Economic Impact Assessment: Value of Wave Energy Deployment to the Scottish Economy

A report to Wave Energy Scotland prepared by
the Policy and Innovation Group
at the University of Edinburgh

January 2025

THE UNIVERSITY of EDINBURGH
School of Engineering
Policy and Innovation Group

wave energy SCOTLAND

Executive summary

Scotland is one of the leading nations at the forefront of the global development and deployment of wave energy devices. In addition to the significant resource contained in Scottish seas, Scotland is also home to several of the world's leading wave energy device developers and possesses the underpinnings of a suitably equipped supply chain to support them.

A commercially successful domestic wave energy sector has the potential to provide a **meaningful contribution to Net Zero, Just Transition, energy security and economic growth commitments and ambitions**, both in Scotland, and the rest of the UK.

As Scottish wave energy technology developers prepare to reach levels of competitive deployment that allows them to successfully bid for and win Contracts for Difference, preparations must begin for a future where the sector moves towards array-scale deployment. **A competitive Scottish supply chain, capable of producing wave energy devices and key subsystems at volume, is needed now**. This supply chain investment, coupled with **access to market support for wave energy, is essential to ensure that Scotland capitalises on its position as a pioneer of this technology**.

If Scotland is successful in achieving device commercialisation at an array scale, there could be a potential market for almost **4.5 GW of wave energy in Scotland by 2050,** feeding into potential deployments of 6.4 GW in the UK and 180 GW across the globe in the same timescale. Projects in the UK could generate over **£4.2bn in economic benefit to the Scottish economy by 2050**, and **support over 9,700 high-value jobs in 2050**, with significant additional potential from exports.

To ensure that these deployments are led by Scottish companies and organisations, **establishing a highly competitive and modernised domestic supply chain is increasingly important**. This will help to ensure that Scotland remains the location of choice for prospective tidal stream and wave energy developers to develop, build, deploy and maintain their devices.

To achieve these step-changes in supply chain capabilities and deliver the GVA and jobs potential for sector, this report provides policy recommendations focused on the following areas.

Firstly, targeted recommendations to **support both wave energy device developers and their supply chains**, focusing on the need for:

- Discussions with both UK and devolved governments around the continuation and growth of comprehensive market pull policies, which include wave energy.
- Enabling sustained sources of both public and private innovation funding for technology developers, so Scotland can build upon and maintains its competitive edge in these sectors.
- Delivering a step-change in the capabilities of a modernised and highly competitive supply chain.

Secondly, recommendations are given to **develop essential sector infrastructure**, focusing on:

- Development of soft infrastructures, such as developing a pipeline of workers with relevant skills and training. This may include those transitioning from the oil and gas sector.
- Opportunities to collaborate with, and share, the supply chain and infrastructures of other established and emerging offshore sectors, including offshore wind and tidal stream.
- The build out of hard infrastructure, such as ports, harbours, and national grid capabilities.

Lastly, Scotland should utilise the extensive experience of its **well-established enterprise and innovation support organisations, to deliver on the complex task of sustained device development and the modernisation of domestic supply chain capabilities**. If successful, Scotland stands poised to become the nation synonymous with leading the successful development and deployment of innovative wave energy devices and farms.

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Results and recommendations presented here are a from a study conducted by the Policy & Innovation Group at the University of Edinburgh for Wave Energy Scotland.

Policy and Innovation Group

The Policy and Innovation Group is part of the Institute for Energy Systems (IES), which is one of the seven research institutes within the School of Engineering at the University of Edinburgh. The Policy and Innovation Group combines expertise in offshore energy technology, energy system organisations and institutions, and the wider policy and regulatory landscape. They apply a range of quantitative and qualitative research tools and methods including energy system modelling, future transition scenarios, techno-economic analysis and innovation pathways. This leads to the development of policy guidance reports, energy system roadmaps and economic and energy system analysis for technology developers, public and private investment and government departments.

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

Wave Energy Scotland

Wave Energy Scotland (WES) is driving the search for innovative solutions to the technical challenges facing the wave energy sector. Through a competitive procurement programme, they support a range of projects focused on the key systems and sub-systems of Wave Energy Converters. The aim is to produce reliable technology which will result in cost effective wave energy generation. WES was formed in 2014 at the request of the Scottish Government and is a subsidiary of Highlands and Islands Enterprise. The aim of WES is to ensure that Scotland maintains a leading role in the development of marine energy.

Find out more about Wave Energy Scotland at https://www.waveenergyscotland.co.uk

Suggested citation: D. R. Noble, K. Grattan, and H. Jeffrey, ‘Economic Impact Assessment: Value of Wave Energy Deployment to the Scottish Economy’, The University of Edinburgh, Jan. 2025.

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1 Introduction

Scotland is one of the countries at the forefront of the development and testing of wave energy, and there is significant wave energy resource around Scotland's coast. Globally, the sector is moving towards demonstrating arrays and building the first commercial projects. Wave energy could therefore form the basis of a significant market in Scotland. It is a technology that offers considerable potential to deliver socio-economic benefits to Scotland from both developing the technology and building devices and projects, including considerable export potential. As seen in other renewable technologies, there is the potential for rapid growth in deployment of wave energy with corresponding cost reductions.

Previous studies have quantified the economic benefits of offshore renewable energy, including wave energy, tidal stream, and floating offshore wind, at an international, European and UK level. However, there have been no recent studies focused on the benefits of wave energy in Scotland. As discussed in section 2.4, other studies have also outlined wider power systems benefits to be gained from including wave energy within the installed generation capacity.

These all support the case for pursuing the development of the wave energy sector. Therefore, this study aims to quantify the potential benefits of wave energy to Scotland, in terms of gross value added (GVA) and jobs supported. It also considers the supply chain competitiveness and volume capability required to realise these benefits.

1.1 Scotland is a leading country in the development of wave energy

Scotland has a long history of developing and testing innovative wave energy concepts and remains one of the leading countries developing, deploying and testing wave energy globally.

One of the early leading proponents of wave energy was Professor Stephen Salter. Salter and his wave power group at Edinburgh University designed and tested the Edinburgh Duck to harness the power of the waves in the 1970s in response to the oil crisis. This also required developing the 'wide tank' at Edinburgh, the first multi-directional wave test tank with absorbing wavemakers. This work led to the spin-off of several companies including the world-leading wave tank developer Edinburgh Designs, and Artemis Intelligent Power (acquired by Danfoss) who developed digital-displacement hydraulic systems used in wave and wind power plus other industries.

Scotland's universities continue to be at the forefront of wave energy research and development. This includes theoretical research, numerical modelling, plus physical testing at the FloWave Ocean Energy Research Facility, Kelvin Hydrodynamics Laboratory, and other facilities.

The European Marine Energy Centre (EMEC) was established in Orkney in 2003 to help develop the ocean energy industry. It provides pre-consented test berths for testing wave and tidal stream energy devices. In total, 14 wave devices from 11 developers have been tested at EMEC since 2004, with further wave energy testing and demonstration scheduled over the next few years. Strong research collaborations, and a variety of successes in European Commission funding schemes has also allowed many foreign companies to test at EMEC.

Wave Energy Scotland (WES) was set up in 2014 by the Scottish Government to facilitate research and development activity to accelerate the development of wave energy technologies, and it has been delivering innovation support successfully in Scotland since. WES has run a series of programmes to develop both novel devices and key subsystems. Within this, Scottish companies AWS Ocean Energy and Mocean Energy developed their devices from early-stage concept to at-sea prototype trials (stages 1–3), and they successfully tested their wave energy converters at EMEC in 2021/22. Mocean then further demonstrated their technology over a further 13 months in 2023/24 in the Renewables for Subsea Power project, supported by private sector finance.

However, many other countries around the world are also developing and testing wave energy, albeit with no clear leader at this stage. Almost all 22 member countries of the International Energy Agency's technology collaboration programme on Ocean Energy Systems are actively developing wave energy technology or projects [1]. In September 2024, the USA announced over $100m in funding to advance the commercial readiness of wave energy over the next five years, as well as funding to develop new large scale test facilities similar to EMEC. Across Europe, through regional or Commission funding, the availability of test tanks and grid connected real sea test sites has also increased in recent years. Timely action and investment are therefore important to maintain and potentially grow the competitive advantage Scotland has as a leading country in the development and demonstration of wave energy.

1.2 Motivation and previous work quantifying the benefits of wave energy

Previous studies have quantified the benefits of offshore renewable energy, either at an international, European or UK level. However, there are not any up-to-date studies that focus specifically on the benefits of wave energy to the Scottish economy. Previous studies mostly quantify economic benefits in terms of gross value added (GVA) to the economy from producing and deploying these technologies, with some also including the number of jobs supported.

The 2023 IEA-OES vision for ocean energy [2] includes high-level estimates of $340bn in GVA and 680,000 jobs by 2050 from deploying 300 GW of wave and tidal stream energy. At a European level, in 2021 the European Technology & Innovation Platform for Ocean Energy (ETIP Ocean) published a study on the potential economic value of wave and tidal in Europe to 2050 [3]. A range of scenarios were presented, showing the net economic benefit of wave energy in Europe could be up to €84bn.

For the UK, the Offshore Renewable Energy Catapult (OREC) published a study in 2018 quantifying the cost reduction and industrial benefit for tidal stream and wave energy [4]. More recently, in 2021 the Policy and Innovation Group at the University of Edinburgh quantified the value of innovative offshore renewable energy to the UK economy [5]. A 2024 update to this work [6] suggests the GVA to the UK economy by 2050 from wave energy could be £5.5bn.

This report aims to assess the potential economic impact of electricity generation from wave energy to the Scottish economy, as a result of both deploying wave energy projects in Scotland and the UK as well as from global exports. This is quantified in terms of gross value added (GVA) and full-time equivalent (FTE) jobs. A parallel study is using the same approach and methodology to investigate the economic benefits of tidal stream in Scotland [7].

In addition to the economic benefits, other recent studies have quantified a range of power systems benefits of incorporating ocean energy (including wave energy) into a diverse future renewable energy mix [8–11], as discussed in section 2.4. These wider benefits arise from the ocean energy resource being available at different times to other renewable energy technologies; wave energy specifically is well matched to the annual pattern of demand in the UK and may be offset in time from wind.

The economic benefit assessment methodology is set out in section 3, followed by the results in section 4. Section 5 then gives an overview of the Scottish wave energy supply chain and presents a competitiveness review of key subsystems. The report concludes in section 6 with a summary and a series of recommendations.

2 Background on wave energy, resource, deployment and the supply chain

This study focuses on wave energy, as this emerging sector forms the basis of a significant market opportunity in Scotland. As highlighted above, Scotland is one of the countries at the forefront of developing wave energy and has a long history of developing and testing innovative concepts. It also has significant resource potential around the coasts, much of this located in the north-west Highlands and Islands area. In response to the Scottish Government's Energy Strategy and Just Transition Plan consultation and in the run up to UK General Election in 2024, the wave energy sector through the UK Marine Energy Council outlined an industry ambition of 300 MW deployed in the UK by 2035 [12,13], the majority being in Scotland.

The UK Government's recent Clean Power 2030 Action Plan [14] focuses on the short-term goals of almost entirely decarbonising the electricity supply by 2030, as well as ensuring the country can meet the growth in electricity demand in the decades beyond. The report states:

> "*Whilst emerging renewable technologies … are expected to play a limited role in the 2030 energy mix, our ability to deploy them at scale could be important to the UK's achievement of longer-term decarbonisation. … Emerging technologies could also provide broader system benefits, including … power generation that is uncorrelated with other energy sources… In addition, early investment in the deployment of emerging technologies … could provide wider economic benefits and export opportunities for the UK.*"

Although not specifically mentioned, wave energy could be one of these emerging renewable technologies that this action plan already highlights will play a role in meeting longer-term targets, with associated power systems benefits.

2.1 Wave and other forms of offshore renewable energy

There are various methods to harness energy from the seas and oceans, collectively referred to as offshore renewable energy, as detailed in Table 2.1. Although quite different technologies at different stages in their commercialisation, wave energy and tidal stream are often grouped together under the term ocean energy or marine energy.

Wave energy converters (WEC) capture energy from the motion of water particles. The greatest energy is available in open seas and oceans where wind generated waves can develop over great distances. Over the decades, a wide variety of WEC concepts have been developed to harness this energy, some remaining as interesting academic exercises, but others deployed at full scale at sea. They are mostly designed to be located offshore, but some may be mounted on the coastline or integrated into breakwaters. Inconsistencies in support and funding over the early years had hampered efforts to fully prove technologies, and further demonstration is still required to build confidence in the ability of WECs to produce significant amounts of power, consistently, over multiple years of operation.

While wave energy is at an earlier stage of development than tidal stream, in more recent years there has been more consistent progression of the development and demonstration of WEC technologies, including significant commitment of resources on research in Scotland. International collaborations have produced guidance for developers and funders to ensure a more consistent and methodical technology development process and making it easier to evaluate progress [15]. All this work is helping to bring the sector closer to being commercially viable. Wave energy farms are expected to be demonstrated in Europe in the next five years, supported by European Commission Horizon Europe project funding.

Future wave energy arrays have the potential to be co-located with offshore wind farms, which are beginning to consider locations further offshore, in deeper water and have an energetic wave climate. This would enable further opportunities for smoothed, combined power export and improved economics by sharing infrastructure, services and supply chain [16].

Globally, many different types of market applications, projects sites and metocean conditions are being considered for ocean energy applications. Many developers are focused on large-scale WEC connected and providing power to electricity grids; others are investigating smaller or alternative markets such as remote island communities [17], potentially as a stepping-stone to building a larger grid-scale WEC. This will undoubtably result in many different types of WEC being developed to optimally harness the widely varying wave resource. Indeed, different variants of WEC concept may be developed for higher or lower energy sites.

Table 2.1. Summary of offshore renewable energy technologies

Technology	Description
Offshore wind	The most developed ORE technology, with commercial deployment of multi-GW windfarms. Historically, turbines have been mounted on steel monopile foundations, but with projects moving to deeper water, jacket foundations or floating platforms are being developed and installed.
Wave energy	Many concepts have been developed and tested to capture energy from the wind generated waves and swell that propagate across the seas. However, there is no design consensus, and no technology has yet been proven to produce significant amounts of power over multiple years of operation. Further development and demonstration of wave energy is ongoing, including significant research in Scotland.
Tidal range	Tidal barrages or lagoons can be used to impound the rise and fall of the tides and used to drive conventional low-head hydro-electric turbines mounted into the structures. While established technology, only a few schemes have been built worldwide, given their significant upfront costs and potential environmental impacts on estuaries.
Tidal stream	Tidal stream turbines can capture kinetic energy from tidal currents flowing around the coast, in a similar manner to wind turbines. As water has around 800 times the density of air, smaller diameters are used for tidal stream turbines, but the blades need to be much more robust. As they do not completely block the channel, the impact on the marine environment is not as detrimental as tidal range.

Contracts for Difference

Starting in 2014, the Contracts for Difference (CfD) scheme is the UK Government's flagship program for supporting low-carbon electricity generation. It is based on top-up payments between a wholesale market reference price and a strike price, offering developers long-term price stability. CfD are awarded via competitive auctions, which has enabled notable cost reductions. Renewable energy projects often have high upfront costs and long lifetimes with low running costs, making them less attractive for traditional investment. The CfD scheme incentivises investment in these by providing project developers protection from volatile wholesale prices over a 15-year period.

To date, there have been six allocation rounds (AR) which have seen a range of renewable energy technologies bid into competitive auctions for contracts. The CfD budget for these auctions is split into different 'pots' for established and less established technologies and covers a range of technologies from biomass and geothermal to onshore wind, wave and tidal.

In AR 4, 5 and 6, tidal stream benefitted from a dedicated minimum budget in the auction, where support is ringfenced for tidal stream in the CfD auction round before the competition opens up to other renewable technologies. This resulted in contracts being awarded to seven developers across 21 different projects, delivering over 120 MW of tidal stream capacity in the UK, expected to be commissioned between 2026 and 2029. Discussions are ongoing across the sector regarding the future of CfD pots and ringfenced budgets to accelerate wave and tidal energy projects, and in particular a future ringfence for wave.

2.2 Wave energy resource – UK & Scotland

Estimates of the entire wave energy resource within the UK waters vary, depending on the scale and scope of the modelling undertaken. Some resource studies present the full theoretical resource, or the total energy contained in the incoming waves. Others limit this to a practical or economic resource, considering other users of the seas and the costs to build these projects.

The practical wave resource in the UK could be significant, over 100 TWh/year, or around 24 GW of installed capacity. This is enough for 37 million typical UK households[1]. More than 60% of this wave resource is located in Scotland, distributed around the coast, with the most energetic swell along the exposed Atlantic Coast to the north west [4,18–20].

2.3 Wave energy deployment to 2050

While there is not yet a pipeline of commercial wave energy projects, there is ongoing activity to develop the sector, both in Scotland and internationally. Further demonstration and testing of wave energy devices at EMEC is expected in 2025/26 and beyond, including the Ocean Energy buoy and the next-generation Mocean WEC.

In Europe, AW Energy was awarded Horizon Europe funding in 2024 to develop and test an array of four WaveRoller WECs in Portugal over the next five years, within the Ondas de Peniche (ONDEP) project. The ONDEP project also aims to establish 11 wave energy farms in eight countries by 2030. Also in Portugal, CorPower Ocean have been testing their commercial-scale C4 WEC at Aguçadora since September 2023, and plan to install a further three C4 WECs in their HiWave-5 project.

Further afield, the United States' Department of Energy increased funding for ocean energy in 2024, bringing the total budget over the past five years to over $520m. Several wave test sites are being constructed around the country, with multiple developers expected to test WECs in the coming years. At the state-level both California and Oregon enacted laws to facilitate wave energy. In the past few years, China has implemented policies and plans to further develop ocean energy, including large-scale wave energy demonstration projects.

[1] Based on Ofgem estimate of typical household using 2,700 kWh of electricity per year.

Other renewable energy technologies have seen rapid growth in deployment, and with the global focus on decarbonisation and Net Zero, wave energy could follow a similar pathway.

2.3.1 UK deployment

There is the potential in the UK to deploy over 6 GW of wave energy by 2050, based on results of a detailed market allocation analysis of UK deployment of offshore renewable energy by Energy Systems Catapult (ESC) [21]. That study focused on UK deployment of wave energy, tidal stream, and floating offshore wind. The results from an Energy Systems Modelling Environment (ESME) run by ESC are shown in Figure 2.1.

ESME is a widely used optimisation model of the whole UK energy system, obtaining lowest-cost while satisfying constraints such as the provision of energy service demands in buildings, transport, and industry, all subject to CO_2 budgets [22]. These 2050 ESME results present a UK energy mix aligned to the Committee on Climate Change 'Further Ambition' position defined in their Net Zero technical report [23]. Within this work, it is assumed wave energy meets the cost reduction targets outlined in 2018 by the EU Strategic Energy Technology (SET) Plan, of 150 €/MWh by 2030 [24], with continued cost reduction beyond.

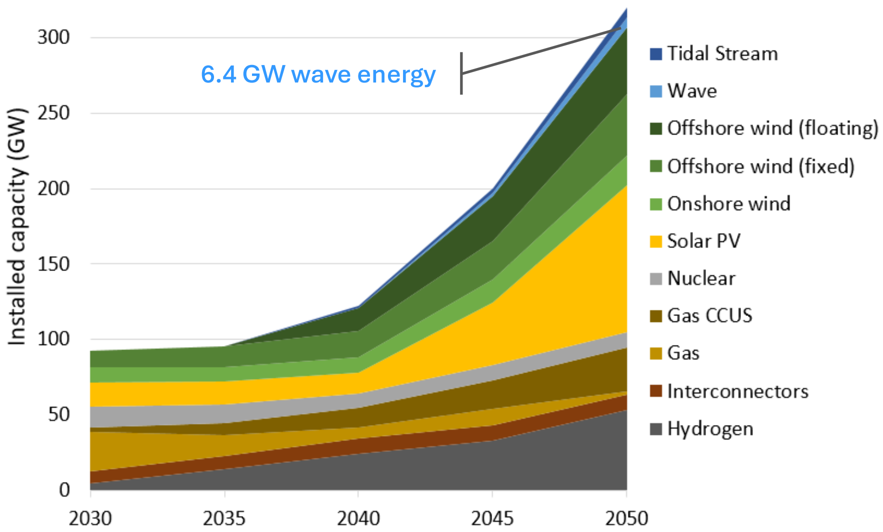

Figure 2.1. Modelled UK energy mix to 2050 under SET Plan LCOE for wave & tidal stream [21]

2.3.2 Global deployment

The global market for wave energy is much larger than the domestic market, albeit with greater uncertainty and relies on deployment targets to be set by governments across the world. Our analysis is consistent with the recent *International Roadmap to Develop 300 GW of Ocean Energy by 2050*, published by International Energy Agency's technology collaboration programme on Ocean Energy Systems [2]. This total comprises 120 GW of global tidal stream deployment, and 180 GW of wave energy. Modelling or estimating where all this deployment will occur is outwith the scope of the present study.

2.4 Wider benefits of wave energy

Several recent studies have quantified a range of wider benefits of offshore renewable energy including wave energy within the electricity generation mix for a country or local grid.

Firstly, ocean energy offers an additional source of domestic renewable energy to help meet energy security, decarbonisation and Net Zero targets. It can also contribute to both Scotland and the UK being net exporters of electricity. As outlined above, there is a wave energy resource of around 14 GW in Scotland, with potential deployment by 2050 of 4.5 GW. This is relatively small, but not insignificant compared to the projected 43 GW of offshore wind or nearly 9 GW of solar expected in Scotland by 2050 in the National Energy System Operator's Holistic Transition scenario in the latest Future Energy Systems report [25, fig. ES.C].

There are also power system benefits, which result from the timing of the resource being offset from both wind and solar [9–11]. Unlike solar, the annual pattern of wave energy resource is well matched to demand in Scotland, with greater generation expected over the winter months, as shown in Figure 2.2.

Power systems modelling within the EVOLVE project considered including 1 GW of wave energy within the future generation capacity mix for the GB grid in 2030, while keeping the total renewable generation availability constant. This showed that the total renewable energy dispatch increased, while the fossil fuel dispatch reduced with associated CO_2 savings of 120,000 tonnes. Incorporating 1 GW of wave energy generation reduced the average marginal price over the year by 0.6%, leading to potential annual cost savings to the consumer of £90 million [26].

Finally, there are economic benefits, both in terms of value added by the supply chain and the jobs supported. Previous studies quantifying this are covered in section 1.2, and the benefits to Scotland are explored further in this study. Given the geographical distribution of the wave energy resource, a significant fraction of these will be skilled jobs in coastal communities and around the Highlands and Islands.

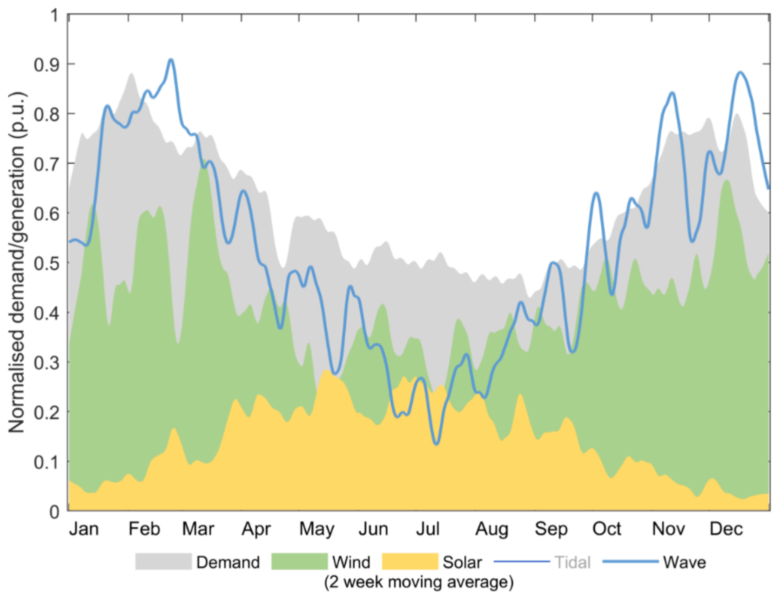

Figure 2.2. Normalised demand and variable renewable generation for Great Britain compared with wave energy resource, based on 2019 weather data.[26]

2.5 Wave energy supply chain overview

Wave energy is an emerging industry, which has yet to reach large-scale commercial deployments. As such, the supply chain that underpins the wave energy sector requires tailored policy support to ensure it evolves to meet this ambition. However, great care must be taken to ensure that the associated GVA and socio-economic benefits that will accompany any supply chain development are retained in Scotland. This can be accomplished in a number of ways:

- Growing the domestic market, with a focus on pilot farms in the short-to-medium term.
- Identifying potential international export opportunities, both technologically and skills based.
- Identifying synergistic overlaps with the development and deployment of complementary technologies, such as the wind and tidal stream sectors.
- Identifying key innovation areas for subsystem development through which the competitive performance of Scotland's supply chain can be increased.
- By sustainably growing the Scottish wave energy supply chain to accelerate and re-risk the delivery of projects.

Achieving these aims is essential to ensuring that the GVA and socio-economic benefits outlined in the later sections of this report are unlocked and their value re-invested into Scottish companies, organisations and communities. Currently, the supply chain for wave energy in Scotland is supporting the construction of bespoke one-off wave energy concept devices from a limited pool of developers. Given the potential increase in demand for wave energy in the coming years, it is vital that Scotland not only increases its ability to competitively manufacture the various subsystems required, but also begins preparations for the sector to scale production to meet the volumes and capacity expected.

There is also a considerable opportunity for the wave energy sector to utilise the growing supply chains for the offshore wind and tidal stream sectors. These will likely have significant overlap, albeit with specific requirements for each technology. The opportunity for co-location of wave energy and offshore wind may also offer additional benefits through a shared supply chain.

The challenges faced by the Scottish supply chain, such as access to funding, availability of skilled workers, innovation of materials and components, and build-out of supporting infrastructure, impact both technology developers and commercial manufacturers alike. However, the policy mechanisms that are required to respond to these challenges and increase competitiveness across the entirety of the supply chain are very different. For example, the policy support required for a technology developer or research organisation to investigate the use of flexible elastomers and polymers for direct generation applications will not be the same as that that is required for manufacturers to incorporate their findings into their manufacturing and fabrication process, despite the fact that they are both contributing to increasing the competitive performance of the sustainable energy technology sector. Therefore, gaining a better understanding of the current state-of-the-art within the Scottish supply chain, and how this compares to its industrial competitors, is a vital step towards improving competitiveness and scalability of production across the entirety of the supply chain.

2.6 Infrastructure to support wave energy

In addition to a strong supply chain, suitable infrastructure will be needed to enable the deployment of wave energy in and around Scotland. Key requirements will be ports and harbours to support both the deployment and operation, plus the electricity transmission grid to deliver the power to where it is needed. There is a significant overlap both with the significant planned deployment of offshore wind, including floating turbines, and with the development of tidal stream projects around Scotland. Although the requirements for wave energy and tidal stream projects will differ from those of offshore wind, and the scale for both is likely to be significantly smaller, all these technologies need to be considered in aggregate when planning these large-scale infrastructure projects.

Incorporating future wave energy projects into infrastructure planning requires visibility of the likely locations for the construction of wave energy farms. As noted in section 2.2, the majority of the wave resource in Scotland is located in the north and west, on the exposed Atlantic coasts. Wave energy is already considered within Scotland's National Marine Plan [27], and this should be updated as plans for wave energy develop further.

2.6.1 Ports & harbours

The UK and Scottish Governments announced in January 2023 that two sites in Scotland were to be given Green Freeport status:

- Inverness and Cromarty Firth Green Freeport: the ports of Inverness, Invergordon and Nigg.
- Forth Green Freeport: Leith, Rosyth, and Grangemouth docks plus Edinburgh Airport.

These special economic zones enable tax incentives and lower tariffs within the defined boundary, for example importing, manufacturing, and exporting goods without being subject to the usual paperwork and import taxes. They are designed to create more high-quality jobs and boost economic output of these regions, as well as attracting other investment including unlocking private funding. The freeports in Scotland are termed green freeports, as they should promote decarbonisation, contribute to the energy transition and Scotland’s 2045 Net Zero target. They also aim to become hubs for global trade, and foster innovation.

In addition to the green freeports, investment will be needed at a range of ports and harbours around Scotland to build and operate future wave energy farms. A recent study into the infrastructural and industrial production requirements for ocean energy in Europe showed that, if wave energy and tidal stream follow a similar deployment trajectory to wind, there will be significant infrastructure requirements over the coming decades, and that planning for this would need to start now [28].

That study estimated ocean energy may only need around 1% of the port space needed for offshore wind projects in the early 2030s; however, by the end of the decade this could grow to around 13% [28]. Given that port infrastructure projects can take a decade or more to develop, it is important to start considering the potential requirements for wave energy and tidal stream projects alongside those for offshore wind.

Wave energy converters are likely to be significantly smaller than offshore wind turbines. They also do not need the unlimited air clearance requirements required for floating wind turbines. Similarly, individual projects are likely to be smaller in scale for wave energy, tens to hundreds of MW versus around the GW scale for offshore wind. These two factors combined means that smaller or more constrained ports may be suitable for wave energy projects, even if they are not suitable for the continued expansion of offshore wind.

A port used to build out wave energy projects of 10–50 MW annually may only require 0.7–6 ha of quayside laydown space, 50–200 m quayside length, water depth of 3–10 m, and clearance of 10–50 m, although this will be dependent on the type of technology used and vessels used to deploy [28].

2.6.2 Electricity grid

The National Energy System Operator (NESO) is responsible for the National Grid in Great Britain [2]. This covers both planning future upgrades at a country-wide level and operating the grid, balancing supply to demand at all times. The high-voltage transmission in Scotland is owned and operated by Scottish and Southern Electricity Networks (SSEN) in the north, and by ScottishPower Transmission in the south. A series of Distribution Network Operators manage the lower voltage supply.

Currently, Scotland is a net exporter of electricity, and this is projected to increase with the continued expansion of all forms of renewable generation. This leads to major grid constraints relating to power flow from north to south. The current peak electricity demand in Scotland is about 4 GW and this is projected to increase to about 6 GW by 2030, and the corresponding generation capacity is presently 17.8 GW rising to approximately 43 GW [29], much of this from offshore wind.

The latest Electricity Ten Year Statement (ETYS2023) [29] highlights that network reinforcement will be required on most of the boundaries used to define critical parts of the transmission system, and plans are in place for some of these. SSEN are planning a transmission network reinforcement to connect Orkney via a new HVAC link, capable of connecting 220 MW, due to be commissioned in 2028. They have also started consultation on a second HVDC link to Shetland with a planned capacity of 1.8 GW, three times that of the first link completed in August 2024.

Further grid upgrades will be required to support the development of increased renewable generation in Scotland, particularly offshore wind including the ScotWind projects. NESO undertook a Holistic Network Design of the grid infrastructure to connect 23 GW of offshore wind in the UK and facilitate the Government's ambition for 50 GW of offshore wind by 2030 [30].

The increased potential from ocean energy, including wave energy, should also be factored into these plans. Indeed, the ETYS2023 already notes "*the prospect of new marine generation resource in the Pentland Firth and Orkney waters in the longer term*", in the assessment of boundary B0 north of Beauly [29]. The National Energy Systems Operator's Beyond 2030 analysis recommends new high-capacity 400 kV circuits will be required, many of these subsea off the east coast of the UK, as well as upgrades to the onshore transmission network. The Eastern Green Link 2 is currently being constructed, a 2 GW offshore link between Peterhead, Aberdeenshire and Drax, North Yorkshire, due to be commissioned in 2029. In November 2024, Ofgem approved an additional five subsea projects, linking the UK with the rest of Europe, including another interconnector between Scotland and Northern Ireland.

As with development of ports and harbour infrastructure, consideration of all forms of renewables in forward planning for grid upgrades will be required to enable the significant future economic potential of wave energy.

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[2] There is a separate grid for covering the whole island of Ireland, which is interconnected to the GB grid.

3 Economic benefit methodology and input assumptions

The main output from this work is an assessment of the future potential economic benefit of wave energy to Scotland. This is quantified in terms of Gross Value Added (GVA) and Full-Time-Equivalent (FTE) jobs, considering the direct and indirect benefits, and where appropriate, also induced effects.

How the market for wave energy will develop over the next decades is not clear, and therefore a series of practical assumptions have been made within the modelling. The reality will be more complex, diverse, and correspondingly more uncertain.

As shown at a high-level in Figure 3.1, the economic benefit is calculated using a set of credible input assumptions on the deployment in key markets, local content retention rates, and the technology and the breakdown of a typical project. A series of scenarios are used to explore the range of potential benefits resulting from the deployment of wave energy, in terms of both GVA and FTE jobs. These are calculated using effects and multipliers from the Industry-by-Industry Input-Output (IO) tables by the Scottish Government, that represent how the different sectors of the national economy interact.

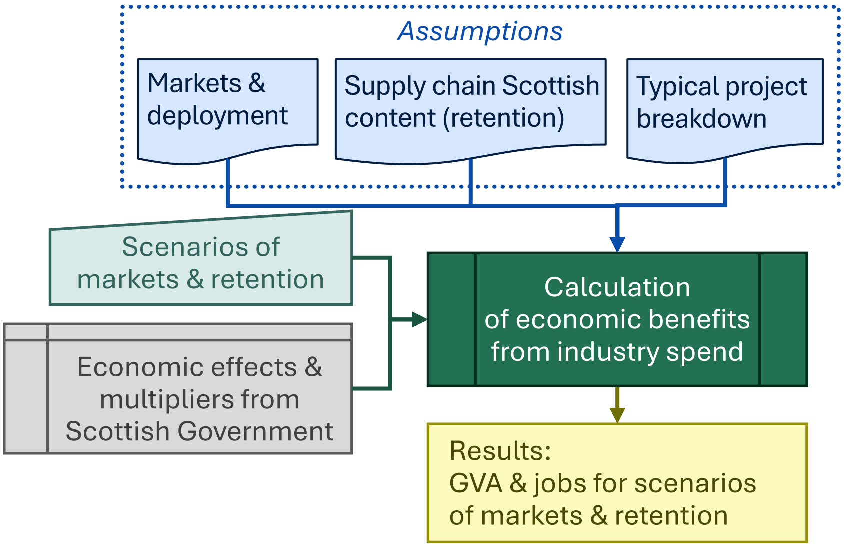


Figure 3.1 . High-level representation of the modelling methodology

The first step is to consider the size and deployment pathway for each of the market geographies considered. The total cost associated with the projects in aggregate is allocated to project stages and supply chain industries, with the contract value that could be won by Scottish content estimated using scenarios with differing retention rates. Finally, the associated benefit to the Scottish economy in terms of GVA and jobs is calculated.

This is discussed in more detail in the following sections:

3.1. markets and deployment pathways to 2050,
3.2. scenarios to illustrate the potential economic benefit,
3.3. local/Scottish content retention rates used in the analysis,
3.4. typical project cost and industry breakdowns, and
3.5. methodology for the calculation of resulting GVA and jobs.

3.1 Markets and deployment pathway

Three markets are considered within this work, shown in Figure 3.2:

1. projects in Scottish waters,
2. projects in the rest of the UK, *and,*
3. the global or export market.

As covered in section 2.3.1, a deployment pathway for wave energy technology in the whole of the UK has been modelled in line with previous work [21,31]. This assumes commercial farms being deployed in the 2030s, with hundreds of MW per year through the 2040s, reaching 6.4 GW by 2050.

Of this UK deployment, 70% (4.5 GW) has been assumed to be in Scottish waters, based on the approximate split of the UK resource in Scotland, and assuming wave energy projects could follow a similar pathway to the tidal projects recently awarded Contracts for Difference (CfD), of which 70% are in Scotland.

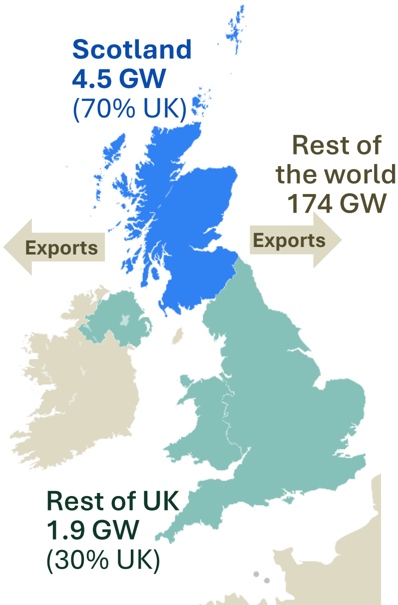


Figure 3.2. Schematic of wave deployment by market

For global deployment, a pathway to 180 GW of wave energy by 2050 has been used, consistent with the IEA-OES vision for ocean energy. 174 GW of this is in the rest of the world, outwith the UK.

In both UK and global trajectories, wave energy deployments are expected to grow year-on-year from 2025 to 2050, although the rate of growth slows over time, as has been observed with other renewable technologies in various regions. The deployment trajectory is smoothed over time, with the implicit assumption that any supply chain and infrastructure barriers are overcome in a timely manner. The expansion of deployment of wave energy is expected to continue well beyond 2050; however, this is not included in the modelling.

While wave energy is an emerging technology with higher levelised costs than other energy sources at present, cost reductions with increasing global deployment are expected, as have been observed for other renewable energy technologies. A central cost reduction pathway with an ambitious but achievable learning rate of around 15% has been used, consistent with previous work and as has been observed in other comparable technologies in recent decades [31]. The cost reduction trajectory is also assumed to be consistent between markets, resulting from collaboration and global supply chains.

3.2 Scenarios used to illustrate potential benefits

For each of the three markets in section 3.1, varying levels of Scottish developer and supply chain ambition has been considered, ranging from moderate ambition up to leaders in the field. Within this, two factors have been used to model the amount of Scottish content within wave energy projects:

1. The percentage share of the market where Scottish companies are involved in projects.
2. Within this subset of the markets, the amount of Scottish content has been modelled using retention rates, as detailed in section 3.3.

These two factors are shown separately for transparency, but could equally be modelled using a single, lower, retention rate.

A set of eight scenarios have been used to illustrate this for the three markets, as summarised below and detailed in Table 2.1. The first four relate to the domestic (UK) market, the latter four are the export market.

- For **Scottish projects**, it is assumed there is some level of Scottish content in all projects, and thus the economic benefit is only limited by the retention rates. The proportion of local content (modelled as a retention rate) is assumed to increase over time as the supply chain develops, as discussed in section 3.3.
- For projects in the **rest of the UK**, it is assumed there are some projects which will have no Scottish content; they will be developed by a non-Scottish company, with the supply chain entirely from the rest of the UK or the rest of the world. We present scenarios where either half or one quarter of projects have no Scottish content, i.e. Scottish companies and their supply chains are active within 50% or 75% of projects in the rest of the UK. For these, similar supply chain retention rates to projects in Scotland are used.
- For the **global export market**, Scottish involvement in a market share of either 5% or 20% is assumed, with constant low or medium market retention rates.

Table 3.1. Scenarios of market share and supply chain retention by market and ambition level

Market & Size		Ambition	Projects share with some Scottish content	Scottish content within those projects (retention rate)
Domestic	**Scottish** (4.5 GW)	Moderate	100%	Medium*
		Leaders	100%	High*
	Rest of UK (1.9 GW)	Moderate	50%	Medium*
		Leaders	75%	High*
Global export (174 GW)		Moderate	5%	Low
			5%	Medium
			20%	Low
		Leaders	20%	Medium

*retention rate reaches this over time

3.3 Scottish supply chain content (retention rates)

The amount of local or Scottish content in the supply chain has been modelled using retention rates[3]. This is simply the amount of supply chain value retained within Scotland, as opposed to going elsewhere. Scenarios consistent with previous sector analyses [4,5,32–35] and with the local content commitments and ambitions set out for the ScotWind leasing round in the Supply Chain Development Statement Outlook documents [36]. A set of low, medium and high retention rates have been developed for five key project cost-centres, as shown in Table 3.2. Retention rates for decommissioning vary by activity, but correspond to those used for installation, O&M and project management. The retention rates represent an average for all projects in each market, although it is acknowledged that there will be significant differences between projects in reality.

[3] These are sometimes referred to as a ‘leakage rates’, where: retention = 1 − leakage.

A very high level of local content has been reported for recent wave energy devices and tidal turbine builds, over 80% in some cases [37]. However, it is assumed this will drop as the industry rapidly gears up to manufacturing 10-100 MW/year, since the supply chain does not yet exist to support this volume. With suitable policy interventions and funding in place the supply chain should develop, and retention rate may increase again over time for domestic projects. The modelled retention rates start at the lower rate and are assumed to increase linearly to the higher rate by 2050. For the global (export) market, a constant rate has been assumed throughout, since other countries' will also develop their own supply chains. The retention levels (low/medium/high) used for the scenarios of Scottish ambition for domestic and export markets are shown in Table 3.3.

Table 3.2. Supply chain retention rates by cost centre for low, medium & high levels

Project cost centre	Low	Medium	High
Development & Project Management (PM)	22%	55%	85%
Generating device manufacture and supply	17%	50%	80%
Balance of plant supply	9%	42%	70%
Installation	10%	43%	85%
Operations & Maintenance (O&M)	17%	50%	85%

Table 3.3. Scenarios of supply chain retention levels for domestic and global markets over time

Market	Scottish Ambition	
	Moderate	Leaders
Domestic (Scotland)	Medium (increasing from Low)	High (increasing from Medium)
Domestic (Rest of UK)	Medium (increasing from Low)	High (increasing from Medium)
Global (export)	Low (constant)	Medium (constant)

3.4 Typical project cost breakdown and allocation to industries

The final set of assumptions relate to the technology, including costs and supply chain industry sectors. This needs to represent a 'typical' wave energy device and project over time, which is an unavoidable simplification. In reality, a range of devices and projects will be developed to suit particular local constraints and characteristics of the natural resources. The cost breakdown is also likely over time to change as the sector and technology develop. It is possible different elements may be more easily automated, or mass produced, leading to different cost reduction trajectories.

A cost breakdown of components for a typical wave energy project was obtained from a study by BVG Associates [38], and then refined using factors from other industries and internal assumptions, splitting these into development, capital, operational and decommissioning expenditures (DEVEX, CAPEX, OPEX, DECEX).

Projects costs have been allocated to supply chain sectors using standard industry classification (SIC) codes, which align with those used in the IO tables. The latest UK and Scottish IO tables are split into around 100 industries, of which 19 are considered most relevant to wave energy projects. This does not capture all aspects of the device build and project life cycle, but it aims to capture the spread of key activities. A more granular breakdown of sectors has been assumed than in previous work, with project costs split into six main cost centres using the 19 SIC codes, as shown in Table 3.4.

The project operational lifetime is assumed to be 25-years, in line with industry expectations. Installation and commissioning occur prior to this, i.e. year 0, with decommissioning in year 26. There is therefore very limited decommissioning by 2050. Construction of the device and balance of plant is assumed to take two years, with the bulk of development and project management costs occurring over five years prior to installation.

Table 3.4. Project stages with Standard Industry Classification codes and timeline used for each

Stage	Share of cost	SIC codes used	Timeline years
Development & project management	5.6%	M691, M692, M70, M71, M72, M73, M74, K65	-4 to 0
Generating device supply	58.0%	C22, C25, C27, C28	-1 and 0
Balance of plant supply	17.5%	C25, C27, C28, C33, F41–43	-1 and 0
Installation	12.0%	H49, H50, H52, C33	0
Operations & maintenance†	4.0%†	C27, C33, H50, K65, L68, M70	1 to 25
Decommissioning	6.9%	E38, H50, M70	26

† annual O&M as a percentage of fixed costs (DEVEX + CAPEX + DECEX)

3.5 Calculation of GVA and jobs

This assessment builds on existing University of Edinburgh in-house GVA models developed for analysis of technologies in Europe, the UK and Scotland [3,5,39]. The model calculates the yearly benefits, per industry and supply chain cost-centre, to Scotland and to the UK, for deployments in Scotland, rest of the UK, and global exports. As described in the previous sections, the model builds on a range of credible assumptions to represent future wave energy projects and technologies.

An annual spend profile was developed based on the deployment and cost reduction trajectories, plus the project timeline assumptions in the previous section. This spend profile includes historical projects and extends beyond 2050 to fully capture all project expenditure. However, only costs occurring in 2024 to 2050 (inclusive) are counted in the analysis.

The GVA and FTE jobs are calculated using effects and multipliers determined from the Leontief inverse of the Industry by Industry (IxI) Input-Output (IO) tables, produced for Scotland by the Scottish Government [40]. These express the GVA and jobs which result from a given spend in each industry within Scotland. The GVA includes direct, indirect, and induced effects, while only direct and indirect jobs have been counted in this work. Direct refers to those immediately linked to the life cycle of the wave energy projects, including Tier 1 suppliers for device manufacture and installation. Indirect then refers to the additional effects resulting from this work by companies supporting Tier 1 suppliers, while induced effects correspond to the knock-on spend within the wider economy. The jobs are quantified as full time equivalent since many of the roles, particularly in the supply chain, will spend only part of their time on wave energy related tasks.

As with all modelling, simplifications and assumptions are required. It is also important to consider that the IO tables are developed using many sources of data, and are a historical view of the economy, which is being used to show potential future benefit. Continuing impacts to the global economy from the COVID19 pandemic and resulting changes in working patterns are not fully captured within these.

The figures calculated only capture the benefits from the lifecycle of developing, building, operating, and eventually decommissioning wave energy projects; they do not capture any additional value resulting from underpinning innovation and research nor the possible exploitation of technical know-how in wider energy markets. It is likely that companies within the wider supply chain developing technology or services for the wave energy sector may also find opportunities in other sectors. It is also assumed that the supporting infrastructure to build and connect wave energy projects is in place, as discussed in section 2.6.

4 Economic benefit results (GVA & Jobs)

For the three markets considered: Scotland, rest of the UK, and global exports, the results are illustrated with a set of scenarios with varying levels of Scottish ambition: Moderate and Leaders, as shown in Table 4.1, and more fully described in section 3.2. Combinations of these scenarios are also presented in the results.

- In the '**Moderate**' ambition scenarios, Scottish developers and their supply chain are involved in a smaller share of export markets and have lower retention rates within those projects, as more of the supply chain is outwith Scotland.
- The '**Leaders**' scenarios have both a larger share of the markets and higher retention rates of Scottish content within projects.

While two levels of ambition are presented, the true figure could fall between or below these. It should also be stressed that to achieve even the moderate ambition scenarios will require significant effort and investment across the sector, including focused policy interventions. It should be highlighted these are not predictions of what will happen, but credible scenarios to illustrate the potential benefits. Within these, the deployment of wave energy, both in the UK and the rest of the world, is predicted to grow year-on-year from 2025 to 2050.

Table 4.1. Scenarios of market share and supply chain retention by market and ambition level

Market & Size		Ambition	Projects share with some Scottish content	Scottish content within those projects (retention rate)
Domestic	**Scottish** (4.5 GW)	Moderate	100%	Medium*
		Leaders	100%	High*
	Rest of UK (1.9 GW)	Moderate	50%	Medium*
		Leaders	75%	High*
Global export (174 GW)		Moderate	5%	Low
			5%	Medium
			20%	Low
		Leaders	20%	Medium

This is a repeat of Table 3.1 for convenience. *retention reaches this rate over time

To achieve even the moderate ambition scenarios will **require significant effort and investment across the sector**, including focused and policy interventions

4.1 Economic benefit in terms of GVA

Results are first presented in terms of economic benefit quantified using gross value added (GVA), including direct, indirect, and induced effects. The total GVA is calculated between now (2024) and 2050, discounted using the UK Treasury Social Time Preference Rate of 3.5%, consistent with previous studies.

4.1.1 Domestic scenarios: GVA from projects in Scotland and the Rest of the UK

The GVA from domestic wave energy projects, i.e. those in Scottish waters and around the rest of the UK, is shown in Figure 4.1. In these, around 4.5 GW of wave energy capacity is projected to be installed in Scotland by 2050, with a further 1.9 GW in the rest of the UK.

For the Moderate Scottish ambition scenario, £1.7bn in GVA results from projects in Scotland, with a further £360m from projects in the rest of the UK, giving a total of almost £2.1bn.

For the Leaders scenario, this increases to £3.2bn from projects in Scotland plus over £1bn from projects in the rest of the UK. The higher ambition Leaders scenario thus has over £4.2bn in GVA to the Scottish economy resulting from projects in Scotland and the UK. Realising this additional benefit will require significant policy interventions plus public and private investment to foster Scottish companies and their supply chains.

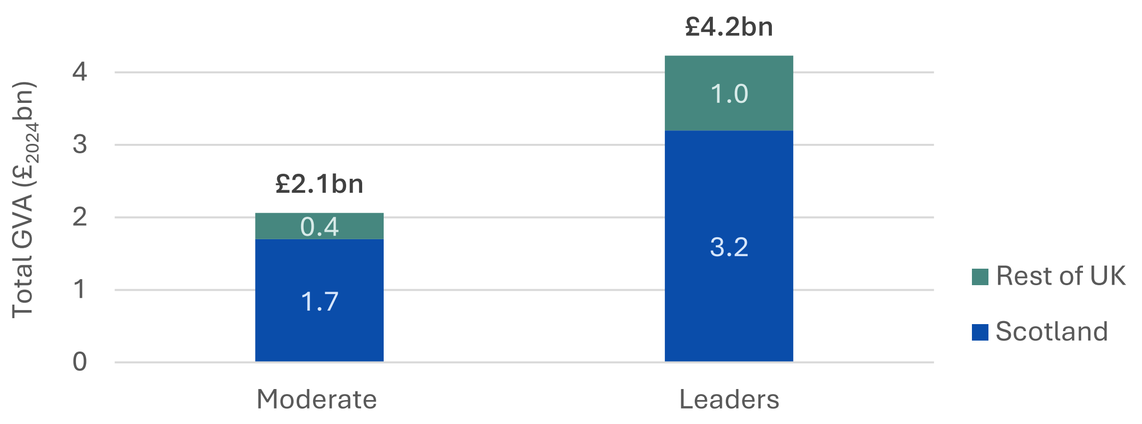


Figure 4.1. Total discounted GVA from 2024 to 2050 by scenario for UK projects

Wave energy deployments in Scotland and the rest of the UK have the potential to generate **over £4.2bn in GVA** to Scotland by 2050

4.1.2 Global export scenarios: GVA from overseas projects

Scenarios of Scottish market share and supply chain retention for global exports are shown in Figure 4.2, broken down by share of the 174 GW global wave energy market that Scottish companies are involved with and by the retention rates achieved within those projects. This shows the economic benefit could range from just over £1.3bn for the Moderate scenario of 5% of the global market with low retention rates, to over £16.5bn for the Leaders scenario with Scottish involvement in a fifth of the global wave energy market and medium retention rates.

It is noted that Scottish involvement in 20% of global wave energy projects is an ambitious scenario but shows the potential scale of the market and benefits available to Scotland with the right policy intervention and support mechanisms implemented in the next few years. In 2018 Vestas had a 22% market share of wind turbines globally [41], albeit this was from manufacturing centres in multiple countries. In both cases, the supply chains would be from a range of different countries.

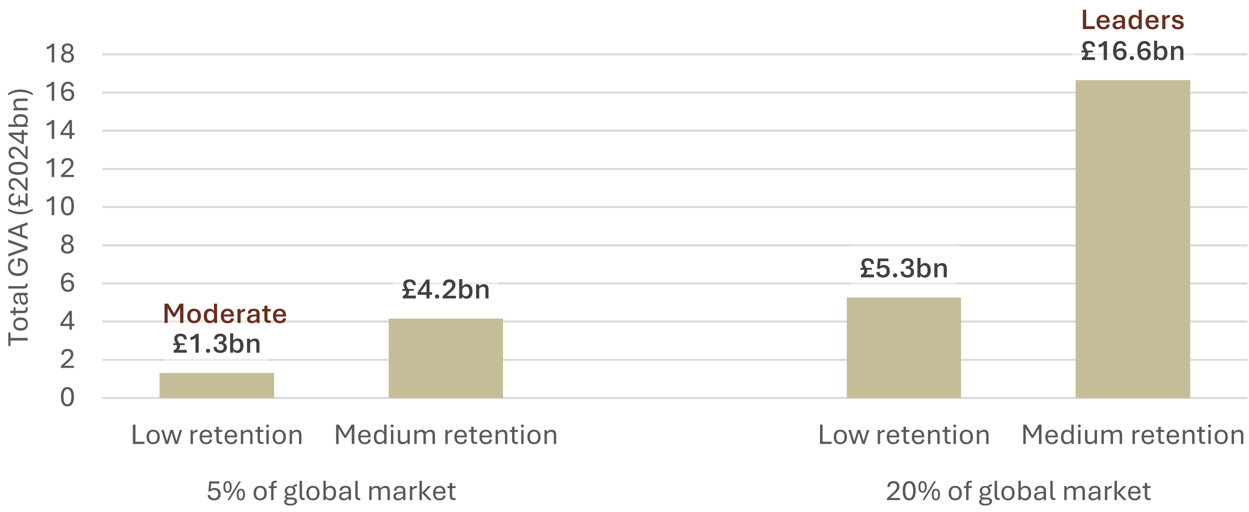


Figure 4.2. Total discounted GVA from 2024 to 2050 for global exports by scenario of Scottish market share and supply chain retention

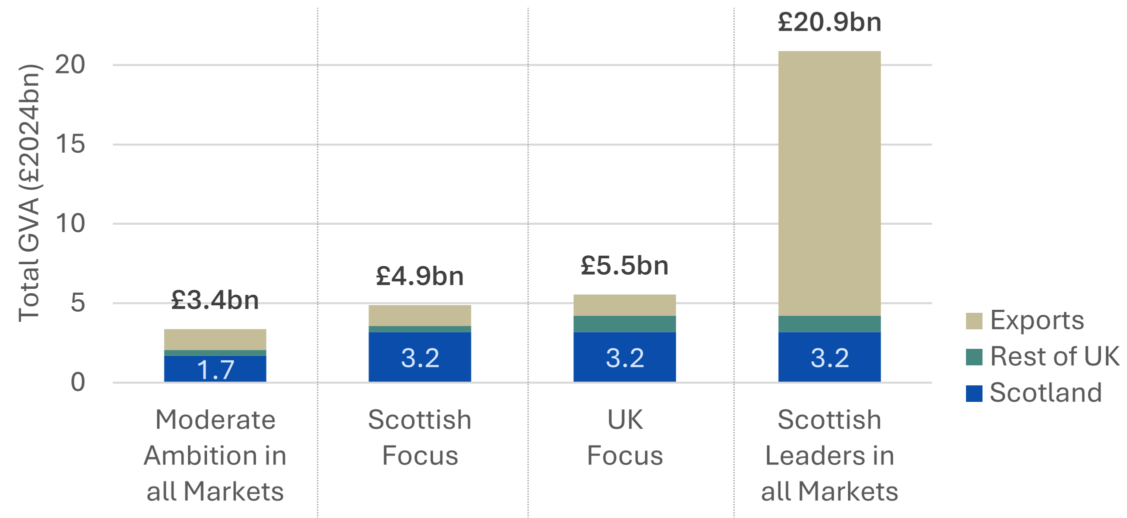
Exports of wave energy technology could have the potential to generate **up to £16.6bn in GVA** to Scotland

4.1.3 Combination of domestic and global scenarios: total GVA from all markets

The total GVA from all markets is then explored using four combinations of these scenarios as follows, with results shown in Figure 4.3:

- **Moderate Ambition in all Markets** — the combined total of the Moderate scenario in the three markets, with lower retention rates and a smaller share of non-Scottish markets. This has a total GVA to Scotland of just under £3.4bn.
- **Scottish Focus** — has higher retention rates in Scottish projects, as Scottish companies are Leaders in this market, but Moderate in other markets. This has a total GVA of nearly £4.9bn.
- **UK Focus** — has higher retention rates and market share in all the UK with Scottish companies Leaders in this whole market, but still with limited global export market share and low retentions. This has a moderately higher GVA than the Scottish Focus, over £5.5bn.
- **Scottish Leaders in all Markets** — is the optimal scenario, with Scottish companies involved in a larger share of all markets and with higher retention rates. This could see over £20bn in GVA generated in total.

The biggest difference within these is the global export market, and as shown previously, both market share and retention rates play a significant role in how successful Scottish companies are. The next biggest difference, is Scottish companies becoming Leaders in Scotland, adding over £1.5bn compared to the Moderate ambition in all markets. It should be noted that all these markets are significant prospects for Scottish developers and their supply chains.



	Moderate Ambition in all Markets	Scottish Focus	UK Focus	Scottish Leaders in all Markets
Exports	Moderate			Leaders
Rest of UK	Moderate		Leaders	
Scotland	Moderate	Leaders		

Figure 4.3. Combinations of total discounted GVA from 2024 to 2050 for all three markets

4.1.4 Split of GVA by project cost centre

The split of GVA by the main project cost centres is shown in Figure 4.4, for the UK focus scenario. The modelling assumptions used mean this split does not vary significantly between scenarios. By far the largest component is the generating device supply, at half the total GVA. Ongoing O&M is then over a fifth of the total. The remaining third is split between balance of plant supply, installation, and development and project management. As the project lifetime is modelled as 25 years, and there are few deployments at present, the GVA from decommissioning is not presented here but would be a growing sector post 2050.

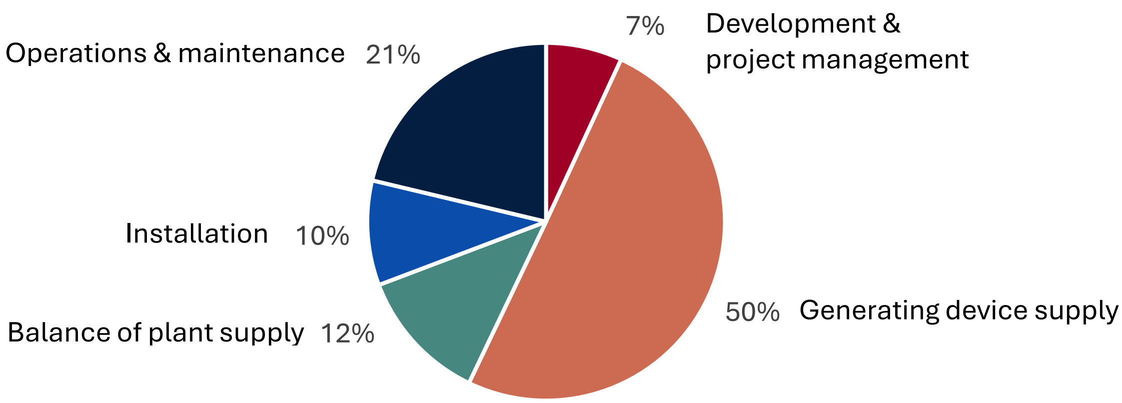


Figure 4.4. Split of total discounted GVA from 2024 to 2050 by main cost centre

Almost **half the gross value added** comes from **manufacturing the wave energy device** with **operations and maintenance** accounting for **over a fifth**.

4.2 Economic benefit in terms of jobs

The results can also be quantified in terms of the number of full-time-equivalent (FTE) jobs in Scottish companies, resulting from projects in Scotland, in the rest of the UK, and from global exports. Some jobs, especially those relating to O&M, may require workers to be based near the project site rather than in Scotland, but they could still be employed by a Scottish company. Conversely, Scottish companies may be able to undertake some aspects remotely, or Scottish experts may travel overseas to the project site.

The results presented include both direct and indirect jobs, rounded to the nearest 50. They are shown for the medium term by the total number of jobs supported in 2035, and for the longer term by the total number of jobs supported in 2050. They are first shown by market and scenario and are then broken down by cost centre and industry.

4.2.1 Total FTE jobs in 2050

The total FTE jobs supported by the wave energy sector in 2050 are shown in Figure 4.5, broken down by market for the four combined scenarios presented earlier.

- The **Moderate Ambition in all Markets** scenario has over 7,800 jobs; nearly 4,500 of these from projects in Scotland, nearly 1,000 from projects in the rest of the UK, and over 2,400 from the global export markets.
- The **Scottish Focus** scenario has nearly 7,400 jobs from Scottish projects, bringing the total to over 10,700.
- In the **UK Focus** scenario, projects in the rest of the UK make up nearly 2,400 jobs, with over 12,100 FTE jobs in total for this scenario.
- Finally, the most ambitious **Scottish Leaders in all Markets** scenario could see over 30,000 jobs from the export markets. Combined with over 9,700 jobs from domestic projects, this brings the total to nearly 40,000 FTE jobs.

These are FTE jobs in Scottish companies, resulting from developing, building and operating wave energy projects in Scotland, the Rest of the UK, and from global exports. This includes those directly employed by developers and Tier 1 suppliers, plus indirect jobs in the supply chain.

Exports in the 'Scottish Leaders in all Markets' scenario represents a very significant opportunity for Scotland, with over 30,000 jobs by 2050, however this is an ambitious scenario where Scottish companies have significant input to a quarter of all wave energy projects globally. It should also be highlighted that some of these jobs, particularly linked to the project development, installation, and O&M may be located outwith Scotland, closer to the project site.

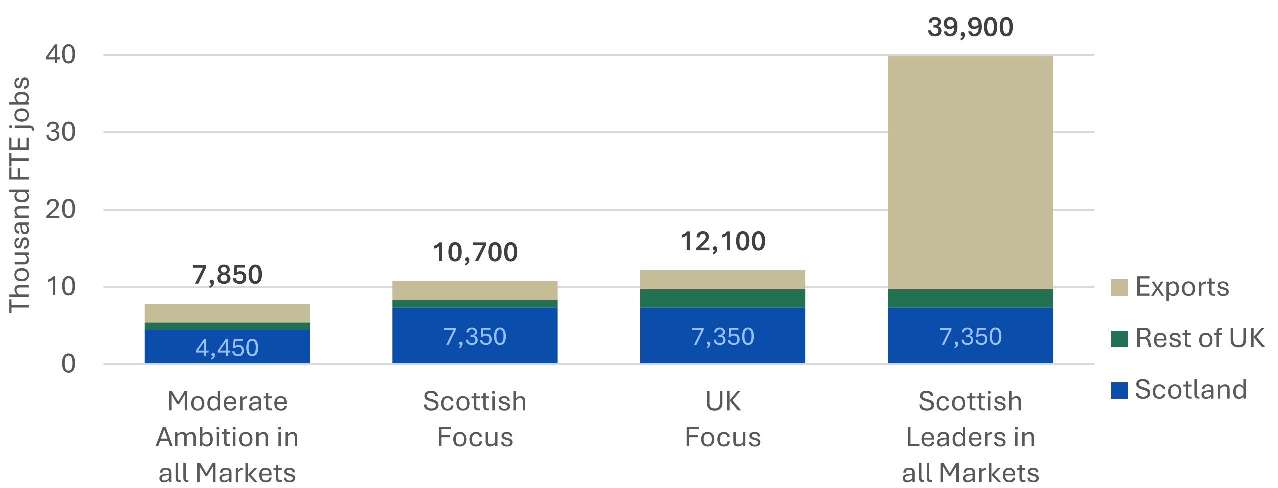


Figure 4.5. Total FTE jobs in 2050, by market and scenario (results rounded)

4.2.2 Jobs by main cost centres

The total number of jobs supported in five main cost centres are broken down in Figure 4.6, shown for the UK focus scenario in 2035 and 2050. There is a projected eight-fold increase in the number of FTE jobs in the wave energy sector between 2035 and 2050, driven by the ambitious deployment trajectory to 4.5 GW in Scotland and 180 GW in the world.

The largest growth in absolute terms is the number of jobs supported by the build and supply of the generating devices, increasing from 800 to over 6,100. In terms of share however, it is the jobs associated with O&M, which increase from around 8% in 2035 to almost 24% in 2050, resulting from the increased number of projects in the operation phase. The relative shares between the other cost centres stays fairly constant between 2035 and 2050, as the project cost breakdown used in the analysis remains constant. Again, decommissioning jobs are not presented, however decommissioning would be a growing sector post 2050.

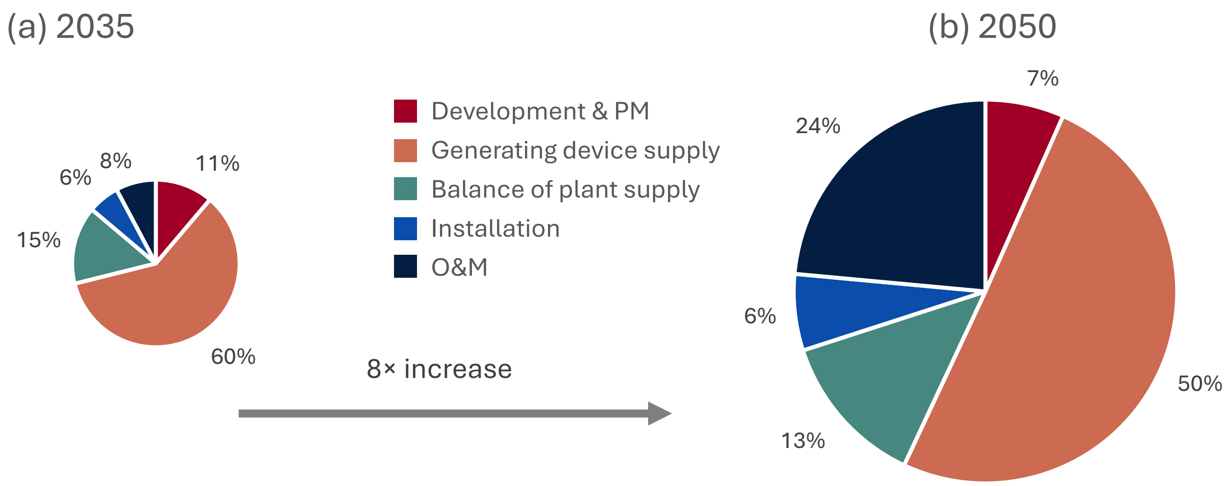


Figure 4.6. Total FTE jobs for UK focus in (a) 2035 and (b) 2050, split by cost centre. Areas of pie representative of total number of jobs.

Around **half the jobs are associated with building the wave energy devices** by 2050 almost a quarter of all jobs are in operation and maintenance of wave energy devices and farms

4.2.3 Jobs by industry

The breakdown of direct jobs by standard industry classification (SIC) codes is shown in Figure 4.7 for the UK focus scenario. It should be noted that these are closely linked to the input assumptions in terms of the cost breakdown and allocation of cost centres to SIC codes.

Within our analysis, SIC section C (manufacturing) accounts for over 70% of all direct jobs within the wave energy sector. Unsurprisingly, around half of this is the manufacture of electrical equipment, with a considerable share also allocated to the fabrication of metal products, i.e. the device hull or other main structures. Most of the transportation and storage is assumed to be water transport for the installation, operation and maintenance.

It is clear there is a significant overlap with other sections of the Scottish economy, particularly the oil and gas industry. Therefore, there is the opportunity for these new jobs in the wave energy sector to contribute meaningfully to the Just Transition as the sector develops.

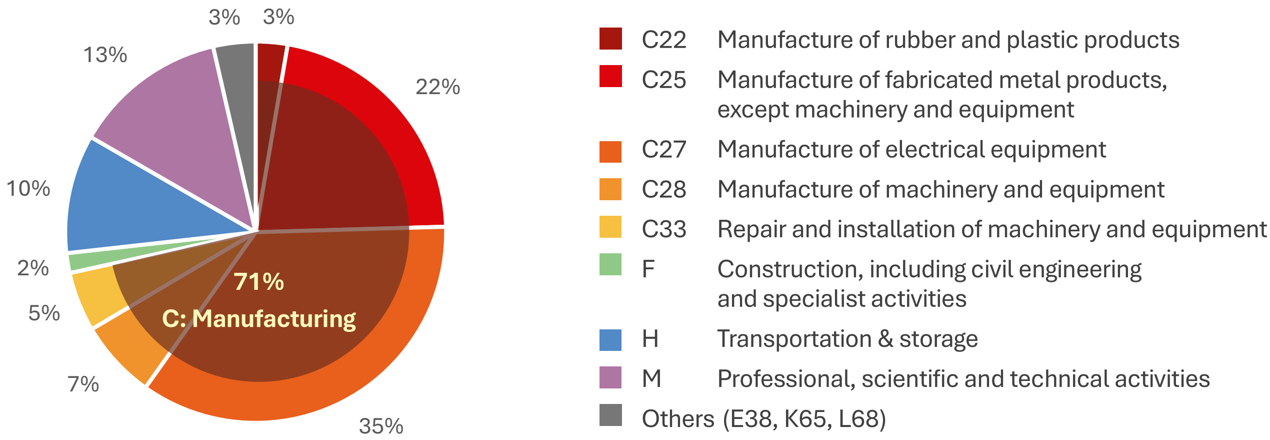


Figure 4.7. Total direct FTE jobs in 2050 for UK focus scenario, split by industry (SIC)

Over **two-thirds of direct jobs** are in the **manufacturing sector**, predominantly for electrical equipment and fabricated metal products.

A strong supply chain will be required in Scotland to support the development, building and operation of wave energy devices and farms, in Scotland, the rest of the UK, and for global exports. This is discussed further in section 5.

5 Scottish wave energy sector supply chain and competitiveness review

The continued development of the supply chain in Scotland for wave energy is of vital importance to the realisation of the GVA and job benefits outlined in the preceding sections of this report. The potential for significant future deployment of wave energy devices underlines the necessity of carefully considering how Scotland's domestic supply chain capabilities can be scaled to provide the subsystems, components and areas of expertise required to meet these volumes. At the time of writing, there are a limited number of people producing the specialised subsystems required for wave energy converters, such as generators and other power take-off components, leading to a relatively small supply chain.

Transparency surrounding the long-term requirements of the supply chain is vital to ensure that as the sector moves towards commercial status and begins to target funding mechanisms designed to deliver devices to the water, there is a high level of Scottish supply chain content contributing to these successful projects. For Scottish wave energy developers, supply chain manufacturers, and national governments, there is increasing importance to having a comprehensive and long-term strategy that ensures both continued innovation with regards to wave energy devices, and their underpinning supply chains. However, it is also important to note that the supply chain for the wave energy sector is still, largely, in the early stages of its development, with technology developers working on an individual device level. As such, the current ability of the Scottish supply chain to produce device subsystems at high volumes should be tempered in the immediate short-term.

To investigate the Scottish supply chain opportunity and future requirements, this chapter of the report aims to analyse the supply chain actions required to support the manufacture of core wave energy device subsystems and areas of expertise. As shown in Figure 5.1, this starts with an overview of the wave energy supply chain, identifying a number of common supply chain categories, covering device subsystems and areas of expertise, that support the wave energy sector. Sections 5.2 and 5.3 then introduce two separate evaluation frameworks:

1. Wave energy supply chain classification framework
2. Wave energy supply chain competitiveness framework

Following an overview of publicly available information on the current market leaders and state-of-the-art for each supply chain category in section 5.4, these evaluation frameworks will be used to help shape recommendations for the future development of each category.

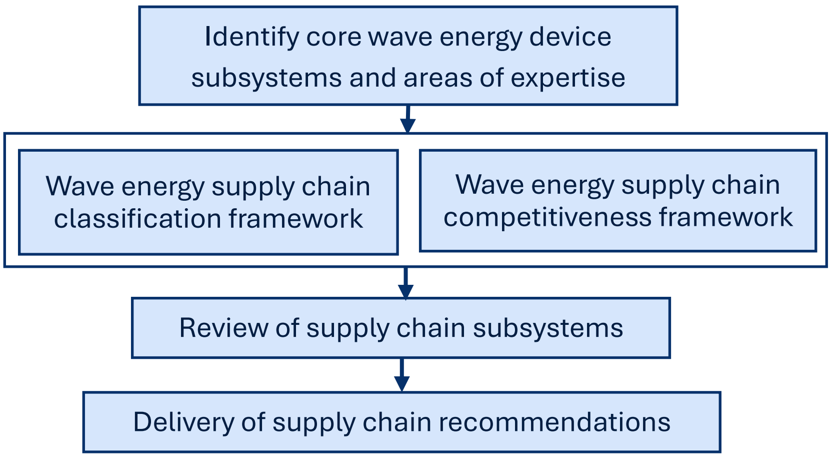


Figure 5.1 Overview of section 5 methodology

5.1 Supply chain categories for device subsystems and areas of expertise

Developing the Scottish supply chain so that it is prepared to support and underpin future wave energy device deployments with a high level of Scottish content is a non-trivial objective. Scotland currently holds a strong position as one of the pioneering nations in the development of high-TRL wave energy technologies. This expertise, built up over several decades, has made Scotland's research, development and deployment facilities and capabilities synonymous with the advancement of the sector.

Scotland is not the only nation actively developing a wave energy sector. Other competing nations, such as the USA, Australia and Portugal, have also identified the benefits of wave energy, both socio-economic and from an energy systems perspective. Given that there is the potential for technological overlap between the wave energy sector and other prominent sectors, such as wind turbine manufacturing, ship building and oil & gas industries, Scotland's competitive advantage could be eroded as the wave energy sector moves forward into an era of global commercialisation and volume deployment. Many of these other nations also benefit from comprehensive policy programmes, well maintained innovation ecosystems, access to private capital and the materials and processes required to underpin robust supply chains. However, the Scottish wave energy sector will be able to benefit from actions in response to the UK's Clean Power 2030 Action Plan [14]. This plan outlines a "*secure, sustainable, competitive and reliable supply chain"* that is delivered *"by both powering up our domestic manufacturing and ensuring access and competitiveness in international markets"* is essential to achieving this ambitious goal. This ambition stretches beyond 2030, with a sustained increase in the need for supply chain competitiveness due to continue out towards 2050.

Therefore, to ensure that Scotland maintains a position as a leading nation developing wave energy technologies and realises the opportunity to deliver device deployment with high levels of Scottish content, it is important to assess the country's capabilities with regards to the development of various supply chain categories, including key device subsystems and areas of expertise. The manufacture, configuration, assembly, and deployment of wave energy devices is a complex systems integration process and one that can vary depending on the design of the device in question. There is, as yet, no convergence in the design of wave energy converter concepts owing to the complexity of harnessing the energy within ocean waves. However, there are several common supply chain categories, covering device subsystems and areas of expertise, that are required for overall device deployment across different wave energy concepts:

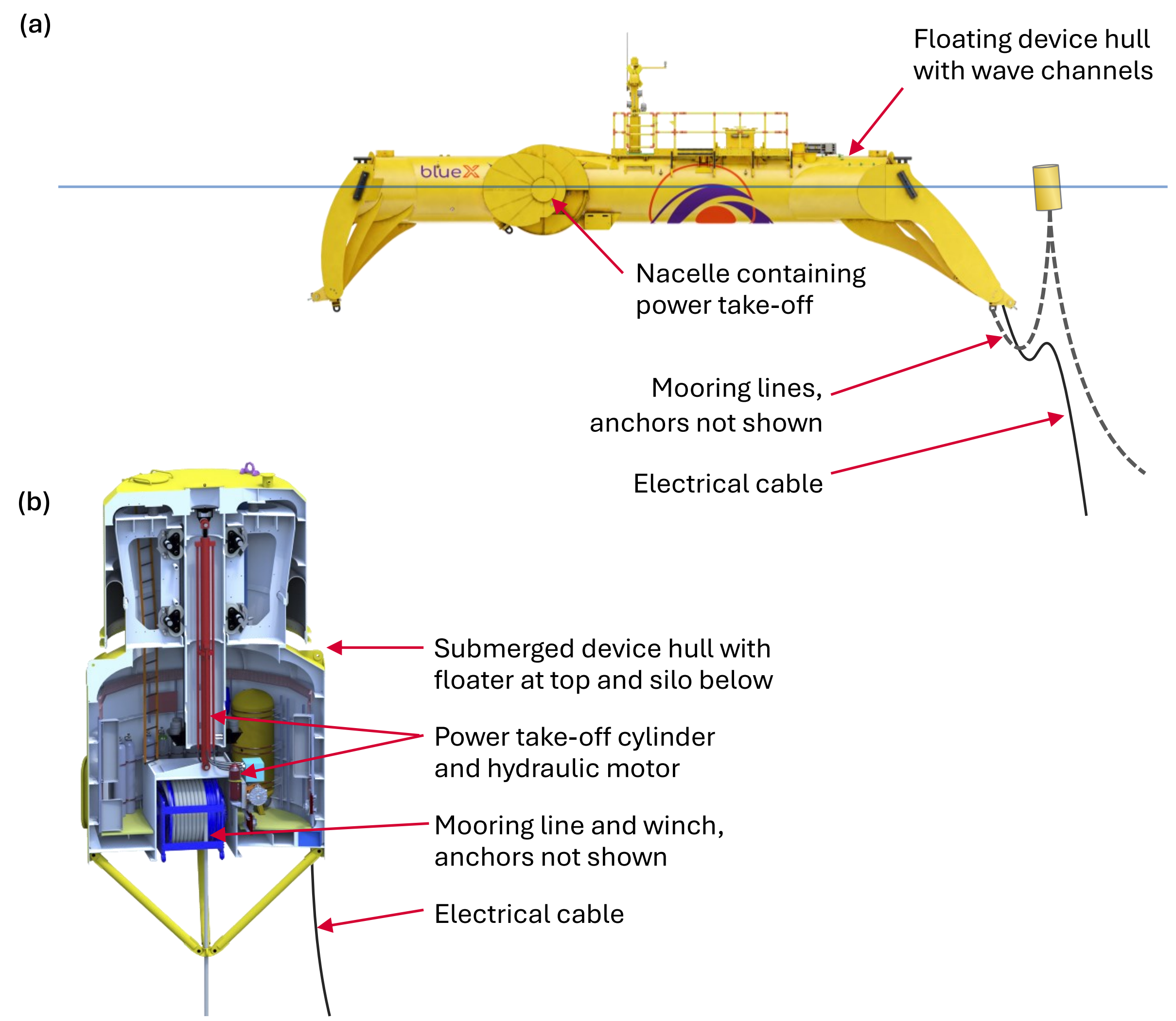
Device subsystems

1. Device hull and structures
2. Power take-off (generators, gearing and control systems) and power conditioning systems
3. Subsea electric cables
4. Device anchors and moorings

Areas of expertise

- Development and testing of devices
- Overall device manufacture/assembly and subsystem integration
- Project development
- Installation, operation and maintenance

These are shown in Figure 5.2 for two Scottish wave energy devices (a) the Mocean BlueX and (b) the AWS Waveswing, illustrating how these different subsystems are utilised across wave energy devices with fundamentally different designs. It is important to note that while these device subsystems and areas of expertise have been identified at a high level to fit with the scope of this report, there is the potential for a large amount of variance in the technologies that underpins each of these categories. Regardless, it is essential for the Scottish wave energy supply chain to develop the ability to competitively manufacture and supply in volume the device subsystems described in the following sections.



(c)

Development and testing of devices | Device manufacture and subsystem integration | Project development | Installation, operation and maintenance

Figure 5.2 Typical subsystems for (a) floating and (b) submerged devices, and (c) areas of expertise

5.2 Supply chain classification framework

As the wave energy sector prepares to scale in line with sector deployment projections, it will be necessary for the Scottish supply chain to evolve alongside it. However, given the range of subsystems identified in the previous section, careful thought must be given to the level of policy support offered versus the potential socio-economic impact and benefit that it will bring to the Scottish supply chain and wider economy.

To help identify which of the underpinning wave energy sector device subsystems and areas of expertise should be prioritised for policy support, this section provides an overview of current state-of-the-art of the various supply chain categories in question. This will enable the opportunity provided by each supply chain category to be assessed, as defined by the four ranking classifications in benefit from infrastructure and supply chain investments and clustering activities, similar to those that have previously been made into other offshore renewable energy sectors.

Table 5.1.

Several of the supply chain categories have been identified as having the potential to move from one classification to another, depending on the level of policy and financial support provided. This has been represented by an arrow indicating the transition from one classification to another. However, even for those categories that were given a single classification, sustained support will be required to ensure that this position does not drop to a lower classification. The wave energy sector may also stand to benefit from infrastructure and supply chain investments and clustering activities, similar to those that have previously been made into other offshore renewable energy sectors.

Table 5.1. Outline of supply chain classification framework

Classification	Description
Leading the Sector	The Scottish supply chain already holds a high level of expertise, both in competitive manufacturing and the potential for volume production. Policy recommendations should aim to maintain and expand this position, while maximising international export opportunities.
Matching the Sector	The Scottish supply chain holds a moderate level of expertise in the manufacture of this subsystem and/or in developing this area of expertise, however other nations are at a similar level with regards to their ability to manufacture competitively and at volume. Policy recommendations should focus on providing support so that this supply chain category continues to grow at a rate consistent with the opportunity that it represents.
Following the Sector	The Scottish supply chain already faces strong international competition with regards to the competitive manufacture and volume production of this specific subsystem and/or area of expertise. Policymakers should carefully consider the credibility of developing the supply chain for this category.
All to Play For	Currently no one country holds a world-leading position with regards to the competitive manufacture and volume production of this subsystem/area of expertise. Policy recommendations should aim to accelerate the growth of this sector in Scotland, positioning the Scottish supply chain to emerge as a world-leader.

These four classifications are illustrated in Figure 5.3, where the vertical axis represents the current strength of Scotland's supply chain, and the horizontal axis shows both the strength of other counties (increasing towards the left) and conversely the potential opportunity for Scotland (increasing towards the right).

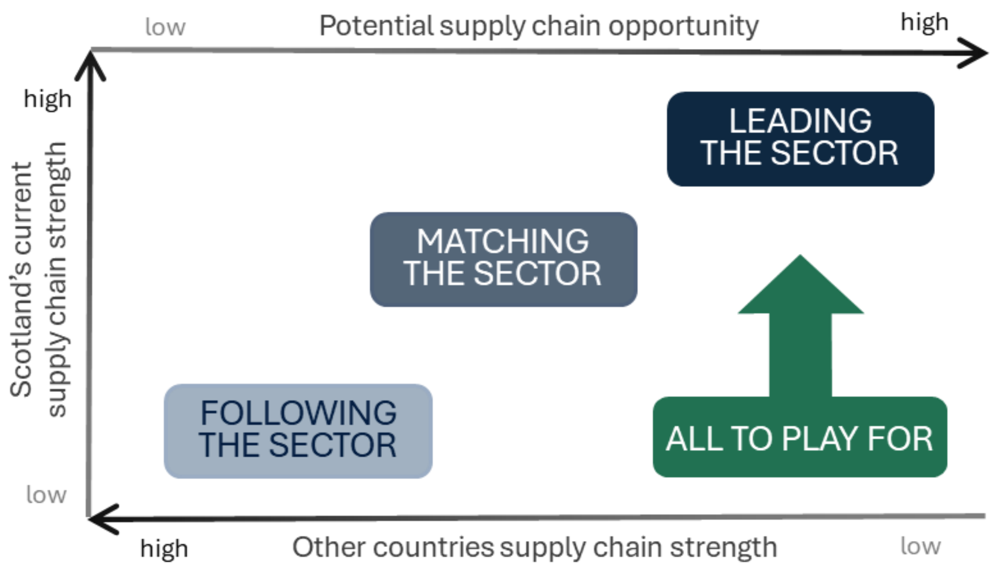


Figure 5.3. Wave energy supply chain opportunity ranking

5.3 Supply chain competitiveness framework

Assessing the supply chain opportunity through an overview of the current state-of-the-art for each supply chain category is only the first step in developing a comprehensive understanding of the Scottish wave energy supply chain capabilities. The development of device subsystems and/or areas of expertise representing the greatest opportunity to the Scottish economy and renewables industry will require the development of comprehensive and informed recommendations. These recommendations should aim to ensure that the underlying factors which may determine Scotland's ability to produce device subsystems and areas of expertise competitively and at volume are addressed.

To ensure that the various underlying factors that contribute to a supply chain's competitive performance are adequately addressed, this chapter makes use of a novel competitiveness framework, as shown in Figure 5.4. This has been designed with the intention of outlining several key factors by which the competitiveness of the wave energy sector's supply chain can be assessed and measured, detailed in Table 5.2. Taking inspiration from the World Economic Forum's Global Competitiveness Index framework [42], a widely used example, this report has identified the following factors, each designed to target a specific aspect of competitiveness policy relating to the wave energy sector.

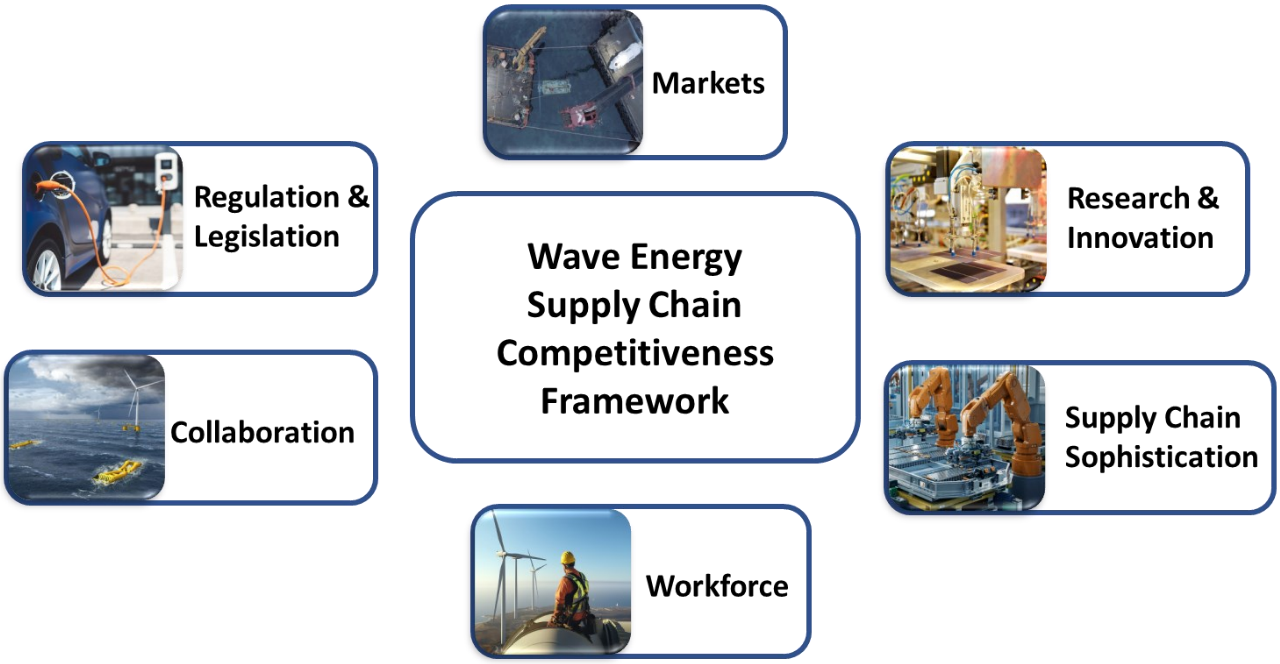


Figure 5.4. Wave energy supply chain competitiveness framework

Table 5.2. Summary of wave energy supply chain competitiveness framework

Factors	Description
Markets	Providing a highly visible and supported route-to-market for underpinning innovations, from technical equipment to manufacturing processes, is essential to increase sector and investor confidence
Research & innovation	Research and innovation efforts are pivotal for the future progression of wave energy helping to provide sustainable solutions to societal, economic and environmental challenges
Supply chain sophistication	Modernising the entire Scottish supply chain, focusing policy and financial support towards areas such as automation and digitisation, to ensure competitive and volume delivery of key device subsystems
Workforce	Assessing the ongoing availability of a skilled workforce across all education levels, bolstered by the availability of focused training to maximize workforce potential and ease the transition from other sectors and countries
Collaboration	The ability to facilitate knowledge exchange and collaborative working between different sectors and stakeholders, combined with the development of innovation clusters
Regulation & legislation	Designing a fit-for-purpose regulatory and legislative framework that helps rather than hinders the accelerated development and deployment of new wave energy technologies and employs appropriate financial tools to support and protect the sector.

5.4 Review of supply chain categories

The following section provides an overview of the supply chain categories considered as part of this report. In doing so it will detail a non-exhaustive list of companies and organisations operating both in Scotland and in other nations around the world. Many of these organisations can be considered multi-national in scope, with their main offices often in different locations from their manufacturing hubs. In the instances where there is limited development of a supply chain for the wave energy sector, companies and organisations with experience in manufacturing device subsystems for complimentary industries, such as the floating offshore wind or tidal stream sectors, have been selected. It is also important to note that due to the relative nascency of the wave energy sector, some of the companies listed below, especially those producing bespoke device subsystems, are still in the early stage of development. As such, expectations around their ability to produce device subsystems at high volumes should be tempered in the immediate short-term. These companies do, however, remain an exciting prospect and, potentially, an integral part of Scotland's future supply chain.

Device subsystems

5.4.1 Device hull and structures

Device hulls and other main structures represent the largest fabricated subsystem of wave energy devices, regardless of the specific design or configuration of the device in question. These subsystems are primarily fabricated using steel and/or composite materials but the use of other materials, such as concrete, have been researched in various projects. The fabrication of floating and submersible platforms is a complex task, requiring high-skilled fabrication techniques and significant space for construction and assembly. However, as the fabrication and manufacture of structural elements for wave energy has been limited to a small number of devices, it is indicative to look to the capabilities of other large-scale fabrication sectors for an indication of how this subsystem may develop, as shown in Table 5.3.

Despite the relatively low number of wave energy devices that have been deployed so far, there is a selection of Scottish companies, shown in Table 5.4 who have played, or have the potential to play, a primary role in the fabrication of wave energy hulls and structures.

Table 5.3. Examples of non-Scottish potential wave energy device hull and structures fabricators

Company	Nationality	Evidence of Supply Chain Capabilities
CS Wind	South Korea	CS Wind recently announcement of the expansion of its North American factory, which is set to become the world's largest wind turbine tower manufacturing plant. This expansion will see it increase its production capacity to 10,000 wind turbine towers annually.
Siemens Gamesa	Spain	Siemens Gamesa has commissioned German steel manufacturing company Salzgitter AG to begin fabrication of its new GreenerTower, a wind turbine made of more sustainable steel and showcasing a marked reduction in associated CO_2 output.
GRI Renewable Industries	Spain	GRI Renewable Industries has worked with Poland's state Industrial Development Agency (GK ARP) to develop an offshore wind tower factory in the Baltic coast city of Gdańsk.

Company	Nationality	Evidence of Supply Chain Capabilities
Titan Wind	China	Titan Wind has a European manufacturing presence in both Germany and Denmark, with the Danish facility producing wind turbine towers.
Mainstay Marine Solutions	Wales	This location has comprehensive new-build and maintenance facilities that benefit from an ideal location in the deep-water port at Pembroke Dock on the Milford Haven Water way. In 2019 they won the contract for the fabrication and assembly of the Bombora mWave device

Table 5.4. Examples of Scottish potential wave energy device hull and structures fabricators

Company	Location	Evidence of Supply Chain Capabilities
Steel Fabrication		
Gray Fabrication	Fife	Extensive experience in the rolling, bending and pressing of heavy plate and has in the past supplied sub-structure components to leading tidal device developers within Scotland.
Texo	Dundee	Texo Engineering & Fabrication has worked with leading wave energy sector developers to design and begin the fabrication of wave energy converters substructures. Texo has a proven track record in the delivery of a complex offshore energy technologies and will help to increase the overall capacity and capability of Scottish steel fabricators to develop highly bespoke sub-structures for the wave energy sector.
Global Energy Group (GEG)	Inverness	GEG owns the Port of Nigg, Scotland's leading renewable energy hub. GEG has extensive experience in providing pre-assembly support for some of the largest offshore wind projects in the UK and its fabrication division has also supplied critical subsystems to these projects. It was recently announced that Global Energy Group were the preferred supplier to lead the manufacture and assembly of several tidal turbine devices as part of their recent CfD award, extending their capability to provide specialised fabrication services to the offshore energy sector.
Malin Group	Glasgow	The Malin Group combines a range of specialist marine engineering companies, with expertise in the fabrication of high integrity, bespoke, offshore steel structures. Their primary fabrication facility is located on the west coast of Scotland and houses one of the largest indoor fabrication sites in the UK.
Composite manufacturers		
Balmoral Comtec	Aberdeen	Balmoral Comtec completed the installation of a manufacturing plant at its new advanced composite facility at Montrose Port, providing a quayside facility where large-scale components for the offshore energy sector can be built, including wave energy substructures.
Shetland Composites	Shetland	A leading manufacturer of composite products for the offshore energy and oil and gas sectors, this includes supplying tidal turbine blades to one of the world's leading tidal turbine companies.

Summary

Scotland possesses a strong basis for fabrication expertise, both in conventional materials such as steel and in the application of novel composite materials. Scotland also benefits from its position as an industry pioneer in overcoming the initial challenges and barriers associated with wave energy device fabrication. However, without significant expansion of existing fabrication facilities and expertise, future large-scale projects could either be curtailed or led by manufacturing and fabrication companies from outside Scotland. Avoiding this scenario will require investment in specialist equipment, automation capabilities, the future workforce and the fostering of attractive industrial settings to ensure that Scotland can compete on both price and quality.

Scottish developers have so far only commissioned a small number of devices, and the fabrication of wave energy hulls and substructures remains a relatively niche industry. The upside of this is that it has enabled high levels of local content as device developers have largely engaged with regional fabricators within Scotland. This has also helped to nurture bespoke knowledge and grow fabricating expertise in response to the unique challenges posed by the wave energy sector. The development of the Nigg Offshore Wind facility provides a strong indicator that Scotland will continue to expand its fabrication capabilities, with the on-site tubular steel rolling facility enhancing the overall capacity of the Scottish offshore renewable energy manufacturing sector.

However, Scotland's position of strength with regards to the fabrication of wave energy device hulls/structures could be eroded if it is taken for granted. Competing nations, with developed manufacturing capabilities in complimentary industries, such as wind turbine manufacturing, shipbuilding, oil & gas and the aeronautics industry, could begin to focus their own domestic supply chains on this opportunity. While the evidence above underlines Scotland's ongoing commitment to expanding its own steel and composite fabrication capabilities, there are international competitors who are both employing innovative manufacturing processes and targeting ambitious manufacturing capacities.

Device hulls/structures
Current supply chain classification — **MATCHING THE SECTOR**

Recommendations to improve supply chain capabilities

- Focused efforts are required to bring an increased number of large-scale manufacturing and fabrication facilities to Scotland. This will require significant financial support to ensure that potential facilities are well provisioned and have sufficient space. Scotland should proactively engage with potential OEMs, who would stand to benefit from these upgraded facilities, as a source of potential investment. For example, the Port of Nigg is likely to be a long-term location where the potential clustering of different offshore developers will lead to localised areas of fabrication expertise.
- By co-locating wave energy fabrication facilities alongside those of the more mature wind and tidal stream sectors, multiple developers can work together, utilising fabrication facilities at a capacity and capability required by shared industry, but not usually available in a single location. The provision of space suitable for assembly may also attract fabricators and manufacturers, helping to foster 'clustering benefits' for workforce and supply chain, as well greater efficiencies from sharing

high-cost infrastructure. Wave energy developers have the added benefit of being able to deliver prefabricated hulls/structures to ports for assembly with relative ease, compared to the wind sector, due to their overall smaller size.

- Significant investment will be required in the upskilling of the existing workforce to ensure that Scottish workers are able to compete with established fabricators, both in the rest of the UK and Europe. This should include efforts to ensure that a steady pipeline of new workers emerges to support the evolving sector, drawing both from the oil and gas sector to help facilitate a Just Transition, and young people entering the workforce.
- The implementation of policy frameworks, similar in design to that used in the recently announced CfD AR7 Clean Industries Bonus [43], could be considered to help promote a minimum level of Scottish content in wave energy projects deployed within Scottish waters. This could help to secure a long-term and predictable market for fabricators of both device hulls/structures and device subsystems.
- Continued efforts to extend the CfD scheme, and sector-specific ringfenced funds, to the wave energy sector could help to bring about a transparent wave energy deployment pipeline. This will help in outlining not only device hull/structure needs beyond 2030, but in a range of subsystems. This will help to enable producers to understand the long-term needs of the sector, bolstering capacity planning in a range of ancillary sectors.

5.4.2 Power take-off and power conditioning systems

The term power take-off (PTO) is a general term that encompasses the subcomponents responsible for enabling wave energy devices to convert the energy absorbed into usable electricity. Unlike the wind energy sector, there is no industrial standard device for wave energy conversion, with this non-uniformity carrying into PTO system design. The issue of PTO variance is further compounded by the need for bespoke generator, gearbox and gearing and control system designs to accommodate for the challenging energy environment in which these devices are deployed. What is consistent across these designs is the need to ensure that the PTO system employed is able to harness the high variability of the wave energy generation profile, which can exhibit large and rapid differences in displacement, accelerations and impact forces.

The following subcomponents will be considered, with each of them receiving an individual supply chain classification:

- PTO, which considers:
    - Generators
    - Gearboxes and gearing
    - Control systems
- Power conditioning systems

Recommendations for these subcomponents will be presented collectively at the end of section 5.4.2

5.4.2.1 Generators

The generator of a wave energy device converts the mechanical energy into electrical energy by using the properties of electromagnetic induction. Due to wide range of PTO systems currently under development, there are a number of ways in which the motion of the waves can be harnessed and converted to electrical power. Given the challenges posed both by the energy generation profile of ocean waves and the need to operate in extremely harsh and violent environments, the fabrication of robust and reliable generators is a major innovation challenge for the sector.

Table 5.5 lists some leading European suppliers of generators to both the wind and tidal stream sectors. However, it should be noted that the global market for wind turbine generators is currently dominated by China, who manufacture 73% of the world's supply [44].

Table 5.5. Examples of non-Scottish generator manufacturers

Company	Nationality	Evidence of supply chain capabilities
Winergy	Germany	A primary supplier of both gearboxes and generators to the wind sector, with over 125GW of gearbox capacity supplied to date, Winergy operates production facilities in Europe, USA, China and India.
ABB Motion	Sweden/ Switzerland	A major manufacturer of generators for both wind and tidal stream sector, offering bespoke generating options for both technologies. ABB Motion has manufacturing facilities in Sweden, Estonia, Finland and India.
Ingeteam	Spain	Specialising in electrical engineering and the production of generators for the energy sector, Ingeteam has installed over 80GW of wind turbine power worldwide, representing an 8% share of the global market. Ingeteam are also investing heavily in power and control electronics, with the opening of a new research facility in Northern Spain.
Elin Motors	Austria	A major manufacturer of generators and motors, Elin Motors possesses one of Europe's most modern motor and generator factories in Weiz Austria.

Scotland does retain a level of domestic expertise in the manufacture of generators, driven in part by the long association with the oil and gas sectors. However, there are few manufacturers producing generators at the scale and ratings required by the offshore renewable energy sector. While this doesn't mean that, with the right levels of investment and support, companies couldn't be developed to meet these standards, it will require time and the implementation of bespoke policy programmes and financing to ensure that Scottish manufacturing expertise in this area is grown. There is much more limited evidence of Scottish capability in the production of generators at the scale required to meet the potential demand of the wave energy sector, as shown in Table 5.6.

Table 5.6. Examples of Scottish generator manufacturers

Company	Location	Evidence of supply chain capabilities
TDC Parson Peebles	Rosyth, Scotland	An established high-value manufacturer, Parson Peebles has extensive experience supplying and supporting power generation solutions to the oil and gas sectors. They are also engaged in national hydropower pumped storage, wave and wind farm projects.
CGEN Engineering/ Fountain Design	Edinburgh, Scotland	Driving the innovation of lightweight modular generators, ideally suited for applications within the wave energy sector.

Summary

Generator manufacture is an established sector, and one that is pivotal to the ongoing global Net Zero transition. As a result, there is extensive international competition, much of which is underpinned by historic and long-term development of manufacturing capabilities and capacities. In nations where expertise in the manufacture of generators has emerged in recent years or decades, this has often been paired with the establishment of significant wind turbine manufacturing capabilities. These conditions are difficult, and sometimes economically unviable, to reproduce. Therefore, advancement of this subsystem should focus on developing Scotland's existing capacity to service more bespoke sectors, such as tidal stream and wave energy.

Generators
Current supply chain classification — **FOLLOWING THE SECTOR** → **MATCHING THE SECTOR**

5.4.2.2 Gearboxes and gearing

While not used in all concepts, a gearbox or other type of gearing, can be used to increase the rotation speed of the generator, allowing the size of the generator to be adjusted in response to the design specification of the device. The global market for wind turbine gearboxes is currently dominated by a number of Chinese companies, who manufacture 80% of the world's supply [44]. In addition to this, there are a number of smaller European companies contributing to wind projects across Europe and the UK, detailed in Table 5.7. There may be opportunities to use non-standard gearboxes, such as magnetic gears, in some WEC concepts.

Table 5.7. Examples of non-Scottish gearbox manufacturers

Company	Nationality	Evidence of supply chain capabilities
Wikov Group	Austria	Wikov Group, based in Prague, has worked experience of delivering gearboxes to both the wind and tidal stream sector.
Winergy	Germany	A primary supplier of both gearboxes and generators to the wind sector, with over 125GW of gearbox capacity supplied to date, Winergy operates production facilities in Europe, USA, China and India.
ZF Wind Power	Belgium	ZF is one of the leading providers of wind power gearboxes with a global market share of approximately 25%. ZF also operates six manufacturing plants across Belgium, India, Germany, USA and China.
Cascade Drives	Sweden	Developed in conjunction with leading wave device technology developers Corpower, Cascade Drives is a relatively new manufacturer of an innovative mechanical drive train that converts linear motion into rotation. This gearbox has already seen deployment and utilisation specifically in the wave energy sector, however it is not currently manufactured at volume.

Summary

By 2026, Europe is expected to encounter a supply chain bottleneck with regards to the supply of gearboxes, as the roll-out of wind turbines outstrips supply [44]. As a result of historical tendencies to outsource the production of these components to nations such as China, Scotland is not well-situated to challenge this current shortfall, nor does it have facilities or expertise in large enough quantities to do so. The established presence of existing expertise and well-equipped manufacturing facilities in Europe, alongside the expansive policy support programmes being offered in the USA, indicates that even if Scotland were to attempt to anticipate a response to this potential shortfall, there is limited advantage to building out domestic capacity.

Gearboxes
Current supply chain classification

FOLLOWING THE SECTOR

5.4.2.3 Control systems

Control systems play an important role in ensuring that wave energy devices maximise their ability to extract energy from the seas in which they are deployed. Ocean waves have constantly varying size and frequency, often in a range of different directions, and control systems are used to help match the response of the wave energy converter to the wave. The behaviour of the converter can be adjusted by changing the stiffness and/or the damping of the PTO system. More advanced control strategies can include some wave prediction, trying to match the behaviour of the WEC to what it expects the wave to be in the coming seconds. The control system can be tuned to optimise different properties, such as maximising power output for each wave, balancing power output against loads in the structure or even some sort of protection mode if sea conditions exceed certain limits. With the right control strategy, power production can be increased and subsequently the WEC become more cost-effective, but this may be offset by increasing complexity in the PTO design specification. The control system comprises both hardware and software elements, some of which may be transferable and adaptable from other sectors. Conversely, bespoke control systems for wave energy may be developed, and this is an area of active research. While many examples of sensors and computing processes can be found in other sectors, the software that will need to be developed will be unique to the wave energy sector. Example companies working on control system hardware and software are listed in Table 5.8 and Table 5.9.

Table 5.8. Examples of non-Scottish control systems manufacturers

Company	Nationality	Evidence of supply chain capabilities
Emerson	USA	Emerson possesses extensive capabilities with regards to turbine control and automation and has a proven track record of working with turbines at array scale, both on-shore and off-shore.
Embotech	Switzerland	Embotech develops software for real-time decision-making in autonomous systems, including wind turbines. Their software, FORCESPRO, is used to design control systems for wind turbines, and has been embedded in a number of leading wind turbine manufacturers control software.
Innosea	France	Innosea is a specialist multi-disciplinary marine renewable energy firm with experience of working with leading tidal stream and wave energy developers to develop innovative control systems.

Table 5.9. Examples of Scottish control systems manufacturers

Company	Location	Evidence of Supply Chain Capabilities
MaxSim/University of Edinburgh	Edinburgh	MaXSim is a small-scale academic-led spin out company from the University of Edinburgh that has successfully progressed to the third stage of Wave Energy Scotland's control systems funding call.
Queen Mary University/ Mocean Energy	London/ Edinburgh	Researchers from Queen Mary University School of Engineering and Materials Science are working with Mocean Energy to develop an adaptive hierarchical model predictive control framework for wave energy converters (WECs).
Sequentec	Midlothian	Sequentec is a small company specialising in the design and production of electronics and control systems as well as developing prototype boards and test systems. They are able to design and produce electronics and control systems for applications where a traditional PLC based approach may not offer the processing power, flexibility or redundancy demanded by the application. They have a proven track record of designing real time control systems and hardware for offshore wave power converters.
Industrial Systems and Control Ltd	Glasgow	Industrial Systems and Control Ltd provides control engineering services to industrial end-users through first class tools, technologies and consultancy capabilities and has established itself as a leading industrial control consultancy. ISC have been involved in wave energy R&D activities, providing control systems to WEC developers in conjunction with Wave Energy Scotland research projects.

Summary

The development of control systems for the wave energy sector is a key undertaking with regards to maximising the efficiency and cost-effectiveness of wave energy devices. However, control systems that cater to the unique challenges and energy profile of the wave, like the sector itself, are still relatively new. While there is an opportunity for companies and organisations currently providing control systems for the wind and tidal stream sectors to evolve and provide complimentary products for the wave energy sector, there is also an opportunity for domestic wave energy developers, working closely with early-stage academic researchers and innovation accelerators, to establish a prominent position within this subsystem market.

Developments in both the control algorithms and the hardware that they run on will accelerate in the coming years providing an interesting opportunity for Scottish companies.

Control systems
Current supply chain classification

ALL TO PLAY FOR

5.4.2.4 Power conditioning system

The power conditioning system (PCS) is the general term for hardware such as inverters, rectifiers and drive controllers, used to convert electric power from one from to another or to limit current and voltage to maximise power output. A growing fraction of the power generation on the national grid today is PCS based, underlining its importance to the Net Zero transition. Additionally, the rate of penetration levels of PCS-based generation and storage is increasing rapidly due to the increased addition of offshore energy sources that produce variable AC, such as wind turbines. Example companies are listed in Table 5.10 and Table 5.11.

Table 5.10. Examples of non-Scottish power conditioning systems manufacturers

Company	Nationality	Evidence of Supply Chain Capabilities
GE Power Conversion	Paris	GE power conversion designs and delivers advanced motor, drive and control technologies that help improve the efficiency and decarbonization of energy-intense processes and systems, helping to accelerate the energy transition across marine, energy and industrial applications.
Siemens	Germany	Siemens is the largest industrial manufacturing company in Europe, with extensive experience in power conditioning in a range of sectors including energy, rail transport and industrial automation.

Table 5.11. Example of a Scottish power conditioning systems manufacturer

Company	Location	Evidence of Supply Chain Capabilities
Supply Design	Rosyth, Scotland	Supply Design, based in Rosyth, specialises in the design and development of high-performance power converters for leading OEMs and has direct experience of working with the offshore energy sector.

Summary

There are established European supply chains for the majority of OEMs, and companies who are utilising PCS have either direct experience of delivery for renewables projects or complimentary sectors. However, given that there is a level of existing expertise in Scotland, this sector should be carefully monitored to assess the opportunity for these companies to provide bespoke PCS solutions to the wave energy sector.

Power conditioning system **Current supply chain classification**	**FOLLOWING THE SECTOR** →	**MATCHING THE SECTOR**

5.4.2.5 Overall Summary

Scottish expertise in the manufacture of the subcomponents underpinning the PTO and PCS is varied. International competitors such as the USA, China and developed European nations enjoy a large technological lead, underpinned by robust supply chains. While Scottish expertise in complimentary industries, such as oil & gas and the wind sector, has meant that a limited number of companies are now well positioned to contribute to the wave energy supply chain, this may not translate into large-scale sector progression. Funding and investment should be provided to the companies who have an established presence, raising awareness and alerting them to the possible opportunities of serving a smaller, more bespoke wave energy market. However, long-term alteration of current market structures is unlikely given that major competitors have spent decades honing their skillset, technological designs and development capabilities.

Recommendations to improve supply chain capabilities

- Given the large lead enjoyed by major competitors in the development of gearboxes, Scottish government and policymakers should carefully assess the viability of funding this area over other subsystems that have fewer barriers to entry. However, the implementation of a targeted innovation call to support the next generation of PTO and PCS technologies, where the progression of the technology in question builds upon or advances existing Scottish expertise, should be considered.
- Any Scottish industrial strategy should focus on developing workforce capabilities with regards to the assembly of pre-manufactured subcomponents. This will enable a proportion of the associated value chain to be retained by Scottish developers and help to establish and grow Scottish reputation as a world leading systems integrator. This ambition should be supported by the requisite investment in state-of-the-art assembly facilities.
- Investment into Scottish capabilities to maintain and repair PTO systems could further siphon off a proportion of the value associated with this subsystem, ensuring economic returns to Scotland even without a solid manufacturing base.
- Legislation mandating a minimum level of Scottish content in wave energy projects deployed within Scottish waters could help to secure a long-term and predictable market for manufacturers of potential high-value subsystems.

5.4.3 Subsea electric cables

Offshore energy devices have the additional challenge of ensuring that the power they generate can be exported consistently and reliably back to shore. Whether the devices are on the seabed or floating, a wave energy farm will utilise subsea cables and connections in the system. Quick connection systems are being developed for wave energy and other applications. These will link devices, potentially via offshore hubs and substations, to export cables that deliver the power to shore and the grid. Most of these cables are static and will be on or in the seabed, however a portion of the cable at the device, and hub/substation if used, will be exposed to environmental loads such as wave action and tidal currents. Floating devices will require dynamic cables capable of also withstanding the, potentially considerable, motion of the device. These cables come in a range of power ratings, with higher capacity cables typically used for export. Given the lack of established array configurations for wave energy devices, there is no standardised layout, and cable ratings are typically configured to the output of the device. While there is significant commonality with the subsea cables used for offshore wind projects, those for wave energy farms will likely be physically smaller and lower voltage.

The manufacturing process for subsea cables typically involves a conductive core, made from either copper or aluminium, insulated with a synthetic material. Various specialised equipment is also required for manufacture, including plastic extruders, vertical layup machines, horizontal armouring machines, and cable spooling equipment. There is also a need for appropriate storage, transportation and deployment tools and vessels.

A number of high-profile European cable manufacturers are listed in Table 5.12. There have been two recent high-profile examples of investment into Scottish subsea cable manufacturing capabilities, listed in Table 5.13.

Table 5.12. Examples of non-Scottish subsea electric cable manufacturers

Company	Location	Evidence of supply chain capabilities
NKT	Denmark	NKT has production facilities in 10 European countries, and recently acquired a cable manufacturing business in Runcorn, providing NKT with cable manufacturing capacity in the UK. NKT has also opened a new UK head office in Teesside, England, to serve ongoing and future projects along the UK east coast.
Nexans	French	Nexans is the second largest manufacturer of cables in the world and has recently finalised the expansion of its Norwegian subsea cable facility to address regional and global demand.
Prysmian	Italy	Prysmian is the world leader in the production of cables for the offshore sector and has extensive global production facilities, catering to a range of markets. This includes a headquarters in Southampton and three further manufacturing facilities in the UK.
Hellenic Cables	Greece	Hellenic cables, a Greek company, has production plants and logistic centres in Greece, Romania and Bulgaria.
JDR Cables	UK	JDR cables, a British company, has expanded manufacturing facilities at its Hartlepool factory in recent years, in response to the increased demand for subsea cables from the UK's oil and gas and wind industries. This has also resulted in the planned opening of a new factory in Blyth, with construction currently underway.

Table 5.13. Examples of planned Scottish subsea electric cable manufacturers

Company	Location	Evidence of supply chain capabilities
Sumitomo Electric UK Power Cables Ltd. (SEUK)	Scottish Highlands	SEUK is developing a facility in the Scottish Highlands capable of producing high-voltage transmission cables. This collaborative project, involving funding from Scottish Government, Highlands and Islands Enterprise and Scottish Enterprise, intends to satisfy the growing demand for subsea cables in the North Sea region, reducing lead times and bolstering Scotland's own domestic production capabilities.
XLCC	Hunterston	The UK Infrastructure Bank has recently announced an investment into the subsea HVDC cable manufacturer XLCC to develop a new factory in Hunterston, with the capacity to produce thousands of kilometres of HVDC cable annually. This project has also committed to providing over 200 apprenticeships as part of its employment process, helping to grow the skillset of the regional manufacturing base.

Summary

With a rapidly increasing number of offshore energy project preparing to come online in the coming years, the availability of medium and high voltage cables capable of transporting power to shore will be critical. However, since the early 2000s, domestic manufacturing of high voltage cables has largely ceased in the UK and the country has become wholly reliant on cable imports from a range of qualified and established European companies. This has been offset in recent years as both the UK (JDR Cables) and Scotland (SEUK and XLCC) begin to increase their domestic capability to manufacture high voltage subsea cables. This is an important step in ensuring that Scotland possesses both the strategic capability to deliver on its Net Zero ambition and the flexibility to meet a range of deployment scenarios.

Subsea electrical cables
Current supply chain classification

FOLLOWING THE SECTOR → MATCHING THE SECTOR

Recommendations to improve supply chain capabilities

- Given the large lead enjoyed by major competitors in the development of this subsystem, Scottish government and policymakers should carefully assess the impact of prioritising these areas over other subsystems. However, given the combination of recent large-scale investment into Scottish cable manufacturing capabilities and the immediate and localised market presented by future deployments in Scotland, the supply chain to support the development of this subsystem is set to undergo a rapid evolution.
- While short-term demand is likely to be met by existing European manufacturers, the medium and long-term supply of high voltage cables is more likely to be sourced from Scottish factories, adjacent to deployment sites. To prepare for the progression of this subsystem sector, Scottish government and policymakers should provide targeted support where necessary to ensure close collaboration between device developers and cable manufacturers. Investment in the necessary ancillary infrastructure, such as cable installation vessels and monitoring systems, can increase Scottish expertise and deepen associated value chains.

- While new factories have been built with the primary function of supporting offshore wind deployments in the North Sea and other large-scale projects around the UK, a steady and transparent pipeline of wave energy deployments should constitute a customer base worthy of cable manufacturing to desired specifications.
- Continued technology innovations, such as the development of subsea hubs that enable multiple wave energy devices to be connected to a single export cable, allowing overall cabling requirements to be reduced, are necessary to ensure that Scotland remains at the forefront of development and deployment.

5.4.4 Anchors and moorings

Mooring systems for wave energy devices can be designed in a variety of configurations and styles with two main options being preferred. Firstly, spread mooring systems, consisting of three or four mooring lines encircling the floating device with either catenary, semi-taut, or taut moorings. Secondly, single-point mooring systems, consisting of a single attachment point to the device that allows the device to weathervane. Mooring lines can be designed with various line types, such as chain, wire rope, or synthetic rope, and can be anchored by various types of anchors, such as deadweight (gravity) anchors, drag embedment anchors, suction piles, or plate anchors. They can also include any number of mooring connectors, clump weights, or buoyancy modules, in any combination of line types, to effectively moor a wave energy device.

The role of anchors and moorings in the offshore energy industry is well-established, however the progression of the offshore wind, tidal stream, and wave energy sectors has introduced a new level of industrial demand for these subsystems that means that innovations in their design, cost, scalability and installation process need to be addressed. There is a need for new anchor, mooring and foundation designs that are able to provide more lightweight and efficient solutions that would be cheaper, locally manufactured and require smaller installation vessels.

There are several international companies, listed in Table 5.14, many of whom have a UK or Scottish presence, specialising in anchors and mooring systems, catering primarily to the needs of established industries, such as oil & gas and the offshore wind sector. In addition to this, there are a number of companies with the capabilities to provide marine operations services to the wave energy sector, both domestically and abroad.

Table 5.14. Examples of anchor and mooring manufacturers and/or marine operation service providers

Company	HQ Location	Scottish presence	Evidence of supply chain capabilities
Delmar Systems	Houston, Texas	Aberdeen	Delmar Systems has an extensive track record of supporting floating renewables, from site selection to the optimisation of mooring systems and loads. Delmar Systems has also recently expanded its manufacturing presence in Aberdeen.
Mooreast	Singapore	Aberdeen	Mooreast provides a wide range of anchor options for floating offshore technologies. In 2023 Mooreast signed a cooperation agreement with the Energy Transition Zone (ETZ) in Aberdeen. Under this agreement, Mooreast will work with ETZ to help support the creation of a manufacturing hub aimed at supplying future projects in the Scottish offshore energy sector.
InterMoor	Houston, Texas	Aberdeen, Montrose	InterMoor specialises in all aspects of mooring, including wave energy converters and floating wind turbines and is capable of delivering a customised cradle-to-grave mooring solution, from engineering and design through to offshore installation or retrieval and decommissioning of its mooring systems. InterMoor has a UK presence in both Aberdeen and Montrose, covering both offices and onshore operations.
Leask Marine	Kirkwall	Kirkwall	Leask Marine has extensive experience providing a range of services to the wave and tidal stream sector, including mooring system specifications, anchoring solutions and operation services.
Schottel Marine Technologies	Germany	Leith	Schottel Marine Technologies specialises in the production of innovative, low impact anchor solutions, designed specifically for the offshore energy sectors. Its acquisition of Edinburgh based Swift Anchors enables previously disregarded or challenging sites to be opened up for development.
Subsea Micropiles	Dublin	Aberdeen	Subsea Micropiles are leading the adaption of land-based micropiling technology to create superior marine foundation and anchor solutions for the ORE sector. In 2024, Subsea Micropile was identified by Scotland's Offshore Wind Energy Council for priority assessment in its Strategic Investment Model Funding round.
MOREK	South-West England	N/A	MOREK is an established provider of marine engineering services with extensive experience of designing mooring spreads for a number of wave energy technologies.

Summary

Currently, the majority of anchor manufacturing facilities are located outside of the UK, which compounds the supply chain challenge posed by the growing pipeline of wind, tidal stream and wave projects. Lead times for acquiring anchors could be increased as a result, potentially delaying the installation of wave energy devices as they compete with established commercial wind farm and tidal stream developers.

The chain and synthetic material manufacturing industry is spread across Europe, with a limited presence in Scotland to date. While there would be a requirement for the construction of manufacturing facilities, sourcing of raw materials and capabilities with regards to welding and machine operators there is the potential for Scotland to invest and build within this market as demand dictates.

Anchors and moorings
Current supply chain classification

FOLLOWING THE SECTOR → **ALL TO PLAY FOR**

Recommendations to improve supply chain capabilities

- Continued financial support for companies driving the development and uptake of the next generation of anchoring systems.
- Ensure that Scottish capabilities with regards to installation fleets evolve alongside anchor development and match the requirements of the sector.
- Integrate the development of remote operated vehicles for anchor installation and maintenance, like those currently under development, into standard practice where possible.
- Aim for increased collaboration between the wave energy sectors and the tidal stream, wind sectors and accredited research institutions to accelerate the development and qualification of moorings and anchors, helping to lower cost and associated risk.
- Ensure that sustained innovation support for the wave energy sector is complimented by a collaborative learning process with the floating offshore wind sector, which is actively pursuing innovation in the same areas.
- Ensure that lessons with regards to best practice, deployment protocols, maintenance and monitoring are learned from sectors with extensive experience, such as the oil and gas sectors.

Areas of Expertise

5.4.5 Development and testing of devices

Building up a national skillset with regards to the research, development and testing of devices is a necessary step in becoming an established leader in the wave energy sector. This will require strategic and significant financial investment into key underpinning infrastructure and hardware by national government and private investors, to deliver a variety of testing infrastructures capable of supporting the sector. A primary focus is the establishment of qualified and well-resourced test centres, capable of providing device developers with the opportunity to perform accelerated testing in a controlled and managed environment both for full scale components or subsystems, and scale testing for others. Accelerated life tests may be required for certification of certain components, while scale model testing is useful for understanding device hydrodynamic behaviour.

This is a challenging task given the complex metocean conditions that the sector must deploy and operate devices in. It will also require large amounts of up-front capital and expenditure to lay the groundwork, waiting for future customers and income. However, this up-front investment is essential to ensure that Scotland remains the preferred testing location of device developers around the world.

Summary

As one of the leading nations in the development of wave energy devices, Scotland has over the previous decades demonstrated its ability to provide a pathway for potential device developers to follow from the inception of ideas to the implementation of concept and designs. This has included, but is not limited to, the building of strong links between device developers and the supply chain; the provision of direct innovation funding; and facilitating interactions with national governments on policy support programmes. In addition to this, Scotland is home to a range of highly innovative wave energy technology developers who have been successful in bringing their technology to market and in accessing funding at national and European levels. Finally, Scotland possesses a truly world-class testing facility in the European Marine Energy Centre (EMEC), with the capabilities to act as innovation catalyst and accelerate technologies to the market. EMEC is the world's first accredited wave and tidal test centre, with more ocean energy devices tested in Orkney, Scotland, than at any other site. Scotland also possesses a range of test facilities, such as the Kelvin Hydrodynamics Laboratory and FloWave test tank, where scaled devices can be tested in simulated-at-sea conditions, plus the Fastblade facility, with the capabilities to test composite structures.

Development and testing of devices
Current supply chain classification

LEADING THE SECTOR

Recommendations to improve supply chain capabilities

- Provide ongoing tasking and funding to existing innovation and support organisations to oversee the well-coordinated and accelerated delivery of device research & development and overall improvements in Scottish supply chain capabilities.
- A primary focus should be to ensure that Scotland is able to provide and promote the capabilities of its testing facilities to bring in prospective developers from around the world.

- Engage in ongoing dialogue with national and international funding agencies to prolong and shape high-level innovation funding support for device developers and the supply chain.
- To help sustain the role of test centres such as EMEC, a clear pipeline of projects should be established and commit to progressing from prototype demonstrations to array deployments over the coming decade.

5.4.6 Overall device manufacture/assembly and subsystem integration

While the preceding sections of this report have considered the Scottish capacity to manufacture individual device subsystems, there is also a need to consider the actions required to enhance Scottish device developers' ability to act as a device manufacturer/subsystem integrator across the supply chain. As the wave energy sector prepares for the deployment of arrays of full-scale wave energy devices, careful consideration should be given to the possibility of Scottish device developers obtaining space to complete the overall device manufacture and developing the necessary underpinning skillsets to establish Scotland as the primary location for the integration of various key device subsystems. Although the development of this capability may not be conventionally viewed as part of the supply chain, development of skills and expertise is vital to ensuring that a portion of the supply chain value, and accompanying GVA and jobs, is always retained within Scotland, even as device export value increases.

Many Scottish wave energy device developers are expressing a desire to maximise local content. There is therefore a compelling case for developing overall device manufacture and subsystem integration capabilities now, while order quantities remain relatively low and developers can afford a high level of oversight. However, as the sector grows to meet the potential deployment trajectory outlined in this report, there will need to be a level of investment into facilities and workforce capabilities to ensure that Scotland remains competitive with other countries who may have similar capabilities gained from other complimentary sectors. This may include the development of factories that offer high levels of automation, procedural efficiency, and storage.

Device manufacture and subsystem integration
Current supply chain classification
MATCHING THE SECTOR

Recommendations to improve supply chain capabilities

- Support Scottish device developers to establish and maintain factory facilities where subsystems can be delivered, stored, assembled, tested and shipped. This should be underpinned by requisite investment in state-of-the-art facilities, allowing for automation in the testing and certification of the device and enhanced training and upskilling of workers.
- A highly visible and transparent market will provide the confidence for both wave energy developers and supply chain manufacturers to secure large-scale investment into requisite factories and facilities.
- Actively pursuing the potential sharing of assembly and storage infrastructure with more established renewable technologies may help to maximise access to already congested portside space.

- Ensuring that any site chosen is well connected by transport links and other supporting infrastructure can increase overall procurement efficiency, helping to ensure that subsystem integrators can proceed at speeds required to match deployment forecasts.

5.4.7 Project development

Many energy projects are developed from early feasibility studies through planning and consenting by one or more project developers, supported by a range of consultants and specialists. This can be a long process, and not all projects will make it to construction. Wave energy farms, in common with other energy projects, will require environmental impact assessment. In turn, this will require a range of specialist surveys and analysis. Project development requires expertise in a wide range of areas. These include resource and metocean assessment, farm layout optimisation, securing the seabed lease and grid connection, plus dealing with the commercial aspects including securing financing and power purchase agreement, plus market support where available.

Historically and currently, wave energy device developers are also acting as project developers, consenting sites to demonstrate their own devices, however this is expected to change as the sector matures. The development of wave energy farms will have many commonalities with other forms of renewable energy, especially offshore. Projects developers currently focusing on other sectors are likely to consider wave energy projects too in due course, as the technology continues to mature.

Summary

Few project developers are focusing on wave energy at present given the pre-commercial status of wave energy technology. However, there are many companies developing offshore wind projects in Scotland, focusing on both fixed bottom and floating windfarms. There are many complimentary skillsets between the development of ocean energy projects, regardless of the technology in question. These can include instances of best practice on the technical, environmental, health and safety, legal and commercial aspects of project development.

Given the high concentration of ocean energy projects in its waters, and the presence of accredited test centres, Scotland is well positioned to establish itself as a world-leader in the development of wave energy projects. As the sector continues to mature, Scotland has an opportunity to export this expertise to other locations, building upon its advantage as an early adopter of wave energy technologies.

Project development **Current supply chain classification**	**ALL TO PLAY FOR**

Recommendations to improve supply chain capabilities

- Establishment and promotion of guidelines for project development in the wave energy sector, informed by a range of actors, including technology developers, test centres and support agencies.
- Direct engagement with technology developers who are leading on the development of projects to showcase their devices, providing support where necessary.

- In the longer-term future, where wave energy projects have scaled to match the ambitions outlined int this report, support WEC developers to engage directly with project developers to streamline the development of large-scale wave energy projects.
- Emphasis on enabling existing companies involved in the value chain of project development across the renewables sector, including surveys and environmental assessments, to also engage and work in wave energy.

5.4.8 Installation, operations and maintenance of devices

Installation of the device covers the towing/shipping of the device to the point where it will be deployed and its connection, via electric cables and moorings. Operations and maintenance (O&M) cover the ongoing services associated with the upkeep and servicing of all components of a wave energy device, including the vessels required to fulfil these tasks, throughout its lifetime. It may also cover other non-hardware aspects, such as providing marine operation services or software requirements. All of these tasks require a highly specialised skillset with regards to training, equipment and vessel use. Within the offshore wind sector, O&M provision is largely handled by the wind turbine OEM, in line with any associated equipment warranties which can often tie OEMs to the project for a set number of years. The wave energy sector is widely expected to follow a similar model of O&M management as that of the offshore wind sector. This will mean that individual device developers will aim to keep responsibility for O&M within their own organisational structures, enabling the growth of their in-house capabilities and maintaining associated revenue streams.

Summary

Scotland has an established reputation as expert in wave energy O&M, honed by the success of domestic testing centres like the European Marine Energy Centre and high deployment rates in national waters. This strong base has led to the development of a competitive edge in areas such as environmental services, asset management and expertise in installation vessels. Scotland is currently able to leverage this position as a tool to draw developers from outside the UK to its waters for both early-stage testing and longer at-sea trial periods. Given the establishment of numerous offshore wind projects in Scottish waters, combined with the historic presence of the oil and gas sector, Scotland is well positioned to continue developing expertise in this area.

Installation, operations and maintenance Current supply chain classification	LEADING THE SECTOR

Recommendations to improve supply chain capabilities

- Continued support for Scottish O&M facilitators to develop new and more efficient methods for O&M, such as remote monitoring and inspection, digital twins and increased number of appropriate-sized O&M vessels.
- Ensure adequate facilities are available for O&M logistics, which will be vital for attracting investment and sector-leading companies. This may include sustained development and upgrading of existing port and harbour facilities, the development of a comprehensive O&M base network, development of the supply chain that supports the delivery and provision of spare and replacement parts for deployment vessels.
- Identify which ports and harbours are most strategically positioned to act as bases for O&M activities.

- Ensure that the workforce underpinning this sector continues to grow in line with scheduled deployments, ensuring that equal focus is given to both vocational training and the transitioning of workers for ancillary sectors.
- Work proactively with those engaged in environmental monitoring and consenting to ensure appropriate use of regulation that helps, not hinders, the development of the wave energy sector.
- SMEs are particularly well suited to exploit opportunities that require a local presence, commercial/technical flexibility or specialist/ innovative solutions. Several UK SMEs have already been successful in this market but there is considerable scope for further involvement, which should be delivered specifically to SMEs.

5.5 Summary of supply chain competitiveness review

Scotland's position as one of the leading nations in the development and deployment of wave energy devices is well understood and is reflected in a high concentration of Scottish device developers, collectively demonstrating sustained levels of technological innovation. However, as the sector continues to grow and planned deployments move from single devices to potential array-scale, there will be a concurrent growth in the requirement for specific wave energy device subsystems and areas of expertise. While significant progress has been made in the development of the Scottish wave energy sector, the supply chain remains relatively small, and some of the of the companies listed above are still in the early stages of development.

As is outlined in the previous sections of this report, Scotland currently possesses a range of capabilities in the manufacture and development of these device subsystems. By strategically targeting subsystems where there is either overlap with existing Scottish expertise or a potential market that can be leveraged to draw outside expertise and investment into the country, Scotland is well situated to capitalise on the manufacture of specific subsystems. Similarly, the development of skills and facilities to underpin critical areas of expertise should also be an area of strategic importance. It is important to note that much of the benefit that can potentially be accrued, through the growth of GVA and jobs, is highly contingent on ensuring that Scotland develops a robust domestic supply chain that delivers high levels of Scottish content to projects deployed in Scottish waters.

Finally, when attempting to attract established companies to Scotland, careful consideration must be given to the pros and cons of establishing conditions that they might find attractive to invest in. Evaluating which incentives Scotland can offer, from preferred manufacturing locations and access to port and harbour facilities to preferential tax rates, must be balanced against the potential GVA it can provide to the Scottish economy.

Table 5.15 provides a summary of the classification's given to the each of the supply chain categories withing this section. For many of the categories, an arrow has been used to show where there is potential for a certain category to move from one classification to another, should the correct support be provided. However, even for those categories that were given a single classification, sustained support will be required to ensure that this position does not drop to a lower classification.

Table 5.15. Classification of current capability of the Scottish supply chain for wave energy

Subsystems and other areas of expertise	Classification
Device subsystems	
Device hull/structures	Matching the Sector
Power take-off and power conditioning systems:	
Generators	Following the Sector → Matching the Sector
Gearboxes and gearing	Following the Sector
Control systems	All to Play For
Power conditioning system	Following the Sector → Matching the Sector
Subsea electric cables	Following the Sector → Matching the Sector
Anchors and moorings	Following the Sector → All to Play For
Areas of expertise	
Development and testing of devices	Leading the Sector
Overall device manufacture/assembly and subsystem integration	Matching the Sector
Project development	All to Play For
Installation, operations and maintenance of devices	Leading the Sector

Section 6 of this report will now build upon the subsystem classification established in section 5, summarised in Table 5.15, and is intended to guide prospective policymakers in the identification of priority supply chain categories and the policies required to support their continued growth and development.

6 Summary and recommendations

6.1 The potential for Scotland

As a result of sector-wide efforts to promote sustained technological innovation, the Scottish wave energy sector enjoys an enviable position as one of the leading nations with regards to research, development and deployment of wave energy devices. In addition to the significant wave energy resource in Scottish seas, Scotland is also home to several leading wave energy developers and possesses a world-leading innovation support programme with an intimate understanding of the sector. Additionally, due to the domestic progression of the tidal stream and offshore wind sectors, the Scottish wave sector has the future possibility to share and utilise an already established supply chain.

There is growing confidence that in the coming years there could be a steadily increasing pipeline of projects fuelling the expansion of the wave energy sector. Coupled with the development of the underlying supply chain, there is an increasingly attractive prize on offer, should Scotland capitalise on this position. A domestic wave energy sector, with a nationally embedded supply chain, has the potential to **provide a meaningful contribution to both Scotland and the wider UK's commitments and ambitions on Net Zero, the Just Transition, energy security, and economic growth.**

Contributing to a Net Zero energy system

As Scotland attempts to meet its ambitious Net Zero targets, there is a need to develop a robust energy system that exploits a range of energy sources. Modelling shows that with appropriate market and innovation support, there is the potential for wave energy to provide a meaningful contribution towards a future Net Zero energy system across the UK and strengthen our overall energy security.

There is the potential for **6.4 GW of wave energy to be deployed in the UK by 2050**, of which **70% (4.5 GW) could be in Scottish waters**.

Fuelling economic growth

There is a time-sensitive opportunity for Scotland to establish itself as a world-leading location for the development, deployment, maintenance and decommissioning of wave energy devices. This will require correct and long-term decisions be taken now, with regards to supporting device developers and their underpinning supply chains, tying future GVA and jobs to a strong domestic wave energy market.

The economic analysis within this report shows the potential for domestic deployment of wave energy devices to generate **over £4.2bn in GVA by 2050** to the Scottish economy. There is also the potential for significant **additional GVA of up to £16.6bn from export markets** associated with successful Scottish companies.

Delivering on Just Transition commitments

By establishing a successful and commercialised wave energy sector, underpinned by a robust supply chain, Scotland also has the potential to provide high-skilled jobs across the country, in sectors ranging from the manufacture and fabrication of subsystems to the ongoing operation and maintenance of wave energy devices.

The analysis in this report also demonstrates that in 2050, there is the potential for **over 9 000 FTE jobs, resulting from domestic projects in Scotland and the UK**. Many of these high-value jobs could be located in coastal communities around Scotland. With greater uncertainty, there is **significant additional potential from export markets** of up to **30 000 jobs associated with Scottish companies**.

6.2 An end to business as usual

It is important to note that the **economic benefits highlighted in this study should not be taken for granted**, nor are they indicative of a business-as-usual approach to technology development and deployment. **Significant effort, financial support and policy interventions will be essential**, even to reach the lower ambition scenarios outlined in this report. Without taking proactive and targeted steps, there is the very real possibility that the significant socioeconomic benefits associated with these wave energy developments could be led by, or even lost completely to, overseas competition.

To ensure that Scotland secures these economic benefits, it is essential that national government, enterprise agencies, device developers and the supply chain can access and utilise an appropriate balance of coordinated policy support and long-term public and private finance. This is essential to ensure that **Scottish wave energy device developers continue to develop innovative and cost-competitive technologies**, both in Scotland and across the globe.

Sustained support is also required to ensure that the **domestic supply chain is equipped to underpin device manufactures projects competitively and at an increased volume**. This will require significant targeted investments in Scottish manufacturing capability to help realise significant supply chain opportunities for Scotland. This should be focused on the key device subsystems and areas of expertise identified in section 5. Investment will be required in a range of areas, including supply chain automation and digitalisation, future skills and training, plus the upgrading and modernising of manufacturing facilities. There should also be a focus on the continued development and promotion of Scotland's role as a services provider, opening up the opportunity to export Scottish expertise in a range of supporting sectors. Finally, opportunities to identify any technological overlaps or facilities development with other mature energy sectors, such as offshore wind, should also be prioritised.

The recent Clean Power 2030 Action Plan also underlines the sense of urgency associated with the need to ensure the deployment of a diverse and robust energy system, in which emerging renewable technologies have a meaningful role to play. The wave energy sector should be acutely aware of the potential opportunity to be amongst these emerging technologies. A similar sense of urgency should also be felt by those developing the supply chain, for which the resulting GVA and jobs outlined in this report rely upon.

The following two sections provides a series of recommendations designed to guide and inform prospective policymakers on possible policy interventions, both for enabling the wave energy sector and for developing the underpinning infrastructure to support these developments. The wave energy sector will also have the potential bonus of being able to learn from the tidal stream sector, which at present is similarly working to unlock the potential jobs and GVA that could accompany the commercialisation of that sector. The tidal stream sector is also keenly aware of the importance of developing a robust domestic supply chain and the need for the upgrading of underpinning infrastructure, all of which is likely to have significant overlap with that of the wave energy sector.

6.3 Recommendations to enable the wave energy sector

The first three recommendations, detailed below, aim to enable the development and growth of the wave energy sector. These recommendations will target the issues directly facing the capabilities and capacities of both wave energy device developers and the supply chain that supports the sector.

Working with UK Government to support the future wave energy market

This report has primarily focused on analysing the GVA and jobs associated with the deployment of 4.5 GW of wave energy in Scotland and has examined the capacity of the Scottish supply chain to underpin this deployment. However, it is important to underline the necessity of government-led financial support in realising and achieving these potential benefits. The UK Government's CfD scheme, and its technology-specific ringfence funds, have played an important role in establishing a secure market for tidal stream developers. There is the hope, that as the wave energy sector continues to mature, and an increasing number of companies can bid competitively for CfD awards, that this scheme will be extended to wave energy developers. As this is a UK Government policy, the Scottish Government needs to continue to actively collaborate closely with the UK Government to ensure there is an adequate and long-term market support mechanism in place. This could include the expansion of the CfD scheme and appropriate technology ringfence funds to include wave energy or the adoption of a new market pull mechanism with a similar aim to facilitate the deployment of wave energy devices.

Recommendation 1

Adapting established **market support mechanisms**, such as the CfD, will be essential to **ensuring a market into which Scottish wave energy developers can supply and deploy their devices**. This should be coupled with the **establishment of a highly visible and accountable future deployment ambition**, which will bolster the growth of the domestic market, provide clarity with regards to supply chain requirements and increase investor confidence in a range of supporting sectors.

Sustaining innovation across Scottish wave energy device developers

Alongside market support, significant innovation funding, drawing from both public and private sources, is required to **enable continued innovation to the already innovative wave energy devices**. This is vital to ensure that Scottish device developers continue to reduce costs and win projects, both here in Scotland and across the globe, in a variety of wave climates and markets, maintaining and solidifying Scotland's position amongst the world-leaders in wave energy development.

Recommendation **2**

Targeted and sustained research and innovation support for wave energy technology developers is essential to ensure that Scotland builds upon and maintains the competitive edge that it has established in this sector. This is vital to ensure that **Scottish companies continue to innovate, reduce costs, win projects and deploy their devices,** in both domestic and international markets.

Increasing the capabilities of Scottish supply chains

Supporting the development of the companies and organisations within the underlying supply chain, who ultimately will be responsible for the building of key subsystems and developing skills in relevant areas of expertise, is a complex task. Therefore, to ensure the sustained competitiveness of the sector and deliver high levels of Scottish content in future wave energy projects, thus ensuring associated domestic GVA and jobs, it is vital that that support programmes prioritise the modernisation of the underpinning Scottish supply chain. While there is a clear need to strategically invest in the manufacture of key device subsystems, priority should also be given to sustaining and advancing Scottish areas of expertise in the marine operations service industry. Tackling both issues is particularly important so that the supply chain can competitively supply developers at the volumes required to support predicted sector growth.

Recommendation **3**

The modernisation of Scottish supply chain capabilities, from the manufacture and utilisation of novel materials to the adoption of automation and digitalisation, should be **embraced and supported at all levels of the supply chain.** In areas where **Scotland already possesses a world-leading status** or is **matching the competitive performance of other nations**, policy and financial support should aim to **nurture, strengthen and maintain this position**. In areas of subsystem manufacture with **no clear market leader**, Scotland should position itself to maximise the benefit of investments into supply chain sophistication and **seize these all-to-play-for markets**. Policy support should be tailored to ensure that there is a **straightforward route towards the commercialisation of new ideas**, translating early-stage innovation into supply chain expertise and manufacturing capability.

6.4 Recommendations to develop underpinning infrastructure

The next three recommendations, detailed below, aim to target the challenges surrounding the development of infrastructure that underpins the future of both wave energy device developers and the supply chain that supports them. The wave energy sector may also stand to benefit from investments that have been made into other offshore renewable energy sectors.

Preparing a pipeline of sector-specific skills

Prioritising the development of soft infrastructures, for example, by ensuring that a visible pipeline of skilled workers will be readily available is a key consideration of any growing sector. This should also ensure that appropriate consideration has been given to the needs of both device developers and the companies and organisations that comprise the sector supply chain.

Recommendation 4

Investment into device innovation and supply chain capability should be coupled with an **equal investment into domestic workforce capacity and skills**. This should not solely target higher education graduates from a STEM background, who are an important consideration of any future skilled workforce. It should also consider the roles of apprenticeships and existing workers transitioning from oil & gas and other relevant sectors, who often have transferable skillsets and exposure to the challenges of working in a marine environment.

Fostering cross-sector collaboration

The high levels of investment already provided to support and grow other offshore energy sectors, such as the offshore wind sector, should be closely examined, both for instances of potential collaboration and for examples of best practice and lessons learned.

Recommendation 5

The maturity of the offshore wind sector, in terms of fabrication facilities and supply chain depth, should serve as both an inspiring template and **a serious opportunity for collaboration with the wave energy sector. Active collaboration between wave energy developers and their supply chain**, where competition allows, could also lead to the **creation of innovation clusters**.

Development of necessary supporting infrastructure

The development of hard infrastructure, such as ports and harbours, will be required to build these projects, together with electricity grid upgrades to connect them. Grid constraints in Scotland are mostly from the north to south, both exporting renewable generation from the Highlands and Islands to the major load in the central belt, but also exporting that power from all of Scotland over the border into England. Early visibility of likely locations for wave energy projects around Scotland's coast, together with geographical understanding of the resource, will help infrastructure planners accommodate their future requirements.

Recommendation 6

Significant grid upgrades will be required alongside the continued development of renewable energy in Scotland, to avoid transmission bottlenecks and potential for increased curtailment of renewable output. **These planned upgrades must also factor in the requirements and potential energy system benefits of the wave energy sector**. **Port and harbour infrastructure upgrades** across the country, currently being planned for offshore wind, should also factor in the additional requirements from the growing pipeline of wave energy projects.

6.5 Delivery of recommendations

The final recommendation, detailed below, outlines a potential pathway by which the successful delivery of the previous six recommendations can be led and championed by existing enterprise and innovation agencies within Scotland.

Delivering innovation support in Scotland

The goals of sustained deployment of highly innovative wave energy devices and the modernisation and enhancement of domestic supply chain capabilities are a complex task that will require ongoing oversight and coordination. Scotland is well positioned to utilise the experience of several well-established enterprise and focused innovation support organisations who have demonstrated multiple successful instances of managing the delivery of innovative technologies and devices at an accelerated and cost-effective rate. While this report lays out several areas where the application of targeted and high-level policy recommendations could be effective, these enterprise and innovation support organisations should establish a sector-specific strategic innovation programme with more granular detail and detailed policy actions.

Recommendation 7

Tasking and funding **existing innovation support organisations** to oversee the well-coordinated and accelerated delivery of domestic wave energy devices and improvements in Scottish supply chain capabilities. This will help to ensure that **Scotland maintains its position as a world leader in the delivery of wave energy projects** with high Scottish supply chain content.

Closing message

This report outlines the potential economic benefit for Scotland from a successful wave energy sector. These benefits accrue from developing, building and operating wave energy projects, in Scotland, the rest of the UK, and from the global export market. There is the potential for 4.5 GW of wave energy to be deployed in Scottish waters by 2050, contributing to 6.4 GW in the UK and 180 GW globally. Economic analysis in this report shows, that given the development of a robust domestic supply chain, there is the potential for domestic projects in Scotland and the rest of the UK to create over £4.2bn in GVA to the Scottish economy by 2050, and support over 9,000 FTE jobs in 2050. Export markets offer even greater opportunity, of up to £16.6bn in GVA and 30,000 jobs associated with successful Scottish companies.

As one of the leading nations driving the advancement of the emerging wave energy sector, Scotland is well positioned to accelerate the development and deployment of wave energy technologies in domestic and foreign projects. In doing so, Scotland can seize the significant socioeconomic benefit, in terms of GVA and jobs, associated with their manufacture and operation. This outcome also presents Scotland with the opportunity to leverage a home-grown technology sector into the advancement of its Net Zero, Just Transition, economic growth and energy security goals and ambitions.

Achieving these outcomes will require significant shared responsibilities across the entirety of the supply chain, from technology developers and commercial manufacturers to the organisations and government departments tasked with overseeing sector delivery. Without providing significant coordinated investment and guided policy support to Scottish technology developers, accompanied by strategic investment into high-value areas of the domestic supply chain, there is a clear danger that Scotland's lead will be eroded. This could ultimately lead to the progression of the wave energy sector overseas, as has happened in other energy sectors. This situation must be avoided if Scotland wishes to capitalise on GVA and jobs figures outlined within this report.

Scotland has come far in the last decade, progressing a novel energy sector at an accelerated rate, resulting in technology and devices that are poised to enter a phase of commercial deployment. It is therefore vital that in the coming years, Scotland works efficiently and collaboratively to maintain this position. In doing so it can establish a reputation as the premier location for the wave energy sector to develop, build, deploy and maintain their devices, utilising sector-leading innovation capabilities, a highly skilled workforce and a robust Scottish supply chain.

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