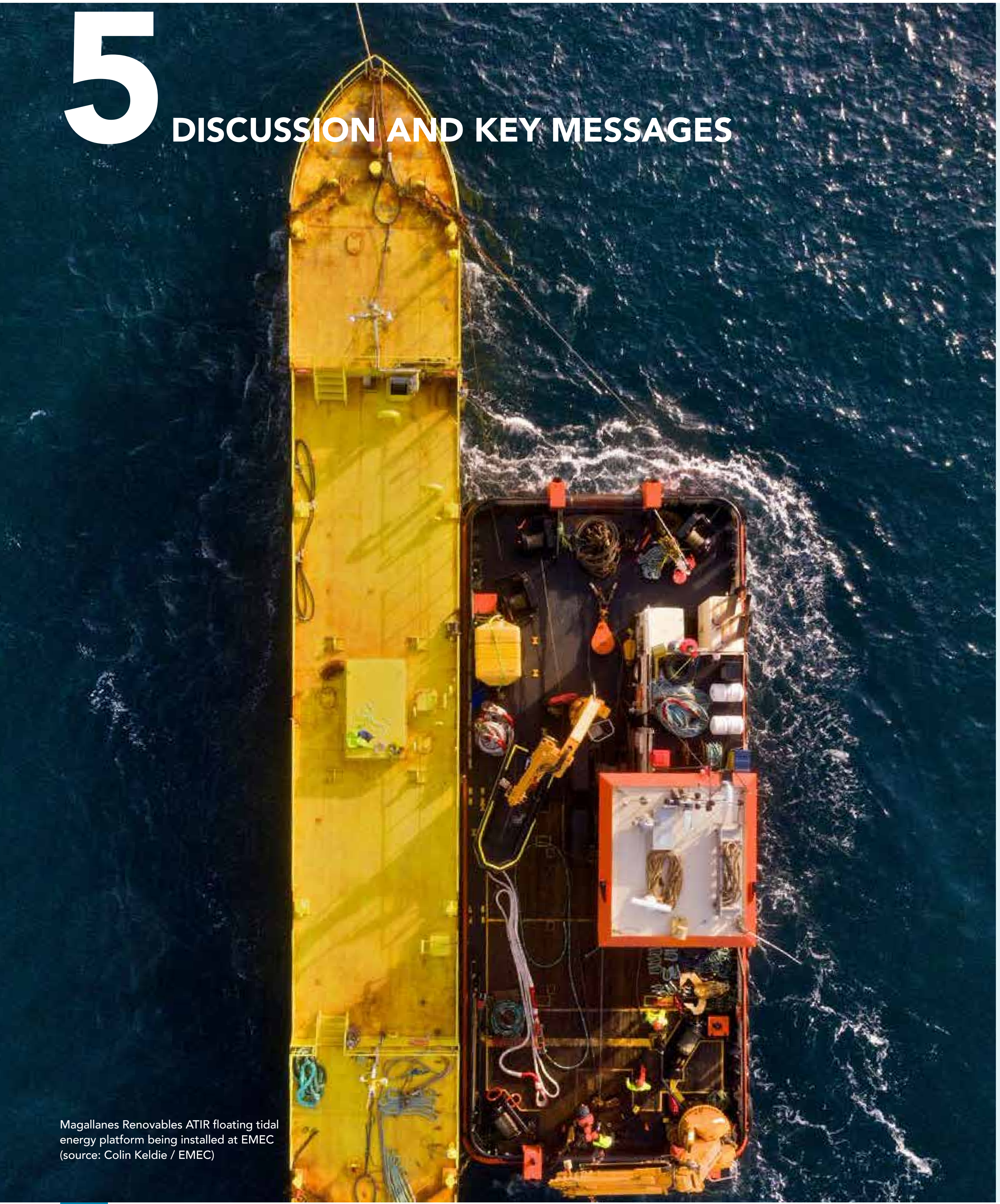
OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

Supergen Offshore Renewable Energy



AWS Ocean Energy deploying Archimedes Waveswing at EMEC (source: Colin Keldie / EMEC)

5 DISCUSSION AND KEY MESSAGES



Magallanes Renovables ATIR floating tidal energy platform being installed at EMEC (source: Colin Keldie / EMEC)

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

DISCUSSION

This report has outlined the benefits and costs associated with implementing policy support mechanisms that have the potential to accelerate the commercialisation of the ocean energy sector and drive down the energy generation cost to match that of the wholesale market price. This report has demonstrated that achieving this outcome requires a careful balancing act between two main factors: the cost of implementing the optimal balance of technology push and market pull policies against the overall benefits provided to society through quantifiable metrics that include; GVA to the national economy; energy system balancing benefits associated with increased deployment of renewable energy technologies; subsequent societal and environmental benefits; and the economic benefits captured through the export of UK expertise and supply chain capability into the international market.

As the fourth report in a publication series that has already estimated the potential benefits of the deployment of 6GW of wave and 6GW of tidal stream to be:

- **£11 billion – £41 billion** in GVA to the UK economy;
- **£1 billion** per annum reduction in dispatch costs.

This report has provided a comprehensive overview of the actual current levels of investment and support offered to the sector and forecasted options on how this could be optimised to enable the continued acceleration of technological innovation for emerging wave and tidal stream technologies.

While the initial levels of support offered through mechanisms such as the CfD scheme, have provided a strong base from which to build upon, our analysis indicates that this support must be sustained and evolve to provide the stability and long-term financial security that investors, stakeholders and consumers engaging with the sector desire. Therefore, while the level of return on investment, in terms of GVA and overall system benefits, produced by the wave and tidal sectors has been clearly demonstrated in previous publications in this series, this report has also outlined the key factors that influence and shape the maximum attainable value of these benefits. Establishing the optimal combination of financial investment in both technology push and market pull policies that accelerate technological innovation at a minimum cost, ensures that best value for the consumer and the taxpayer, who ultimately provide the funding for both policy tools, is achieved.

By observing the detailed scenarios presented in this report and the key messages listed throughout and summarised in the following section, it will be possible to find a level of balanced investment that creates wave and tidal sectors operating at minimum cost to the consumer and taxpayer. While this also provides the potential for the UK to lead in terms of sectoral knowledge and expertise, there remains a need to provide adequate investment in UK supply chains and manufacturing capabilities to ensure that the maximum value generated from from these emerging sectors remains within the UK.

By building on our established reputation as the world-leading nation in ocean energy technology development and deployment, in combination with the increased levels of innovation funding and long term market support detailed in this report, the UK has the potential to build a wave and tidal stream sector that is an important and valuable part of our national economy and a vital component in our net-zero commitments. Finally, by creating a truly world-leading ocean energy technology sector, there is also the potential to export both our technological expertise and supply chain capabilities to the growing international market.

Key Messages

This report is the fourth in a series that outlines the policy mechanisms and innovations that will be required to unlock both the economic value and system benefits associated with commercial scale wave and tidal stream energy deployments. This report has built on these results and delivered comprehensive analysis regarding the optimal balance between financial investment in both technology push and market pull policies against delivering 6GW of wave and 6GW of tidal stream at the best value for the consumer and the taxpayer.

Results from this report are summarised in the following key messages:

Key Message 1 – Sector Benefits

The continued commercialisation of the wave and tidal stream sectors, aided by accelerated innovation, has the potential to **establish the UK as the world leading nation in ocean energy technology development and deployment**, delivering a range of accompanying Net Zero, socioeconomic and power system benefits. By achieving the forecasted deployment of 6GW of wave and 6GW of tidal stream, the following benefits can be realised:

- Between **£11billion to £41billion in GVA to the** UK economy by 2050 from both domestic and international deployment of wave and tidal stream technologies, relative to UK international market share;
- Approximately **£1 billion per annum** reduction in dispatch cost.

Key Message 2 – Existing Technology Push Support

Between 2017 and 2022 total funding to support technology push policies specific to the wave and tidal stream sectors in the UK amounted to **£315 million**. However, approximately only 23% **(£74 million)** of this came from domestic sources of funding, with **£44 million** coming directly from the Scottish Government initiatives (Wave Energy Scotland, EuropeWave and the Saltire Prize), concentrating predominantly on medium TRL status projects. The remaining **£28 million** of domestic funding is provided by the UK government, with the bulk of this coming in the form of EPSRC funding to the SuperGen programme.

There is a clear opportunity for the UK government to invest more heavily in technology push funding that focusses on early stage innovation (low TRL status) to drive technology innovation, ultimately helping to advance wave energy technology towards accessing market pull mechanisms and accelerating the cost reduction of tidal stream technology.

Key Message 3 – Existing Market Pull Policy Support

From 2002 until 2017, the implementation of the Renewables Obligation (RO) market pull mechanism has **successfully delivered 8.6MW of tidal stream capacity**. From 2014 to present day, the Contracts for Difference (CfD) market pull mechanism has provided targeted support to the tidal sector and has **contracted an initial 40.82MW of generative capacity** at a strike price of **£$_{2012}$178.54/MWh**. During the same period no wave energy devices have been deployed as a result of the same market pull policies.

In order to ensure that the wave and tidal stream sectors continue to play a significant role in achieving the UK governments ambitious net-zero target, long-term market pull policy support mechanisms, **such as the continuation of the CfD scheme**, are crucial.

Key Message 4 – Tidal Stream Sector Market Pull Funding Analysis

Our analysis has shown that technology push funding, which drives technology innovation, greatly affects the overall market pull funding required for tidal stream deployment in the following aspects:

- A higher learning rate (achieved through increased technology push funding) provides greater overall cost reductions and significantly reduces the total investment required to support market pull polices such as the CfD scheme. In our scenario, increasing the learning rate from 10% to 15% reduced the total investment required in the tidal stream sector from **£18.6 billion to £3.3 billion**; an increase from 15% to 20% further reduced the required investment in the tidal stream sector to **£1.9 billion**;
- The immediate application of technology innovation fueled by technology push funding allows the tidal stream sector to enable faster cost reductions and lower the strike prices offered in subsequent CfDs. This can lead to savings of approximately **£0.6 billion per year** of non-delay in the consistent cost reductions associated with the total funding required for market pull investments. This is a modest amount in comparison to the savings associated with the adoption of a 15% or 20% learning rate instead of a sub-optimal learning rate of 10%.

Key Message 5 – Wave Sector Market Pull Funding Analysis

Our analysis has shown that technology push funding, which in turn drives technology innovation, greatly affects market pull funding for wave deployment in the following aspects:

- A higher learning rate (achieved through increased technology push funding) provides greater overall cost reductions and significantly reduces the total required to support market pull polices such as the CfD scheme. In our scenario, increasing the learning rate from 10% to 15% reduced the total investment required in the wave sector from **£20.5 billion to £3.0 billion**; an increase from 15% to 20% further reduced the required investment in the wave sector to **£1.3 billion**;
- The immediate application of technology innovation fueled by technology push funding allows the wave sector to enable faster cost reductions and lower the strike prices offered in subsequent CfDs. This can lead to savings of approximately **£0.9 billion per year** of non-delay in the consistent cost reductions associated with the total funding required for market pull investments. This is a modest amount in comparison to the savings associated with the adoption of a 15% or 20% learning rate instead of a sub-optimal learning rate of 10%.

Key Message 6 – Future Technology Push Funding Analysis

Our analysis has outlined that funding for technology push policy mechanisms is a vital tool in ensuring that accelerated innovation continues to occur across the wave and tidal stream sectors. Targeting specific challenge areas, as outlined in the Strategic Research and Innovation Agenda (SRIA), will also help to deliver innovation in a cost-effective manner. By establishing two scenarios, **Maximum Collaboration** – where seven leading European wave energy countries and three leading European tidal stream countries, in collaboration with the European Commission, provide innovation funding – and **Partial Collaboration** – where three leading European wave energy countries and two leading European tidal stream countries, in collaboration with the European Commission, provide innovation funding – we have shown the following:

- Under the conditions of **Maximum Collaboration**, a total of **€370 million** (approximately **£325 million**) of tidal stream energy funding and **€207 million** (approximately **£180 million**) of wave energy funding, willl be required per country, supplemented by funding from the European Commission, to enable an accelerated learning rate that will reduce the overall market pull investment required between now and 2050;
- Under the conditions of **Partial Collaboration**, a total of **€555 million** (approximately **£488 million**) of tidal stream energy funding and **€483 million** (approximately **£420 million**) of wave energy funding, willl be required per country, supplemented by funding from the European Commission, to enable an accelerated learning rate that will reduce the overall market pull investment required between now and 2050.

The successful outcome of these technology push policy support mechanisms is highly contingent on two factors:

- Continued **collaboration between the leading European countries** in both the wave and tidal stream sectors;
- The **UK government providing adequate technology push funding** to support innovation across development and deployment in the ocean energy sector, encompassing all stages of technological maturity.

As outlined in these **six key messages**, should the forecasted 6GW of wave and 6GW of tidal stream deployment be achieved, at an optimum cost for both consumers and taxpayers relative to the total amount invested in both technology push and market pull policies, the UK will benefit from world-leading wave and tidal stream sectors in a number of ways:

First, the wave and tidal stream sectors have the potential to become a pivotal feature of our future Net-Zero energy system through the deployment of renewable technology, the generation of sustainable energy and the subsequent national energy system balancing benefits that can be expected.

Secondly, there is a clear opportunity for the UK to increase the GVA and associated socioeconomic benefits to the national economy, both domestically and from exports of UK expertise and supply chain capabilities to the global market. The wave and tidal stream sectors also have the potential to play a vital role in the Just Transition by providing well paid, high quality jobs in coastal and island communities.

REFERENCES

[1] UK Government, "Contracts for Difference (CfD) Allocation Round 4: results," 7 July 2022. [Online]. Available: https://www.gov.uk/government/publications/contracts-for-difference-cfd-allocation-round-4-results.

[2] Wave Energy Scotland, "Five wave energy projects to continue to next phase of EuropeWave," 22 September 2022. [Online]. Available: https://www.waveenergyscotland.co.uk/news-events/five-wave-energy-projects-to-continue-to-next-phase-of-europewave/

[3] K. Grattan and H. Jeffrey, "Delivering Net Zero: Achieving the Deployment of 12GW of wave and tidal Stream in UK Waters by 2050,"Policy and Innovation Group, 2023

[4] Energy Systems Catapult, "Innovating to Net Zero: UK Report," Energy Systems Catapult, Birmingham, 2020.

[5] European Commission, "SET-Plan Ocean Energy - Implementation Plan," European Commission, 2021.

[6] Committee on Climate Change, "Net Zero Technical Report," Committee on Climate Change, 2019

[7] C. Cochrane, S. Pennock and H. Jeffrey, "What is the value of innovative offshore renewable energy deployment to the UK economy?," Policy and Innovation Group, 2021

[8] S. Pennock and H. Jeffrey, "What are the UK power system benefits from deployments of wave and tidal stream generation?," Policy and Innovation Group, 2023.

[9] Innovate UK, "Innovate UK funded projects since 2004," 2 March 2022. [Online]. Available: https://www.ukri.org/publications/innovate-uk-funded-projects-since-2004/

[10] EPSRC, "Visualising our Portfolio," 22 September 20221. [Online]. Available: https://public.tableau.com/app/profile/epsrcdatateam/viz/VisualisingourPortfolio/VoP.

[11] Wave Energy Scotland, "Programmes," [Online]. Available: https://www.waveenergyscotland.co.uk/programmes/.

[12] Welsh Government, "EU Structural Funds programme 2014 to 2020: approved projects," 1 August 2022. [Online]. Available: https://www.gov.wales/eu-structural-funds-programme-2014-2020-approved-projects.

[13] UK Government, "England 2014 to 2020 European Structural and Investment Funds," 20 October 2020. [Online]. Available: https://www.gov.uk/guidance/england-2014-to-2020-european-structural-and-investment-funds.

[14] European Commission, "Horizon Europe Work Programme 2021-2022: 8. Climate, Energy and Mobility," 2022

[15] Ofgem, "Renewables Obligation (RO)," [Online]. Available: https://www.ofgem.gov.uk/environmental-and-social-schemes/renewables-obligation-ro/renewables-obligation-ro-energy-suppliers..

[16] BEIS and Ofgem, "Calculating Renewable Obligation Certificates (ROCs)," 1 April 2013. [Online]. Available: https://www.gov.uk/guidance/calculating-renewable-obligation-certificates-rocs. [Accessed 10 August 2022].

[17] Scottish Government, "Renewables Obligation Banding Review 2011-12," 13 September 2012. [Online]. Available: https://www.webarchive.org.uk/wayback/archive/20160109021217mp_/http:/www.gov.scot/Resource/0040/00401801.pdf. [Accessed 10 August 2022].

[18] Ofgem, "Renewables Obligation (RO) Annual Report 2020-21," 29 March 2022. [Online]. Available: https://www.ofgem.gov.uk/ publications/renewables-obligation-ro-annual-report-2020-21. [Accessed 10 August 2022]

[19] BEIS, "Contracts for Difference," 14 December 2022. [Online]. Available: https://www.gov.uk/government/publications/contracts-for-difference/contract-for-difference.

[20] UK Government, "Contracts for Difference (CfD): Allocation Round 5," 4 February 2022. [Online]. Available: https://www.gov.uk/government/collections/contracts-for-difference-cfd-allocation-round-5.

[21] E. Rubin, I. Azevedo, P. Jaramillo and S. Yeh, "A review of learning rates for electricity supply technologies," Energy Policy, pp. 198-218, 2015.

[22] BEIS, "Energy and emissions projections," 18 October 2022. [Online]. Available: https://www.gov.uk/government/collections/ energy-and-emissions-projections.

[23] E. Brainpool, "EU Energy Outlook 2060: How will the European electricity market develop over the next 37 years?," 17 November 2022. [Online]. Available: https://blog.energybrainpool.com/eu-energy-outlook-2060-wie-entwickelt-sichder-europaeische-strommarkt-in-den-naechsten-37-jahren/.

[24] Office for National Statistics, "CPI INDEX 00: ALL ITEMS 2015=100," 15 February 2023. [Online]. Available: https://www.ons.gov.uk/economy/inflationandpriceindices/timeseries/d7bt/mm23

[25] ETIP Ocean, "Strategic Research and Innovation Agenda for Ocean Energy,"ETIP Ocean, 2022

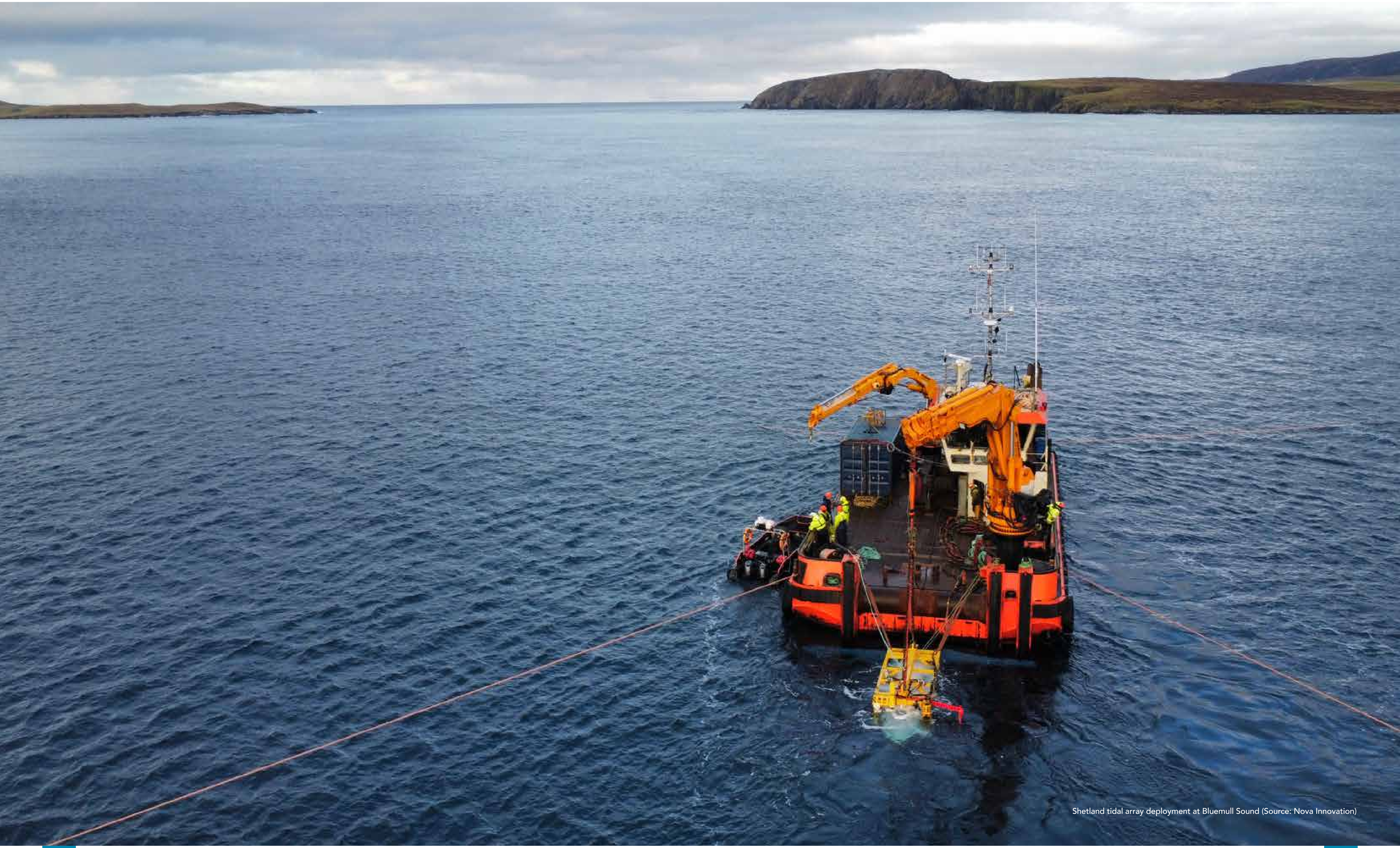
OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050

ANNEX 1

Expanded breakdown of the SRIA Challenge Areas detailed in Table 2 (Page 44), found in Technology Push Development Areas

Challenge Areas	Priority Topics	Number and Size of actions*	Budget Required (million £)	
Design and Validation of Ocean Energy Devices	Demonstration of ocean energy devices to increase experience in real sea conditions	Around 10 large and 10 medium	110	700
	Demonstration of ocean energy technology at array scale	7 Projects at array scale	350	
	Improvement and demonstration of PTO and control systems	Around 10 medium and 5 small	60	
	Application of innovative materials from other sectors	A few medium and around 5 small	25	
	Development of novel wave energy devices	Around 10 small and 5 medium	45	
	Improvement of tidal blades and rotor	Around 5 medium and a few large	55	
	Development of other ocean energy techologies	A few medium	15	
Foundations Connections and Mooring	Advanced mooring and connection systems for floating ocean energy devices	Around 10 medium	50	85
	Improvementand demonstration of foundations and connection systems for bottom-fixed ocean energy devices	Around 5 medium and around 5 small	35	
Logistics and Marine Operations	Optimisation of maritime logistics and operations	Around 5 medium and a few large	55	80
	Instrumentation for condition monitoring and predictive maintenance	A few medium and around 5 large	25	
Integration in the Energy System	Developing and demonstrating near-commercial application of ocean energy in niche markets	Several medium and a few large	50	86
	Quantifying and demonstrating grid-scale benefits of ocean energy	A few small	6	
Data Collection & Analysis and Modelling Tools	Marine observation modelling and forecasting to optimise design and operation of ocean energy devices	A few medium and around 5 small	25	35
	Open-data respository for ocean energy	Around 5 small	10	
Cross-cutting Challenges	Improvement of the environmental and socioeconomic impacts of ocean energy	Around 5 small	10	20
	Standardisation and certification	Around 5 small	10	
			TOTAL	1,006

OCEAN ENERGY AND NET ZERO:
POLICY SUPPORT FOR THE COST EFFECTIVE DELIVERY OF 12GW WAVE AND TIDAL STREAM BY 2050



Shetland tidal array deployment at Bluemull Sound (Source: Nova Innovation)

Supergen Offshore Renewable Energy

THE UNIVERSITY of EDINBURGH
School of Engineering

Policy and Innovation Group

www.policyandinnovationedinburgh.org