OFFSHORE RENEWABLE ENERGY SCIENCE AND INNOVATION AUDIT

A Science and Innovation Audit Report sponsored by the Department for Business, Energy and Industrial Strategy

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Glossary of Key Terms

Turbine	Energy generating structure consisting of the Nacelle (in which is housed the generator, drivetrain components plus control equipment), rotational blades, tower and foundations.
Nacelle	The housing structure (typically at the top of a turbine) that houses the generator, drivetrain components and control equipment.
Generator	Electro-magnetic device that converts the kinetic movement of usually air or sea into electricity.
Turbine Tower	Metal support tower that raises the Nacelle to the correct height above for example the sea bed or ground.
Drivetrain	Gearbox, bearings, drive shaft and other components that connect the rotating blade motion to the generator.
Turbine Foundation	Structure that holds the turbine in place – for example to the sea bed in an offshore wind turbine. Foundations exist in many forms such as monopiles (essentially steel tube structures that are driven into the soil), towers (fabricated metal towers that are attached to concrete foundations), floating foundations (similar to oil rigs) etc.
Levelised cost of energy	The total cost of financing, fabricating, installing, operating and maintaining a power source (expressed as £/MWhr)
Cost for Difference Contract	A market mechanism for ensuring that low carbon power generation is financially viable by guaranteeing that low carbon power generators receive a pre-agreed fixed price (the "strike price") for the power that they produce. In the UK, the power generator sells electricity into the market but is paid a top-up if the market price is lower than the strike price. This reverses if the market price is above the strike price.

1 Executive Summary

In Autumn 2015 the UK Government initiated a programme of Science and Innovation Audits (SIA's) as an approach to strengthen the UK Innovation evidence base. It invited consortia to bring forward proposals which could provide focus on analysing regional strengths and identify mechanisms to realise their potential. In the **north of England and Scotland**, a consortium was formed to focus on our strength and potential in **Offshore Renewable Energy (focused on offshore wind, and a review of wave and tidal energy). It does not comment in detail on other offshore energy sectors like oil and gas, or other offshore based opportunities in the energy sector such as carbon capture and storage.** This report presents the results which include broad-ranging analysis of the **offshore renewable energy sector's** capabilities in the SIA territories, the challenges and the substantial opportunities they offer for future UK economic growth.

The Offshore Renewable Energy Science and Innovation Audit was conducted across the north of England and Scotland by a consortium comprising:

- the Universities of Durham, Hull, Liverpool and Newcastle
- four Local Enterprise Partnerships (Humber, Liverpool City Region, North-East, Tees Valley Combined Authority) and Scottish Enterprise
- the Offshore Renewable Energy Catapult (ORE Catapult)

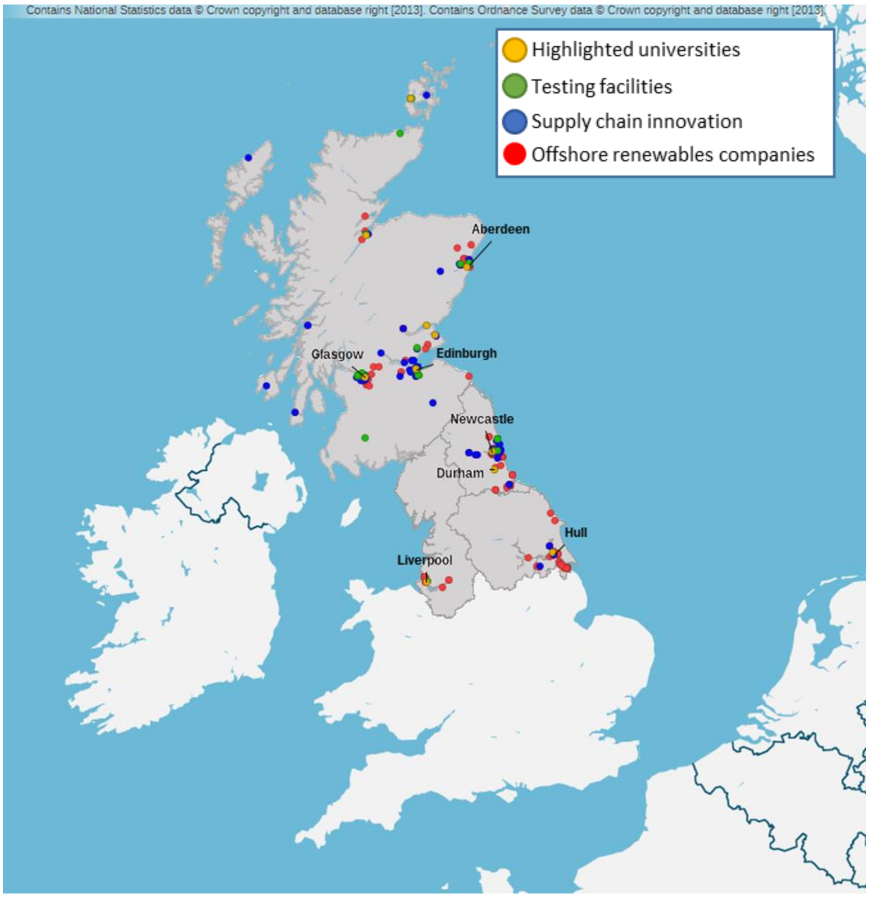

Figure 1: SIA area key offshore renewable energy activity (source: ORE Catapult and Technopolis analysis, 2017)

The SIA was focused on the north of England and Scotland, which both contain major research and innovation assets in Offshore Renewable Energy, but also references related assets and activities from across the UK.

1.1 SIA Hypothesis

The Offshore Renewable Energy SIA consortium was formed so that it covers a geographically distinct unit, embracing the coastal regions of Northern England and Eastern Scotland with their well-developed maritime industries and associated supply chains. The geographical areas included in this SIA are linked through common interest as well as long histories of co-operation and joint enterprise in the offshore energy sector which developed out of their historical maritime activities in the major ports of Northern England and Eastern Scotland. Local Strategic Economic Plans identify offshore energy as a key economic priority and existing connections between the areas include research linkages, key businesses with multiple locations, the existence of established business networks and the primary locations of the Offshore Renewable Energy Catapult. There are also UK-leading local innovation eco-systems in some parts of the territory offering opportunities for dynamic, open innovation activities linking technology bases, for example digital and satellite applications and wider energy technology assets.

The partnership believed that there is potential for stronger alignment of these assets and resources, and that the shared coastal location and the focus into similar offshore and coastal sites provided an opportunity for strengthened collaboration through the SIA process.

Activity outside the SIA area was also recognised and included in the analysis where appropriate so that a true UK picture could be developed – this included taking account of Round 1 SIA's in which relevant activities associated with energy generation and manufacturing were considered.

The SIA was designed to examine the hypotheses that:

- Northern England and Scotland can transform from a majority importer of offshore wind energy technology to a major export hub for UK manufacturing and services in this sector.
- Northern England and Scotland can sustain and grow significant technology clusters by transforming current expertise in oil and gas into a proactive export-led sustainable ocean technologies approach.

To examine this hypothesis, the Offshore Renewable Energy SIA focused on three key questions:

- How competitive internationally are the research and innovation activities of Northern England and Scotland in offshore energy?
- What are the future needs in innovation of the offshore energy sector and the gaps in the current portfolio?
- Do Northern England and Scotland have the relevant skilled workforce in offshore energy?

1.2 Summary Findings

- Universities within the SIA area are engaged in world-class research in the field of offshore renewable energy, but there is potential for increased specialisation compared to predominantly cross-cutting expertise as well as a need for increased research funding for the sector
- The SIA area has a substantial offshore renewable energy supply chain engaged in many innovation projects, including a number of industry-academic collaborations

- Many of the industry's needs revolve around components and enabling technology for the next generation of large wind turbines in the range of 13-15MW and there is a need for greater alignment between current and future industry needs and areas of focus for academic research
- The number of people directly employed in offshore wind in the UK could double between 2017 and 2032 and there is an immediate need to join up education and training providers (supply side) with the future industry demand for a higher-skilled workforce with key skills in areas including (but not limited to) engineering and manufacturing

1.3 Offshore Wind Market Overview

The UK economic opportunity in offshore renewable energy is robust and growing. Over £15bn has been invested in commercial offshore wind projects in the UK to date and a further £15-20bn is in the pipeline. Further cost reductions will lead to deployment of thousands more offshore wind turbines by 2030, allowing UK companies to help deliver value to the UK economy of £4.4bn per year[1]. The cost of electricity from offshore wind has fallen 32% in only four years[2], surpassing 2020 cost reduction targets and putting the goal of being the cheapest, large-scale clean energy source within reach. Offshore wind surpassed 2020 milestones for cost reduction and now sits alongside nuclear as the UK's clearest route to decarbonisation. A truly global market is emerging through strong growth in Europe, North America and Asia. Offshore renewables align strongly with the aims of the government's technology-driven industrial strategy and are especially important for coastal, economically-challenged areas, creating new business opportunities from Cornwall to Caithness, and Hull to Milford Haven.

1.4 Wave and Tidal Market Overview

Whilst the UK leads the world in wave and tidal development, the technologies lag behind offshore wind in terms of maturity and cost. Whilst moving towards commercialisation their ongoing development in the UK remains in the balance due to lessening investor support. Nevertheless, the UK has approximately 50% of Europe's tidal stream energy resource - potentially 30-to-50 gigawatt (GW) of installed capacity, or enough to supply around 20% of the UK's current electricity demand. The UK achieved a milestone in 2017 when MeyGen, the world's first commercial tidal stream project, began supplying power to the grid in northern Scotland.

Although the marine energy market, and particularly wave energy, has not progressed as quickly as some had hoped the UK has invested in infrastructure for innovation that is in demand from global technology developers such as Carnegie, Fred Olson, G-wave and Wello who are backed by overseas public programmes and private venture funds. Devolved administrations in Wales and Scotland are also continuing to strongly support wave and tidal device development and there is a promising opportunity to grow UK supply chains to support these domestic and international device development efforts.

1.5 SIA Approach

The approach taken by the consortium has been to consider the position of the SIA area and, where appropriate, the wider UK picture, regarding Offshore Wind, Wave and Tidal energy, from the

[1] The Economic Value of Offshore Wind: Benefits to the UK of Supporting the Industry
[2] ORE Catapult Cost Reduction monitoring Report 2016

perspective of research, supply chain, skills and innovation. The report aims to link research with the priorities of the sector, where the SIA area and UK can grow and build export opportunity.

1.6 Offshore Renewable Energy Research

1.6.1 International Competitiveness in Offshore Renewable Energy Research

Over the three research areas audited (offshore wind, wave and tidal), the UK performed consistently well – producing a significant volume of research which is very high quality. The strongest UK performance is perhaps in tidal energy research (where the UK is comparatively strong in both quantity and quality) followed by offshore wind. The SIA area is the UK's leading research area across offshore renewable energy as a broad group with a particular comparative strength in offshore wind. Key strengths currently are in tribology, subsea engineering and environmental analysis.

1.6.2 University Expertise within the SIA Area

The SIA consortium area contains a number of world-class universities undertaking research in the broad field of offshore renewable energy but often with a special interest in one of the major areas.

Academic specialism in offshore renewable energy is predominantly focused on turbine technology or wave and tidal device technology. Balance of plant elements, e.g. foundations, cables, installation, etc, tend to be covered by multi-disciplinary or cross-cutting themes such as engineering, energy systems and environmental studies. This provides the benefit of capturing and incorporating the best related knowledge into offshore renewable energy, but also highlights a potential opportunity for increased specialism in these areas.

The quality and strength of UK research linked to dedicated component and device test facilities makes the UK a magnet for technology developers from overseas. It is vital that research and innovation funding is sustained and focused on emerging technologies, including digitisation, artificial intelligence and robotics. The new SuperGen Offshore Renewable Energy Hub (the new combined wind and marine hub) provides an excellent opportunity to improve the integration and focus of offshore renewables research. The need to link research capabilities, funding and commercial partners to the priorities of the sector is critical.

1.7 Innovation in Offshore Renewable Energy

1.7.1 Patent Analysis

As one measure of innovation, a patent analysis of offshore wind was undertaken based on the European Patent Office Worldwide Patent Statistical Database (PATSTAT). The second part of the patent analysis of wind energy focused on the UK and SIA geography between 2004 and 2012. A similar approach was used for wave and tidal.

The patent analysis, based on wind, wave and tidal patents filed by UK inventors shows clear challenges to the UK – particularly in wind energy - where the UK demonstrates a low level of intellectual property ownership compared to global competitors.

The UK and SIA region's innovation output in tidal and wave energy – as measured by patent applications - is more advantageous where it is clear that the UK represents a much higher proportion of the world-wide innovation. This may reflect the much less mature nature of wave and tidal compared to offshore wind but is nonetheless a promising opportunity for the UK. It is crucial that the UK should work proactively through fostering innovation activities in order to maintain this position as the sector moves towards commercial maturity.

1.7.2 Supply Chain Activity

The analysis identified 186 companies in the SIA region with offshore renewables as their core or significant part of their business activity.

Location-wise, the highest concentrations are found in the Humber region (48), North East England (35), North East Scotland (27), followed by Liverpool and East Scotland (23). As well as reflecting proximity to offshore renewables activity, this is also a sign of companies diversifying or transitioning from an oil and gas focus, leveraging transferrable skills, equipment and processes.

The picture from this analysis backs up previous analysis[3] that there is substantial activity in areas where it makes logistical sense, e.g. Ports and O&M together account for 65% of the business identified, but companies in the SIA region, similar to the rest of the UK, are capturing only a limited share of the available market.

1.7.3 Supply Chain Innovation

An analysis of publicly-funded research and innovation projects has identified 109 individual companies in the SIA region currently involved in 124 projects, worth an estimated £72 million[4] (£34 million in research funding plus £38 million internal or match funding), involving industrial lead or partner organisations, with 91 involving purely industry and 33 being industry-academic collaborations.

[3] ORE Catapult - The Economic Value of Offshore Wind: Benefits to the UK of Supporting the Industry
[4] The total funded value for each project has been split evenly by the number of project partners where the partner-specific value is not known

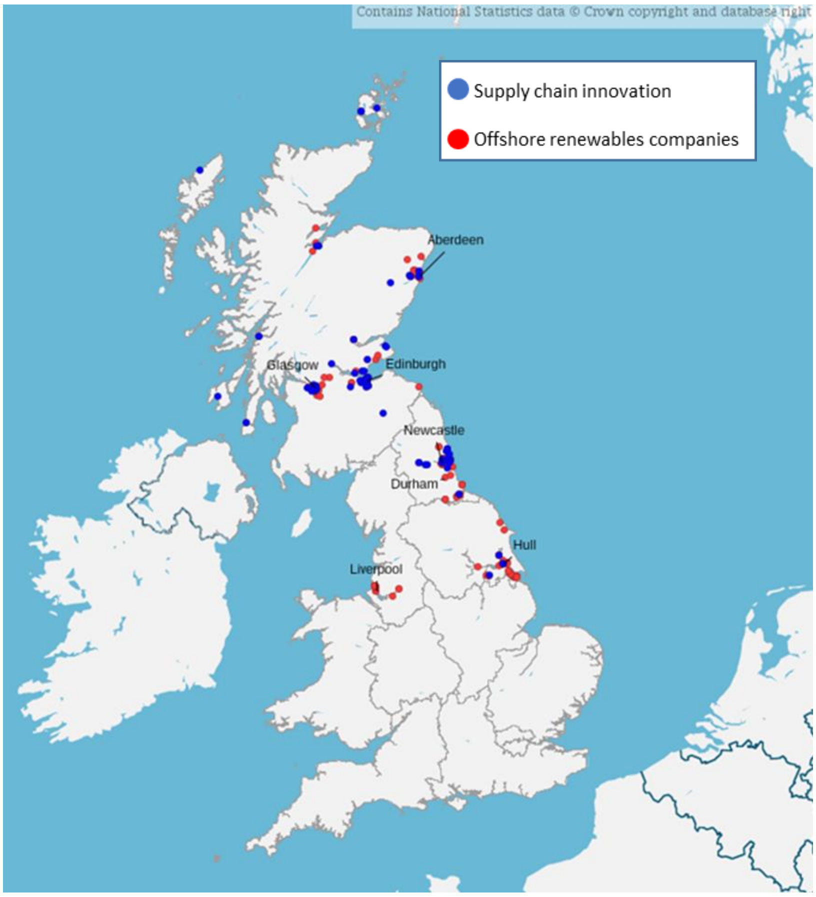

Figure 2: Offshore renewable energy and innovation companies in the SIA region (source: ORE Catapult and Technopolis analysis, 2017)

There is substantial cross-over between the 109 companies identified as being engaged in offshore renewable energy research and innovation projects and the 186 supply chain companies identified as having offshore renewable energy as their core business. The high number of businesses engaged in publicly-funded research and innovation projects illustrates that:

- There is a high number of companies in the SIA region actively engaged in innovation
- Much of this innovation is being conducted by companies for whom offshore renewables is their core business
- 27% of these projects are industry-academic collaborations, highlighting the already strong links and use being made of the facilities and expertise highlighted throughout this report (though it must be noted that collaborations in some cases are with universities outside of the SIA region or even outside the UK). However, this also suggests there is a large amount of scope for increased joint collaborative research activity.

1.8 Skills and Training

Developing the right balance of specialist skills will be essential to continue the area's strong presence at the forefront of innovation. The area has a strong record in both formal education and private training capabilities and there are strong relationships between Universities and Colleges and businesses. However, the area suffers from a shortage of skilled engineers. This is similar to shortages experienced across the UK. The skills required within the sector, e.g. engineering, system design, control systems, robotics and artificial intelligence, high-voltage working, offshore working experience, are similar to those existing within other sectors such as general manufacturing and the offshore oil and gas sector. The SIA region has a strong tradition of delivering engineering skills at all levels from apprenticeships to post graduates and this forms part of the industrial base of the region. The jobs potential created by offshore wind is significant, with the industry set to support up to 60,000 direct and indirect jobs in the UK by 2032, making a compelling case for ensuring the right skills are developed today for the needs of tomorrow.

1.9 Offshore Renewable Energy in the SIA Area

Strategic Economic Plans enable LEP's to frame opportunities and growth plans for offshore renewable energy in the wider context of local economic plans. A number of key sites within the Enterprise Zone portfolio have been designated for offshore and sub-sea energy cluster development. In the North East, these include 7 sites around the North Bank of the Tyne and the Port of Blyth in the Round 1 Enterprise Zone and sites within the Round 2 Zone.

1.10 National and Regional Collaboration and Funding

There is a rich eco-system of support for offshore renewable energy in the UK for both industrial operations and research. It is clear that this connective eco-system plays a crucial role in supporting the industry and is a strong enabler of the innovations that have led to the very significant advances of the last five years.

The importance and benefits of collaboration are well understood across the SIA region. Collaboration between academia, public research bodies and industry are delivering innovative technology. Opportunities are apparent to strengthen these bounds still further and broaden the collaboration to join up with other UK regions.

Whilst this is extremely positive, it must be noted that the funding levels still fall short of those for other energy sectors. For example, EPSRC in 2015 dedicated just 1% of energy funding to wind energy (onshore and offshore combined) and 5% to wave and tidal.

1.10.1 International Competitor Clusters

The wind energy industry has a long heritage in Europe and particularly in Denmark and the adjacent districts of Northern Germany. These clusters are very attractive for investment in new and expanding business and facilities. There is clear evidence in this SIA report (particularly in Section 4 on innovation) of emerging clusters within the SIA area.

Currently, over 200 companies operate globally in the wave and tidal energy sectors. Most are extensively involved in the development of energy converter technology.[5] The marine energy supply chain in the UK has already seen £450m investment[6] and continues to flourish despite market

[5] https://globenewswire.com/news-release/2016/09/29/875604/0/en/Wave-and-Tidal-Energy-Market-Energy-Type-Wave-Energy-Tidal-Energy-Global-Industry-Analysis-US-11-3-Bn-by-2024-Size-Share-Growth-Trends-and-Forecast-2016-2024.html
[6] https://www.regensw.co.uk/Handlers/Download.ashx?IDMF=5aa0d6fe-85ed-4a05-a9bf-64156014098e

uncertainty. Tidal markets will develop in countries with a significant resource, particularly the United States, Canada, France and the UK. The UK is leading the way with the first commercial array at the MeyGen site being developed in the Pentland Firth, Scotland and the first community array scheme in the Shetlands. Markets for wave will develop only when the technology reliability and survivability is proven and where the resource can be economically harvested. Other than the UK and Ireland, the best wave resource is focused along the coasts of California, Argentina, Australia, Portugal, Sweden, Korea, Spain, Iran, and the Atlantic coast of the United States.

The UK is in an enviable position with both good wave and tidal resources around its coastline and leading in both the academic understanding and technology development capability with some of the world's foremost testing assets located in the UK, much of it in the SIA area. However, market signals indicate that other nations are quickly catching up with ambitious domestic programmes and strong Government support.

1.11 Key Findings

1.11.1 International Competitiveness of Research and Innovation in Offshore Renewable Energy

- The academic research produced in the SIA area in offshore wind, wave and tidal is world-class in terms of both quality and volume and there are at least eleven universities in the area with critical mass in, or with close ties to, the field of offshore renewables.
- The existing relevant academic centres tend to cover broad areas such as sustainable practice, advanced manufacturing, environmental science and engineering. There is a potential opportunity for increased specialisation in order to address the industry's current and future needs. For example, a focus on floating wind and novel foundation designs, new bearing and generator designs will be essential to enable the next generation of turbines in the 13-15MW range.
- A number of mechanisms and organisations exist to coordinate academic activities in offshore renewable energy. However, the amount of funding available to offshore wind, wave and tidal is very small compared to other energy sectors.
- The SIA area has a substantial supply chain active in offshore renewable energy and other offshore activities, with significant engagement in innovation projects across the value chain and strong global connections and presence. There are significant technology transfer opportunities between and across sectors and strong local eco-systems which could support open innovation.
- Innovation project funding tends to be concentrated in a small number of large grants, for example tidal or wave device development. As with academic research, there appears to be a lack of resources to focus on areas critical to enabling the next generation of large wind turbines, such as next generation installation vessels and novel foundations as well as turbine components.
- European funding, local Growth funding and Enterprise Zone and other infrastructure development activities have provided important resourcing and enabling support for this sector.

As the UK's relationship with the EU changes, it is important to ensure that there is continuity and more flexibility of support from LEPs and other local partners.

1.11.2 Future Needs in Innovation of the Offshore Renewable Energy Sector

Based on feedback from industry in response to the SIA, and the 2016 Offshore Wind technology Innovation Needs Assessment[7], a number of innovation priorities have been identified:

- Turbines - development of innovative materials and components for next generation, higher reliability, turbines of up to 15MW capacity – design, materials and fabrication of longer blades, larger bearings, generators and drivetrain components

- Installation – vessels and equipment for larger, heavier turbines and installation methods for deeper waters and higher sea states

- Foundations – novel foundation designs including both fixed and floating concepts for low-cost foundations, particularly for water depths of greater than 35m and to support larger turbines and development of serial manufacturing techniques for foundations

- Operations & Maintenance – remote condition-based monitoring, control and maintenance systems, O&M access systems

- Development and FEED – improved wakes and loads models for layout optimisation, advanced resource measurement tools, and data sharing methods

- Transmission – optimised / next generation transmission systems (e.g. high-voltage direct current - HVDC) and improved, lower cost materials, cabling concepts, and installation techniques

- Windfarm clusters to enable operating efficiencies and better sharing of fixed costs

- There are a range of research and innovation opportunities available within the SIA territories through related assets of national and international standing including in digital, satellite, advanced manufacturing and energy technologies

1.11.3 Offshore Renewable Energy Workforce

- The SIA found clear evidence of a number of training courses and providers either specialising in, or directly related to offshore renewables. These are provided at university, further education, industrial training and apprenticeship level. However, the provision is devised on an institutional basis or organised through national policy departments with inadequate reference to local or regional industrial priorities.

- No direct skills audit was conducted as part of the SIA, but UK government forecasts highlight a net demand for engineering and manufacturing roles in Scotland and the North of England

[7] http://www.lowcarboninnovation.co.uk/working_together/technology_focus_areas/offshore_wind/

between 2014 and 2024. A shortage of skilled engineers today and a need to develop tomorrow's innovators needs to be addressed. Across the SIA area, with the support of business organisations, LEPs and Combined Authorities are seeking enhanced influence over skills policy to help strengthen the matching of supply and demand in the labour force and to enable strategic support for skills development. In the context of the emerging Industrial Strategy there is an opportunity to link sector and spatial skills strategies. One strategy identified in this SIA is focused on redirecting skills from Oil & Gas to address the present shortages.

1.12 Recommendations

Offshore wind developers, wind turbine manufacturers and other Tier 1 suppliers find the existence of four interlinked themes compelling when considering locations for new investments or expansion of existing operations:

- Research & Development & Innovation capability
- Available resource with the relevant skills
- Supply chain capability in terms of quality and capacity
- Infrastructure, including land availability, port facilities and accessibility (outside the scope of this SIA)

The offshore wind sector is at a relatively immature state of development (compare to automotive and aerospace, for example). Consequently, integration and standardisation remains relatively under-developed in a number of aspects from low commoditisation of equipment, through health and safety criteria to training and skills. Supporting collaborative activity within the sector and bridging between business, academia and NGOs/GOs will help sector wide standards to emerge, facilitate maturation, reduce risk, help bring down costs further and augment the reputation of the UK (and the SIA area) as a world leader in offshore wind.

The SIA process has identified a number of opportunities that cut across the whole offshore renewable energy sector.

1.12.1 Research & Development & Innovation

- There is a clear need to do more to align key industry growth and development opportunities with the academic research base in order to maximise opportunities to develop cutting edge technologies such as composites, novel blades (smart design, aeroelastic modelling), autonomous vessels, digitalisation in design and control systems – for offshore wind, wave and tidal.

- The SIA, through the linkage to the Industrial Digitalisation review, has identified that there is a clear opportunity in the development of digital technologies for offshore wind – particularly in operations and maintenance of deployed assets and in the design phase of elements such as foundations. This could be driven forward through the Industrial Strategy Challenge Fund.

- Initiatives such as the Offshore Wind Innovation Hub, Academic Research Hubs and the Supergen programme should be given an even stronger mandate to set the industry-academia agenda in order to ensure best value for money for public and private research and innovation funding.

- Funding for innovation initiatives such as those outlined, above, should be made available at levels in line with the UK's ambition in offshore renewable energy. As proposals for the UK SPF are developed, it is essential that provision is in place to replace previous sector funding. Some calibration is necessary between the amounts spent on offshore renewables compared to other energy sources.
- The testing at scale of offshore renewable energy technology is a crucial under-pinning factor in innovation and commercialisation of new technologies and services and this must continue to be supported. This will drive maximum value from existing word-class testing assets as well as driving further investment in new assets.
- Two-way dialogue is needed between innovators and funders on the appropriate mix between capital and revenue funding, including a clear pathway for funding as the UK's relationship with the EU changes, as well as clearly defined milestones and targets for achieving technology and commercial readiness.
- The establishment of a new initiative to support subsea engineering which is a key enabler of offshore renewables. This should involve support for a small number of existing regional clusters of excellence to enable expensive capital testing facilities to be utilised and supported efficiently.

1.12.2 Resources and Skills

- With the UK's installed offshore wind capacity set to double to 10GW in the next three to four years and reach 20-30GW by 2030, a systematic audit across the offshore renewables sector is required, leading to a demand-led, evidence-based roadmap of skills requirements. This could be coordinated between government, relevant industry bodies and LEP's/combined authorities, leading to identification of skills gaps addressing both current and future needs.
- LEP's and Combined Authorities should be empowered to enter structured and formal consultations with industry in order to develop local skills strategies as well as structured and formal consultations with academic institutions in order to implement these strategies most effectively.

1.12.3 Supply Chain Capability

- Opportunities exist in tier 2 and tier 3 supply chain companies in blade design, infrastructure, robotics and artificial intelligence, support to operations & maintenance, and specialist vessel design. These are industry needs not currently being addressed. Targeting research and innovation funding at these areas will mobilise a proven active innovative supply chain together with trusted academic partners towards fulfilling industry needs.
- A proactive government programme, led by the Department for International Trade (DIT), to build stronger links between engineering and design companies in the UK and overseas original

equipment manufacturers (OEM's) could unlock further potential for innovative companies with no direct route to market.

- The existing momentum in development of wave and tidal solutions should be encouraged through providing a route to market in the UK via appropriate support schemes and by creating links at government level with overseas governments in order to share the cost of technology development. This will also create a natural base for building export capability and unlocking the full potential of wave and tidal energy to add significantly to UK GVA.

In order to maximise benefit to the offshore renewable energy sector, and the UK, it is necessary to make progress in each of the three areas identified above. An approach that recognises the interdependence of these key areas of activity is most likely to be successful. For this reason, interdisciplinary, cross-sector collaborative initiatives which integrate research, development and innovation with talent pipeline and industry engagement and enterprise, are particularly well placed within the SIA region to realise the best advantage for the UK.

The region has the potential to draw together many of the existing facets of the research, development and innovation and skills landscapes into a compelling offer for technology developers and project operators. Doing so will create a higher degree of visibility and easier access for developers and innovators into the region.

2 Introduction to the Offshore Renewable Energy SIA

2.1 Introduction

Offshore renewable energy in a number of forms (offshore wind, wave, tidal stream and tidal range) is a crucial part of the UK's energy mix and plays a major role in the meeting of international environmental targets. Recent years have seen a remarkable growth in the deployment of offshore energy and plans for the future are strong. This exciting and dynamic field is thus key to the UK's energy future. This Science and Innovation Audit (SIA) focuses on this creative and dynamic sector – analysing the current situation but more importantly providing insight into the significant opportunities ahead.

This SIA focuses primarily on offshore wind, all forms of wave energy, and both tidal stream technologies and barrage-type developments (such as the Swansea bay project). Expertise in environmental impact analysis, economic research and social factors research were also considered due to their key role in technology adoption.

The Offshore Energy Science and Innovation Audit was conducted across the north of England and Scotland by a consortium comprising:

- the Universities of Newcastle, Durham, Liverpool and Hull,
- four Local Enterprise Partnerships (LEPs) (North-East, Liverpool City Region, Tees Valley Combined Authority and Humber), Scottish Enterprise
- the Offshore Renewable Energy Catapult

The SIA was focused on the North of England and Scotland, which both contain major research and innovation assets and supply chain bases in offshore renewable energy as well as a range of other energy assets and technologies, but referencing other activities in the wider UK.

The SIA was designed to examine the hypotheses that:

- Northern England and Scotland can transform from (largely) an implementation hub for imported offshore wind energy technology to a major export hub for UK manufacturing and services in this sector.
- Northern England and Scotland can sustain and grow a significant technology clusters by transforming current expertise in oil and gas into a proactive export-led sustainable ocean technologies approach.

To examine that hypothesis, the Offshore Energy SIA is focused on three key questions:

- How competitive internationally are the research and innovation activities of northern England and Scotland in offshore energy?
- What are the future needs in innovation of the offshore energy sector and the gaps in the current portfolio?
- Do Northern England and Scotland have the relevant skilled work-force in offshore energy?

These questions were used as the basis of the SIA methodology and permeated all the activities undertaken. The SIA was conducted on an open basis – welcoming input from all parties and engaging proactively with relevant stakeholders. In particular, engagement with a range of industrial companies was prioritised so that their views could be gathered directly. This was supplemented by input from relevant trade bodies and other groups to gather a true sector-wide view.

2.2 The Offshore Renewable Energy Industry Landscape

The offshore renewable energy sector has the potential to deliver substantial economic benefit to the UK. Offshore wind, wave and tidal energy, are each at different stages of maturity and are therefore outlined separately in the following subsections.

2.2.1 Offshore Wind

The progress of the offshore wind market from early demonstrators, through cost reduction and performance improvement, to the current phase of maturing supply chains and consolidation of project developers and OEMs, is significant and it is now set to move into a new phase of global market expansion.

The market prospects in Europe for offshore wind in particular are currently robust, and prospects in North America and Asia are emerging rapidly. In the UK, BEIS is moving ahead with its ambition to provide contracts for up to 10GW of additional offshore wind in the 2020s. Recent scenarios from the Committee on Climate Change[8] forecast a UK installed base of 20-29 GW of offshore wind in 2030. Projects announced in the Netherlands, Denmark and Germany during 2016 indicate a continued rapid fall in the Levelised Cost of Energy (LCOE). The next Contract for Difference (CfD) auction round in the UK will provide a more reliable indication of total LCOE, including the grid costs and project development costs that are borne by project developers in the UK, but funded out of the public purse in the European projects referenced above. However, ORE Catapult's Impact Report[9] indicates that offshore wind is on track to be a low-cost option to help meet future UK carbon budgets. The current Government's focus on nuclear and offshore wind as the main power sources to meet long-term decarbonisation goals is very positive for the future of the industry.

In the longer term, more ambitious possibilities have been identified – including for example the potential for a "UK Offshore Wind Energy Province", supplying a significant part of Europe's low-carbon needs. In scenarios to 2050, where electrification of heat and transport drives a need for hundreds of Gigawatts of renewable power, wind and solar opportunities in mainland Europe would not suffice and demand for UK-sourced offshore wind could reach 100GW-plus. This scenario looks well beyond the current Round Three licensing areas and would feature floating wind turbines far offshore and over a great enough area to provide quasi-baseload capacity – i.e. there would always be some statistically verifiable base level of generation, regardless of weather patterns. The emergence of affordable inter-seasonal storage would be another route to unlocking these very high deployment scenarios. As outlined in the following paragraphs, the ultimate value to the UK economy of unlocking the full potential of offshore wind runs from tens to hundreds of billions of pounds.

[8] https://www.theccc.org.uk/wp-content/uploads/2015/10/Power-sector-scenarios-for-the-fifth-carbon-budget.pdf
[9] https://ore.catapult.org.uk/resources/reports-publications/ore-catapult-reports/

Recent analysis by the ORE Catapult[10] has estimated the annual expenditure on UK offshore wind projects at £3.2bn in 2016, with roughly 32% of this being spent with UK supply chain companies and representing almost £2bn per GW in Gross Value Add (GVA). Developing the capabilities in the UK supply chain increases the potential GVA from UK offshore wind projects, with each additional 10% of spend remaining in the UK being worth an estimated £300m per GW. The contribution of each segment of the value chain to total value is shown in Figure 3. This also illustrates the portion already estimated to be captured by UK suppliers and the size of opportunity in each area if capabilities can be improved. For example, UK companies currently have a relatively low share in valuable areas such as turbines and foundations. This report will investigate to what extent academic research and industrial research and innovation are addressing these, and other, areas.

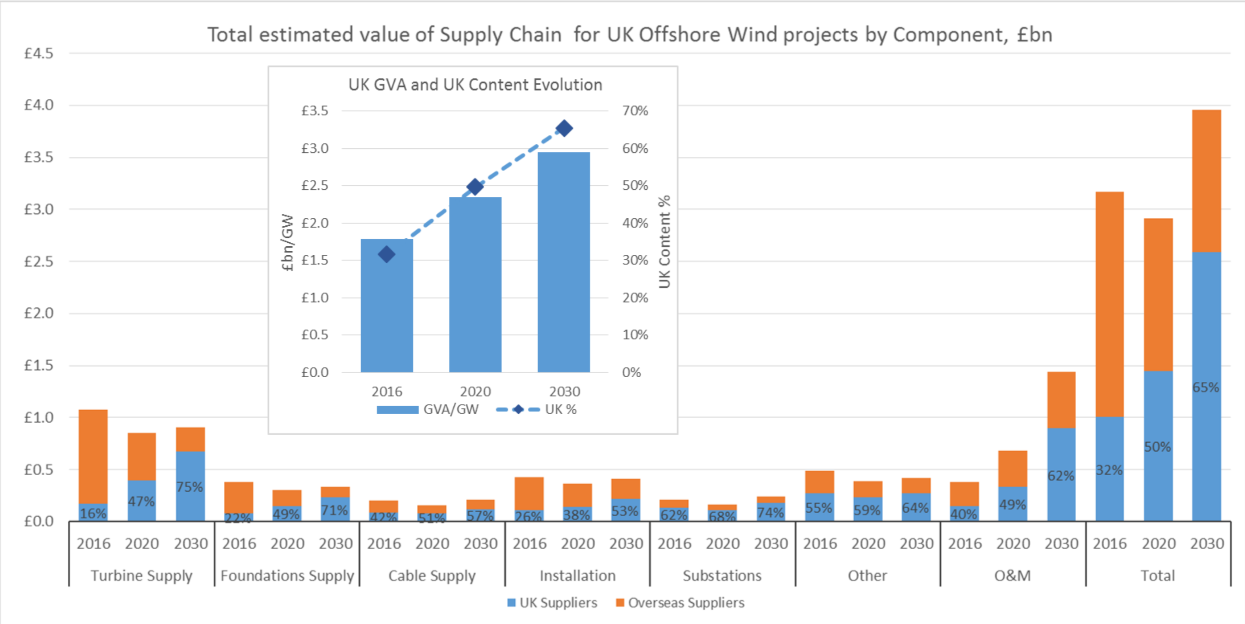

Figure 3: UK Offshore Wind Estimated Annual Spend and GVA (source: ORE Catapult analysis, 2017 (footnote 7))

2.2.2 Wave and Tidal

The International Energy Agency's 2010 Energy Technology Perspectives[11] forecasts up to 240GW of marine capacity could be deployed across the globe, with about 25% coming from tidal sources and 75% from wave, worth £76 billion, by 2050. The potential contribution to UK GDP is approximately £4 billion.

The UK has around 50% of Europe's tidal stream energy resource, with potential to meet up to 20% of the UK's current electricity demand, i.e. 30-to-50 gigawatt (GW) of installed capacity. The UK's tidal range resource is 25 to 30GWs – enough to supply around 12% of current electricity demand. The majority of this is in the Severn estuary (which has between 8 and 12GW), with the estuaries and bays of the North West representing a similar amount and the East coast a further 5 to 6GW.

A 2016 analysis by economic development agencies in the South-West, Wales and Scotland[12] estimated that around 1,700 people work in the UK wave and tidal sectors, with nearly £450 million spent to date in

10 The Economic Value of Offshore Wind: Benefits to the UK of Supporting the Industry
11 https://www.iea.org/publications/freepublications/publication/etp2010.pdf
12 https://www.regensw.co.uk/Handlers/Download.ashx?IDMF=5aa0d6fe-85ed-4a05-a9bf-64156014098e

the UK supply chain. With sufficient policy focus, this could grow to over 20,000 skilled jobs in the next decade. Job creation will be concentrated in distinct regions, and will grow primarily from existing UK industries where there is strong absorptive capacity, especially oil & gas, steel, and maritime.

To be competitive, tidal energy will need to demonstrate that it can align itself with the cost reduction path of offshore wind, and ultimately must at least target generating power for under £100/MWh. The technical and commercial development path for tidal energy includes determining the optimum platform design to harvest tidal energy and fully understanding how to design, build and operate reliably within a hostile sub-sea environment. Significant tidal deployment is not expected to occur until post-2020. However, pre-commercial demonstration of tidal stream arrays is beginning with the deployment of 6MW in Phase 1A of the MeyGen project in the Pentland Firth, in Scotland.

Wave energy technology developers face a number of significant challenges in the journey towards commercialisation. The industry is still in early development, with little evidence of design convergence or standardisation. The wide variety of bespoke wave energy solutions that are emerging are more costly to develop than those within the wind and tidal sectors where standard generic components are deployed. Wave technology developers struggle to attract public and private sector investment and, as first movers, are burdened with the development of both enabling technologies and components for first arrays.

In its investment in world-leading science, research and innovation, technical skills, small companies with the potential to grow and basic infrastructure, the wave and tidal stream sectors and its supply chain meet every pillar of the Industrial Strategy Green Paper. They are building economic clusters of academic research, engineering design and construction, ports, tourism and professional services in areas of relatively low GVA and fragile coastal communities in Cornwall, the Solent and Isle of Wight, Scottish Highlands and Islands, Wales and Northern Ireland. The sectors have already invested nearly £450m in the UK supply chain and achieved £7 investment for every £1 of public money invested.[13]

The practical potential for tidal stream energy is currently estimated at 20.6TWh/year; of which 6TWh/year lies in areas of relatively low productivity in the Highlands, Orkney and the Channel Islands. Similarly, the practical potential for wave energy is estimated at 50TWh/yr with the best resources off the coasts of north-west Scotland and Cornwall. Although this is relatively small compared to a potential for fixed and floating offshore wind of 900TWh/year, it is likely to drive additional GVA to the UK of almost £20bn.[14]

2.2.3 Geothermal Energy

Geothermal energy is little used in the UK, though the potential is significant. The onshore potential has been assessed at 300 Exa Joules by the British Geological Survey, sufficient to heat UK homes for 100 years. The UK offshore region has not been fully assessed, however, it is known from research published

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[13] Ibid
[14] Ibid

by Durham University[15] that co-produced fluids from currently producing oil platforms could be between 2 MW and 30 MW per platform. An audit of offshore potential geothermal energy is required.

2.2.4 Energy storage

The near offshore provides undeveloped opportunities for offshore energy storage, especially compressed air where onshore storage is likely to be socially unacceptable. NE England is particularly favourable because of well-developed salt deposits in which storage caverns could be created.

2.3 Area Examined

2.3.1 Geography

The Offshore Energy SIA Consortium was formed so that it covers a geographically distinct unit, embracing the coastal regions of Northern England and Eastern Scotland with their well-developed maritime industries and associated supply chains. The areas included in this SIA are linked through common interest as well as long histories of co-operation and joint enterprise in the offshore energy sector which developed out of their historical maritime activities in the major ports of Northern England and Eastern Scotland.

The SIA area has attracted significant investment from the offshore wind sector, including £315m investment from Siemens and Associated British Ports in an offshore wind blade manufacture facility and construction base in Hull, creating around 1000 new direct jobs. There has also been significant investment at the Port of Grimsby into operations and maintenance infrastructure of around £50m from wind farm operators and their supply chain.

Local Strategic Economic Plans identify offshore energy as a key economic priority and existing connections between the areas include research linkages, key businesses with multiple locations, the existence of established business networks and the primary locations of the Offshore Renewable Energy Catapult. There are also UK leading local innovation eco-systems in some parts of the territory offering opportunities for dynamic open innovation activities linking technology bases, for example digital and satellite applications and wider energy technology assets.

The partnership believes that there is potential for stronger alignment of these assets and resources, and that the shared coastal location and the focus into similar offshore and coastal sites provides an opportunity for strengthened collaboration through the SIA process.

[15] Auld, A., Hogg, S, Berson, A. and Gluyas, J.G. (2014) Power Production via North Sea Hot Brines Energy 78, 674-684

Activity outside the SIA area was also recognised and included in the analysis where appropriate – this included taking account of Round 1 SIAs in which relevant activities associated with energy generation and manufacture were considered. The primary area of the SIA is shown in Figure 4.

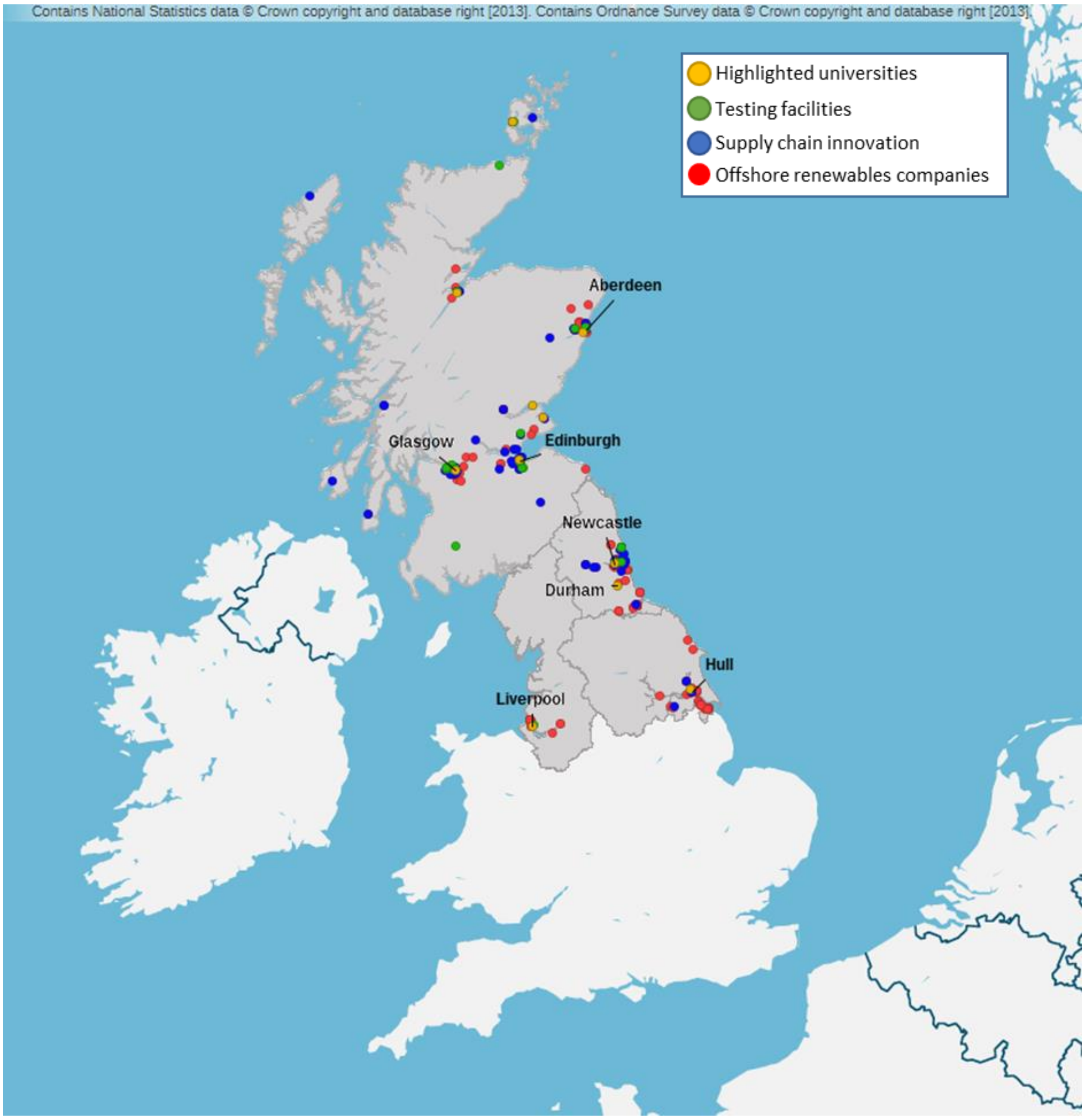

Figure 4: the area covered by the Offshore Renewable Energy SIA (source: ORE Catapult and Technopolis analysis, 2017)

2.3.2 Principal Economic Indicators

As shown in Figure 5, the economic area covered by the Offshore Energy SIA is diverse in nature.

- As of 2015, total regional economic output (Gross Value Added, GVA) is estimated at £171bn in the SIA area, accounting for around 10.4% of total UK GVA. The areas with highest total economic output in the consortium area are in or around Glasgow City (£19.6bn), the City of Edinburgh (£18.4bn), Tyneside (£18.2bn), and Aberdeen City and Aberdeenshire (£18.1bn). The area with the next highest economic output after these four is Liverpool (£10.9bn).

- The productivity of the consortium area's labour market is on average of £44,547 annually in terms of GVA per job filled and of £28.17 per hour worked. These are slightly lower than both the UK averages for GVA per job filled (£49,815) and hourly GVA (£30.94). Two areas within the consortium show averages above the UK averages on both metrics. Aberdeen City and Aberdeenshire has a GVA per job of £60,373 and a GVA per hour of £36.38, while the City of Edinburgh has GVA per job of £52,702 and hourly GVA of £33.04.

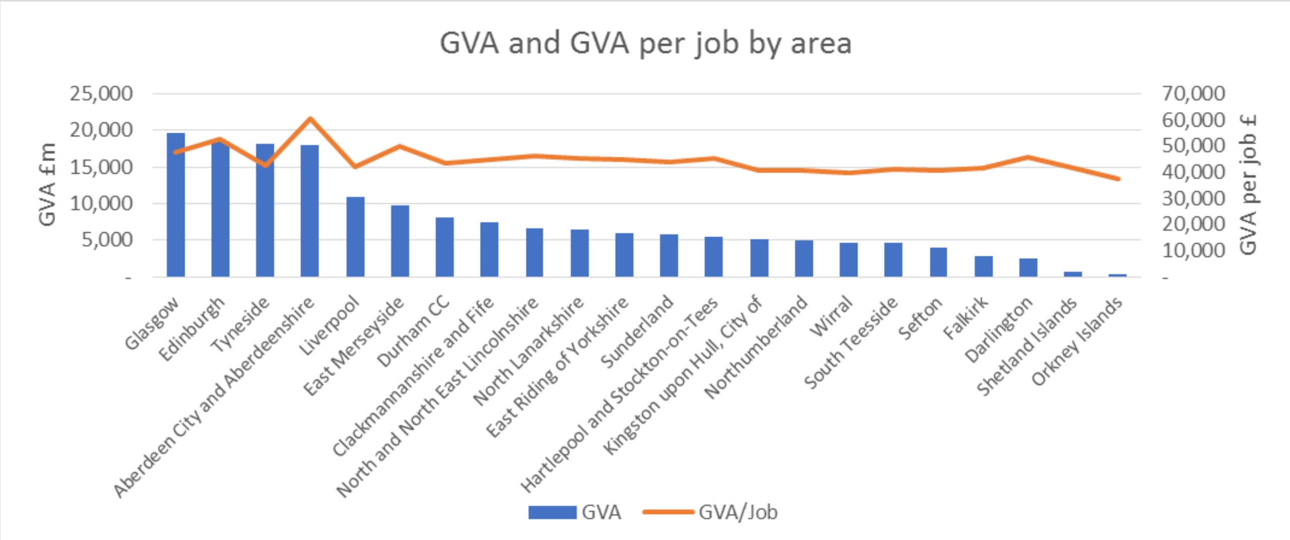

Figure 5: Principal economic indicators broken down by local area (source: Technopolis, 2017)

- The SIA area comprises a resident population of 7.6m, with 4.9m aged between 16 and 64 and offering a total of about 3.8m jobs. This represents 11.6% of all UK population, 11.8% of all population aged 16-64 and 11.2% of all jobs.

- The average annual gross full-time earnings in the SIA are of £26,518. This is slightly lower than the UK average of £28,213.

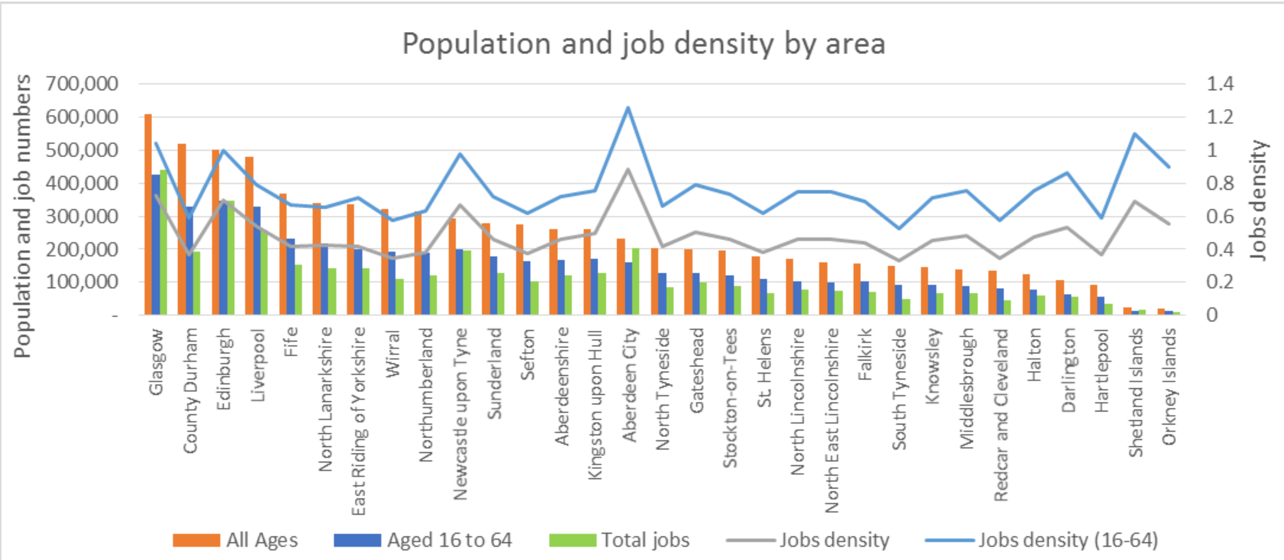

Figure 6: Population and Job Density for the SIA geography broken down by area (source: Technopolis, 2017)

As shown in Figure 5 and Figure 6, as well as having the highest GVA per job of £60,373, Aberdeen City also has the highest jobs density at 0.88 jobs per head of population and 1.26 jobs per 16-64 year old.

2.4 Conclusions

The SIA area is a major contributor of the UK's key strengths in offshore wind, wave and tidal energy. The area supports major centres for technology development, testing, site development and supply chain growth.

3 UK Offshore Renewable Energy Research

The UK has a rich base of high quality University research relevant to offshore renewable energy with significant strengths in offshore wind, wave and tidal energy. This section of the SIA sets out to assess how internationally competitive that research is, both in the UK as a whole and in the SIA area, and what are the main strengths and weaknesses.

3.1 International Competitiveness

The SIA undertook a detailed comparative assessment of UK research relevant to the audit. This was performed by utilising data from leading sources such as the Scopus database and the UK Government run Gateway to Research alongside international databases. Research papers were identified by using key-word searches followed by manual checking of the abstracts of the papers to confirm their inclusion in the survey. This process produced data on research publications in terms of topic area and quality (assessed through citations) and grant funding.

3.1.1 Offshore Renewable Energy Academic Publications by Country

Table 1 shows data from analysis of published research from the major research countries active in offshore renewable energy since 2010 segmented into offshore wind, tidal and wave energies respectively. This analysis includes all relevant research papers to those fields including for example both engineering research as well relevant work on environmental assessment and public policy.

Country	Offshore Wind			Tidal Energy			Wave Energy		
	No. of Papers	Total Citations	Citations per paper	No. of Papers	Total Citations	Citations per paper	No. of Papers	Total Citations	Citations per paper
UK	1,271	8,560	6.7	635	5,526	8.7	615	4,113	6.7
USA	1,714	12,722	7.4	734	7,452	10.2	1,365	10,596	7.8
China	1,435	4,752	3.3	517	1,863	3.6	1,142	3,725	3.3
Denmark	642	4,029	6.3	24	163	6.8	146	910	6.2
Netherlands	391	2,048	5.2	97	968	10.0	122	862	7.1
France	302	1,332	4.4	203	1,309	6.4	295	2,444	8.3
Germany	983	4,550	4.6	128	1,127	8.8	208	1,572	7.6

Table 1: Citations from published research since 2010 from the major research countries active in offshore energy (source: SCOPUS database)

Data on the number of research papers on offshore wind shows clearly that the US is the leading nation in terms of number of publications followed by China and then the UK, which is shown to be substantially more active than Denmark, the Netherlands and France. Data on total cumulative citations for the papers under consideration shows that, while the UK is third behind the US and China in total number of papers, the UK is second in terms of citations illustrating that the quality of UK papers is relatively high compared to those originating from China. This is confirmed by data on total citations per paper in which again the UK is second highest after the US. This situation echoes the performance of the UK across all research fields as highlighted in numerous UK government reports; namely that the UK is typically the second best performing country in research after the US. This is clearly a position of considerable strength and proves that the quality of UK research on offshore wind is of the highest international standard and demonstrably the highest quality research on this topic area in Europe.

Tidal energy is a research field with less activity in general than offshore wind but still significant in many countries. The UK is second after the US in terms of total published papers but is surpassed by both the Netherlands (albeit on a very low publication volume) and Germany in terms of citations per paper. None the less UK research is clearly internationally competitive in this field.

China and the US are both more active in terms of total publications in wave energy than the UK, which is third internationally in terms of volume. However, the comparative quality of UK research in Wave Energy is weaker (for example it is 5th in terms of citations per paper) than in offshore wind and tidal, although this still represents a strong activity.

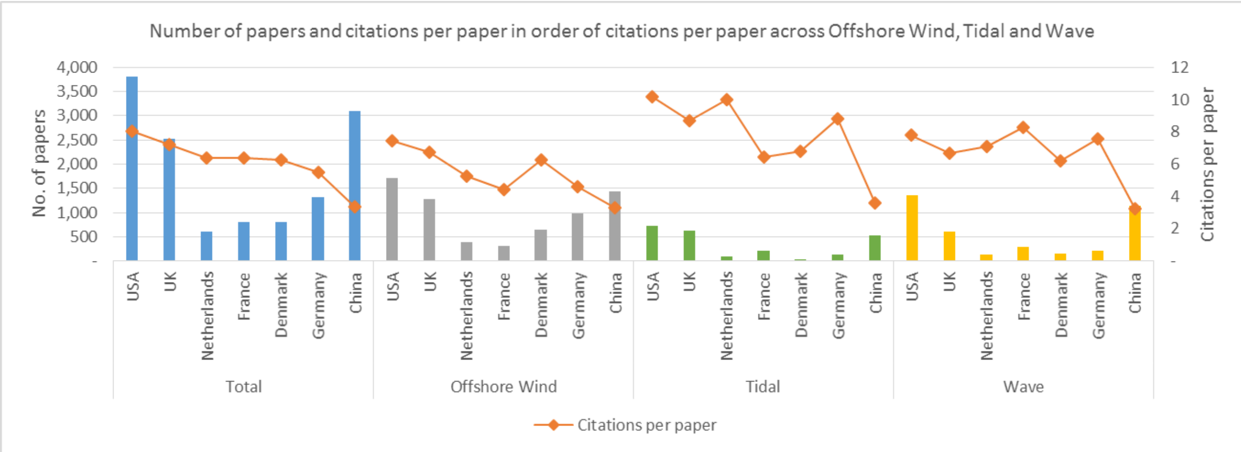

Figure 7: Number of papers and citations per paper in order of citations per paper for offshore renewable energy combined (source: SCOPUS database)

As shown in Figure 7, the US is strong across all three sub-sectors whilst it is clear that Denmark and the Netherlands have significant concentrations on offshore wind and invest much less in tidal and wave energy research. China has significant activity in both offshore wind and wave but is relatively weak in tidal although all three areas under-perform in terms of citations per paper

Taking offshore wind, tidal and wave together, the UK is third behind the US and China in terms of volume of papers, but a clear second behind the US in terms of citations per paper. This is a clear sign of the quality and international competitiveness of UK research in this area.

3.1.2 Offshore Renewable Energy Academic Publications by university

Offshore Wind

A detailed analysis was performed at the individual university level of the relevant publications – both for UK universities and for leading international competitors. A summary is shown in Figure 8. Detailed graphs presenting the raw data can be found in Appendix 2 .

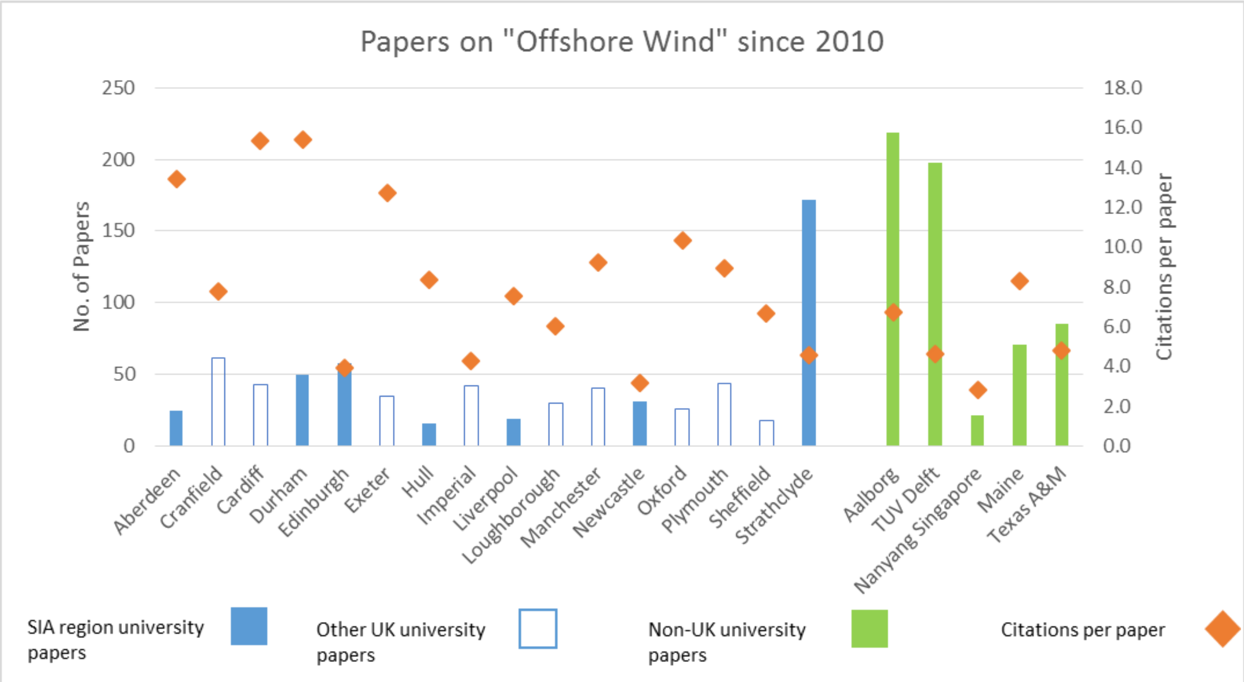

Figure 8: Papers on Offshore Wind since 2010 (source: SCOPUS database)

Data on the number of research papers since 2010 for the leading UK universities active in offshore wind research identifies clearly that some UK universities are producing very high quality research publications in offshore wind. Of particular note in offshore wind is Strathclyde University, which is number 3 in the world for quantity of papers over the time period surveyed (2010-2017). In terms of quality (measured as citations per paper), particular highlights are Durham and Cardiff which are absolute world leaders in this respect. It is also interesting to note that in some countries, for example both Denmark and the Netherlands, one university dominates the overall national statistics – producing in some cases nearly half the total number of papers produced by the whole country. The UK has a more distributed picture with a larger number of universities producing a significant number of publications - the SIA area in total produced approximately 30% of the UK's output in offshore wind research over that time period. The average citations per paper for the SIA region was in line with the UK average at 6.7 citations per paper.

Tidal Energy

UK tidal energy research is strong in terms of international competiveness and again shows a very distributed structure in terms of number of universities involved (see Figure 9). Within the UK, there are peaks of activity at Plymouth University in South-West England, which is complemented by strong activity in Wales. Scotland has a strong activity in tidal energy which is headed by Edinburgh University, supported by Heriot-Watt and Strathclyde. In tidal energy, the SIA area represents approximately 20% of the research output of the UK by volume. The citations per paper for the SIA region, at 9 per paper, is marginally higher than the UK average of 8.7 citations per paper. This activity level in the SIA area is matched almost exactly by that of the cluster in South-West England and South Wales. Internationally, there are strong activities in China (led by Harbin University) and also in the US (where Washington State leads). Tidal energy has long been a strength in France (see later chapters on tidal energy projects in France) and this is reflected in the quality of publications of the research institute at IFREMER in Brest.

Wave Energy

Wave energy research shows some similarity with tidal with strong activities at Plymouth and

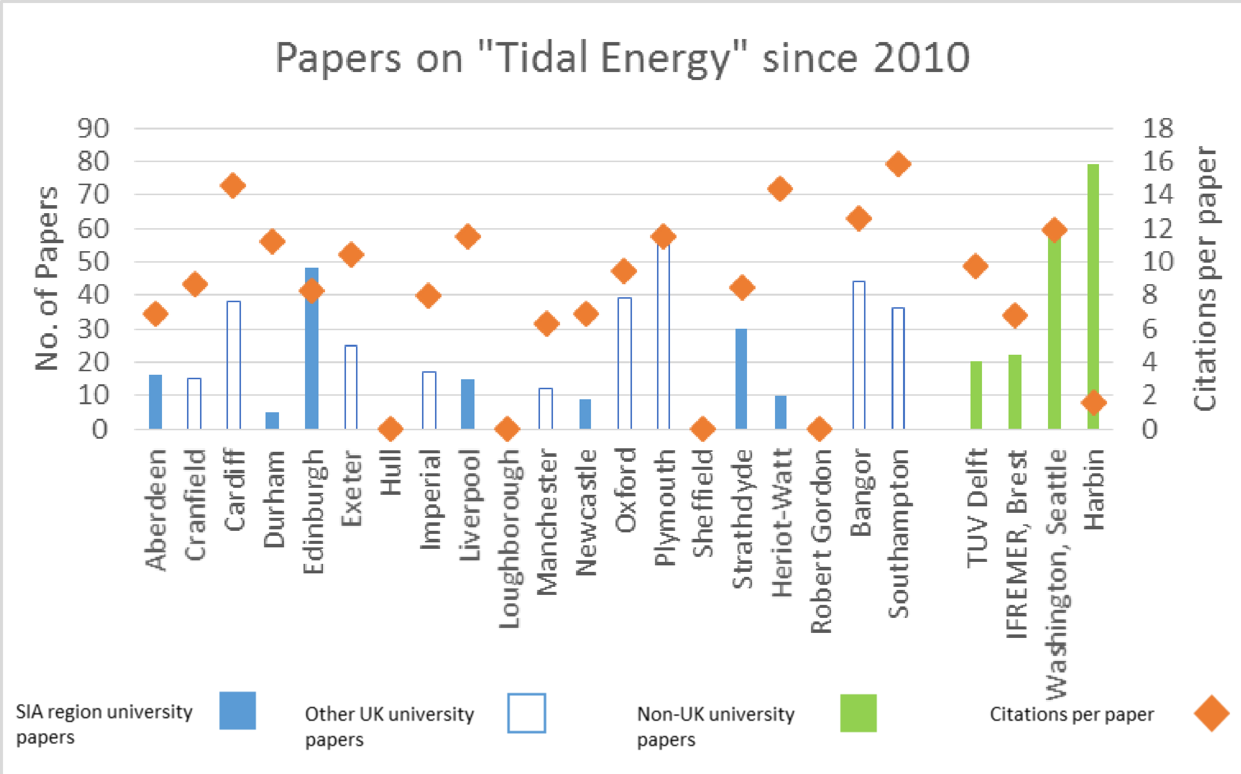

Figure 9: Papers on Tidal Energy since 2010 (source: SCOPUS database)

Southampton in the South of England and at Edinburgh and other universities in Scotland (see Figure 10). The SIA area produces approximately 20% of the UK's research output in wave research which is slightly less than the South-west England and South Wales cluster (at around 27% by volume). The average citations per paper for the SIA region, at 5.1 per paper, is lower than the UK average of 6.7 citations per paper. Internationally, there are strong levels of activities in Denmark at Aalborg and in the Netherlands at TUV Delft. In a similar manner to tidal energy, US research in wave energy is most active in the Pacific North-West at Oregon State.

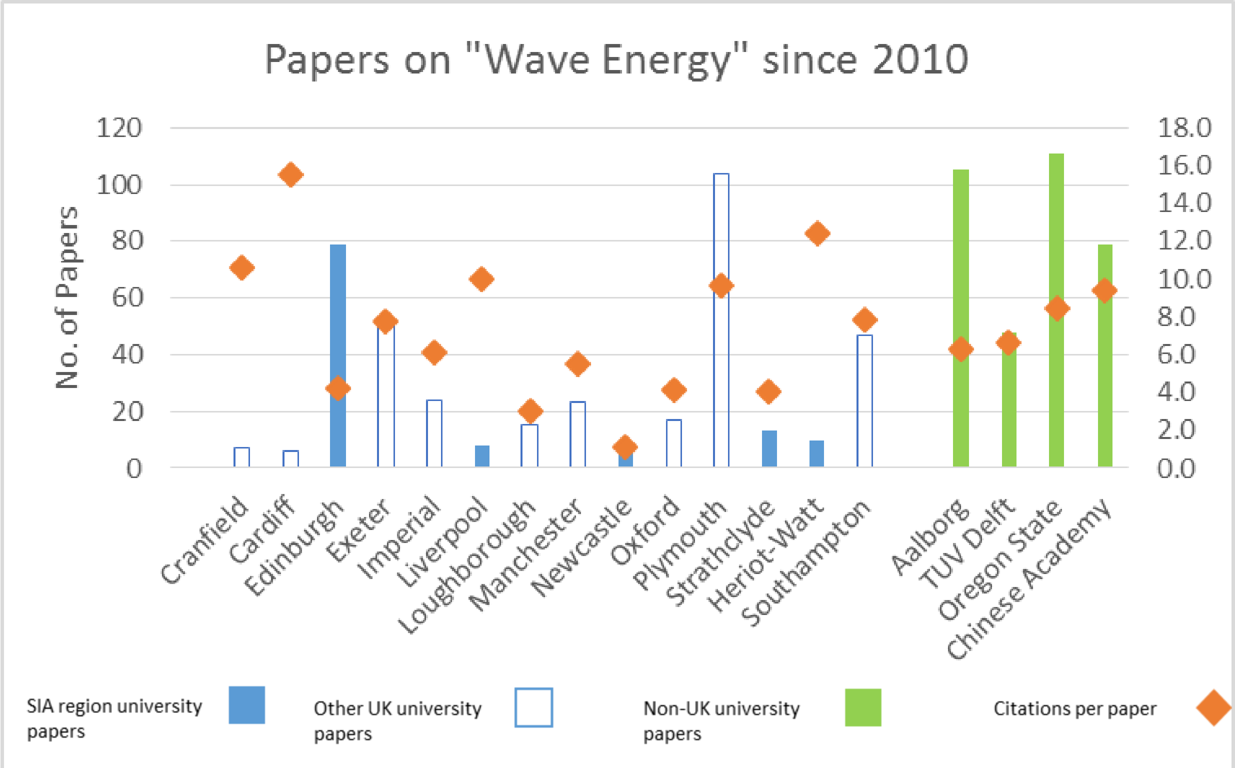

Figure 10: Wave Energy papers since 2010 (source: SCOPUS database)

Academic Publications Summary

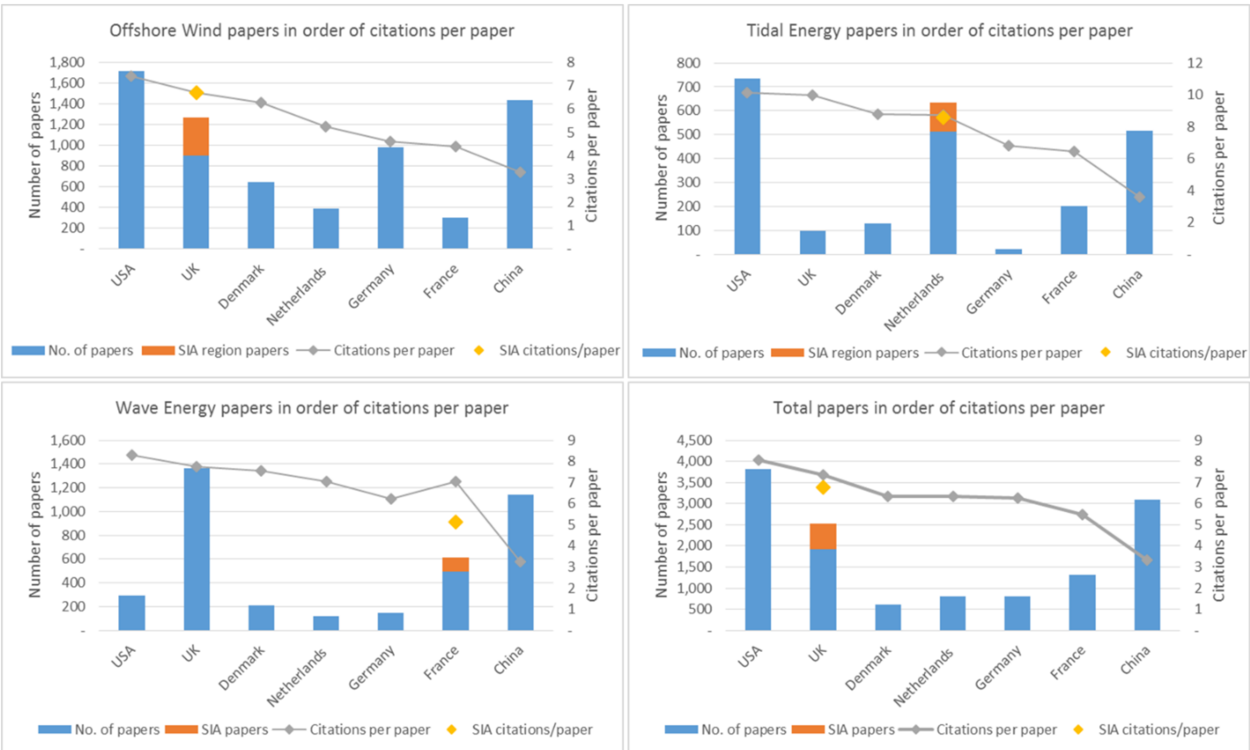

Figure 11: Number of papers and citations per paper, highlighting SIA regional performance (source: SCOPUS database)

Over the three research areas audited (offshore wind, wave and tidal), the UK performed consistently well – producing a significant volume of research which is of a very high quality. The strongest UK performance is perhaps in tidal energy research (where the UK is comparatively strong in both quantity and quality) followed by offshore wind. The SIA area is the UK's leading research area across offshore renewable energy as a broad group with a particular comparative strength in offshore wind, although it should be noted that both tidal and wave energy are well represented. Overall, the quality of the publications within the SIA region as measured by citations per paper is in line with that of the UK as a whole and second internationally only to the USA, as shown in Figure 11.

3.2 University Expertise within the SIA area

The SIA consortium area contains a number of world-class universities undertaking research in the broad field of offshore energy but often with a special interest in one of the major areas. There is not a uniform classification of areas of expertise and activities across all universities, but we have aligned the key themes as far as possible with key components of the offshore wind value chain or with wave and tidal focus.

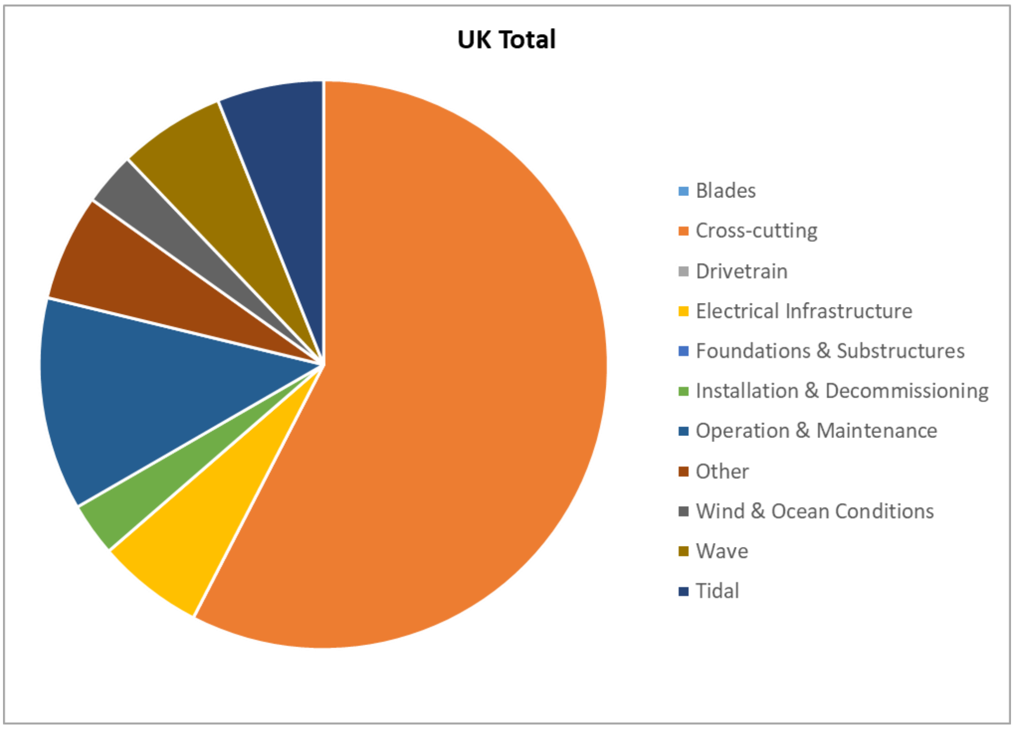

Figure 12: SIA area university specialisms in offshore renewable energy (source: ORE Catapult analysis, 2017)

This categorisation depicted in Figure 12 suggests that academic specialism specific to offshore renewable energy tends to be focused on turbine technology or wave and tidal device technology. Balance of plant elements, e.g. foundations, cables, installation, tend to be covered by multi-disciplinary or cross-cutting themes such as engineering, energy systems and environmental studies. This provides the benefit of capturing and incorporating the best related knowledge into offshore renewable energy, but also highlights a potential opportunity for increased specialism in these areas. This section highlights the specific expertise of each university and illustrates the internationally recognised strength and quality of work in both offshore renewable energy-focused and cross-cutting disciplines.

The geographical spread of these academic institutions is shown in Figure 13. The size of the mini pie chart for each location represents the number of separate relevant disciplines identified.

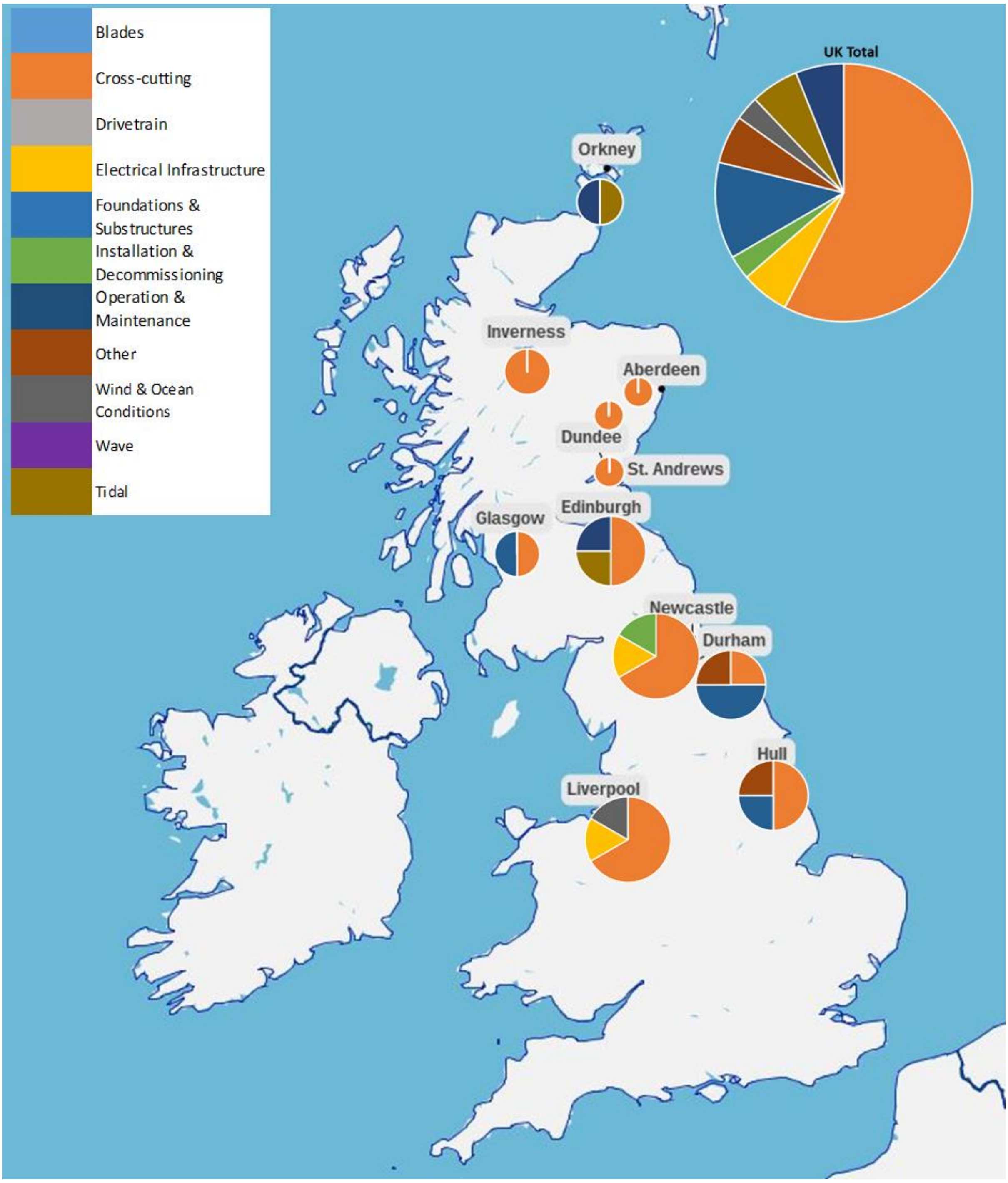

Figure 13: SIA region universities with expertise directly relevant to offshore renewable energy (source: ORE Catapult analysis, 2017)

3.2.1 Durham University

Offshore energy is a key focus of energy research at Durham University and is reflected by key long-term industrial partnerships with the Danish Oil & Natural Gas Company (DONG Energy) and BP and collaboration with a wide range of other industrial partners.

Durham University Energy Institute (DEI) has leading research expertise in offshore wind energy, petroleum exploration and production and trade, carbon capture and storage, marine bio-energy and tidal energy. DEI also has expertise in geothermal energy and energy-storage both of which have significant potential for offshore development.

DEI offshore energy research draws on a wide range of interdisciplinary expertise facilitated through the Durham Energy Institute and the Centre for Earth Sciences including Engineering, Earth Sciences, Geographical and economic aspects of trade, supply chains and investment networks, Biological and chemical research, as well as the political, environmental and social issues connected to offshore energy.

Durham University has a strong partnership with DONG Energy which goes back to 2008 when DONG Energy co-funded the first UK Professorship in Carbon Capture and Storage. Since then there has been close collaboration on a number of projects in the Oil and Gas, and Offshore Wind energy fields which have included multiple MSc and PhD projects. Durham also has a long-standing partnership with BP which has delivered research funding in exploration and production, energy materials and geothermal energy.

Durham is a partner in Project Aura[16] which aims to strengthen the local innovation landscape, to identify and address key technical, operational and economic barriers to drive down the cost of Offshore Wind energy, support the growth and development of the supply chain for the offshore wind sector and promote and sustain the UK's status as a world leader in offshore wind.

Durham is also a key partner in the £20m EPSRC National Centre for Energy Systems Integration (CESI) which is being led by Newcastle University and has Siemens-Gamesa and DONG Energy as industrial partners. The aim is to reduce the risks associated with securing and delivering a fully integrated future energy system for the UK.

A key area of DEI expertise in wind energy is condition monitoring and reliability analysis. The group also undertakes research into large onshore, and offshore, medium and domestic wind.

DEI facilities include a kilowatt scale drive reliability test rig, as well as a number of wind turbine and converter related test facilities, all of which have been used for experimental studies in connection with the Condition Monitoring research. The extensive array of wind tunnels in the School includes a wind tunnel featuring a turbulence generation system capable of producing repeatable unsteady flow events used for aerodynamic studies, principally on vertical axis wind turbines. DEI also hosts a Smart Grid Laboratory with a low-voltage network with wind turbine emulation system and a wide range of other low carbon technologies.

The greatest area of uncertainty in offshore wind lies below the water, for example cabling issues are at the root of 70% of insurance payouts[17]. Researchers at Durham are developing numerical analysis tools to provide greater confidence in two key areas, namely: subsea ploughing for cable installation and

16 http://aurawindenergy.com/

17 http://www.4coffshore.com/windfarms/submarine-power-cable-losses-totalling-over-eur-350-million-in-claims-nid5127.html

foundation solutions in intermediate water depths. These new finite element based modelling tools are being validated against experimental results generated by other university partners. Durham is contributing to a major research project to determine whether cheaper, more environmentally friendly, and more effective foundations can be developed for the offshore renewables industry.

Durham has a strong track record in innovative, science-led research into Oil and Gas, which covers the composition, extraction, distribution of oil and gas, as well as Carbon Capture and Storage and the production of hot water from oil and gas fields for geothermal energy uses. CeREES Centre for Geoenergy is the only research centre in the UK that works across all geoenergy themes, carrying out high level multidisciplinary research in Petroleum, Unconventional Hydrocarbons, Geothermal, Clean Coal, Resources from Waste and Carbon Capture and Storage.

CEREES, in collaboration with Ikon Science and DONG Energy, appointed the first ever UK Professor of carbon capture and storage (CCS). CCS research at Durham focuses on CO_2 storage, the risks associated with site integrity, and monitoring sites. Recent activities in carbon capture and storage include: geological characterisation of potential CO_2 storage sites in the UK continental shelf; research into Enhanced Gas Recovery through CO_2 injection and other mechanisms, development of analytical solutions to predict Joule Thomson cooling in low-pressure depleted reservoirs; simulation of convection enhanced CO_2 dissolution around leaking inclined faults, research into innovative techniques for monitoring CO_2 storage sites to ensure injection sites remain safe.

DEI has pioneered the utilisation of co-produced water in the offshore oil industry for geothermal power production. The technology has been demonstrated to extend field life, reduce CO_2 emissions and produce around 50% of offshore platform power requirements. Energy storage capabilities for the UK are modest. The offshore region presents under developed and undeveloped opportunities for hydrocarbon gas storage and compressed air storage. Nearshore compressed air storage could be a significant opportunity for NE England and is the subject of a current research funding bid by DEI.

3.2.2 University of Edinburgh

The vast majority of the University of Edinburgh's marine energy research takes place within the Institute for Energy Systems (IES), one of five multi-disciplinary research institutes within the School of Engineering. The institute is made up of 13 academics, 25 research staff and 53 PhD students. The Institute also hosts a Sustainable Energy Systems MSc with an annual cohort of around 60 students.

The Institute for Energy Systems (IES) is a multi-disciplinary research institute with a broad renewable energy expertise spanning the energy supply chain from natural resource to generation (e.g. device technology) through to utilisation and policy. The institute classifies this work into three research theme groups: Offshore Renewable Energy Systems; Electrical Energy Systems; and Innovation and Policy.

Within the IES, the Offshore Renewable Energy group supports the development of marine energy resources. These include developing solutions to the technical difficulties posed by connecting marine renewables to networks and improving its competitiveness (Power Systems) and development of alternative energy vectors to assist the power system harness variable renewables (Energy and Climate

Change). Extensive testing is undertaken using the facilities with the School of Engineering. Notably, these include the new combined current and wave test facility (FloWave) and the curved wave tank

This group is also currently home to the SuperGen UK Centre for Marine Energy Research (UKCMER), and the Industrial Doctoral Centre for Offshore Renewable Energy (IDCORE). These are both important research centres and training centres for young researchers and are covered in more detail in Chapter 5.

3.2.3 Heriot-Watt University

Heriot Watt's expertise in Marine Renewables exists primarily at **The International Centre for Island Technology (ICIT)**, a specialist arm of the Institute of Petroleum Engineering. ICIT was established in 1989 to carry out advanced research, postgraduate training and consultancy in marine resource management and related issues including renewable energy research. Being in Orkney it is located close to the industry base centred around the Pentland Firth and many of the Crown Estate leases.

ICIT is a world leader in research, teaching and consultancy with particular expertise in managing the resources of the marine environment. Its five MSc programmes attract students from around the world. The ICIT designs the renewable energy courses to produce highly qualified graduates who can fill the skills gap in the emerging renewable energy sector while the marine resource management programme provides graduates with a broad expertise in the management of marine and coastal resources.

The ICIT has developed a strong research and consultancy portfolio, enjoying mutually productive links with industry, Government and other academic bodies at local, national and international levels.

3.2.4 University of the Highlands & Islands

UHI is based on many campuses throughout Scotland. The marine energy relevant expertise resides predominantly in the **Scottish Association for Marine Science (SAMS)** in Oban, and the **Environmental Research Institute (ERI)** in Thurso.

SAMS is Scotland's largest and oldest independent marine science organisation, dedicated to delivering marine science for a healthy and sustainable marine environment through research, education and engagement with society. SAMS research strengths include marine renewables, aquaculture, marine biotechnology, marine policy, deep-sea systems, climate change and polar science. The SAMS group employs over 165 regular staff and a number of seasonal staff on demand.

The ERI is internationally recognised for distinctive and innovative environmental science. It works with partners throughout Europe and as far afield as North and South America, Asia and Australia. With outstanding natural resources in the Pentland Firth and Flow Country, and a range of analytical and field equipment, it addresses emerging issues related to improving understanding of the natural environment.

3.2.5 University of Hull

Relevant areas of research and innovation strength at the University of Hull include:

Advanced Manufacturing activity aims to apply modern digital engineering principles to ensure efficient and cost effective manufacture. It is focused on the use of novel material and manufacturing processes in the production of blades, including the development of smart surfaces and advanced coatings to minimise damage and provide ice-shedding capability, the development of more sophisticated blade structures to give higher performance at lower cost/weight and the inclusion of sensors for whole lifetime monitoring of blades through production, transport, installation and operation. Through an EPSRC Prosperity Partnership, the University of Hull is working with academic and industry partners on a £7.6M programme of work which will improve blade structures and sensor systems as well as condition and structural health monitoring.

Operations and Maintenance (O&M) research provides gains in the reduction of the LCOE of operating offshore wind farms. Specifically, this covers the physical systems for condition/structural health monitoring, the use of autonomous systems for monitoring and maintenance operations; simulation and visualisation (Hull Immersive Visualisation Environment, HIVE) and process improvements associated to logistics and supply chain considerations. A distinctive and increasingly significant element of this is the study of how human factors impact on technician performance and fatigue and how these can be addressed in staff selection, training, crew transfer and in the development of HSE policies. Hull is involved in work which directly addresses how Human Factors impact technician performance (see Section 3.3.3).

Interdisciplinary Impact Assessment considers the many and varied interactions between offshore renewable energy systems and their environment. Within this context, impacts are investigated at a micro (individual turbine or windfarm) and at a macro (whole region – e.g. the Marine Data Hub, investigating impacts on the North Sea) level. The studies are holistic and wide ranging, incorporating impacts from as many relevant disciplines as possible. Particular strengths exist in research into the effect of foundations on seabed sediment transfer and the impact of offshore structures on plant and animal life. These have been studied through computer modelling and physical models using the university's total environment simulator 'flume' facility, which is especially well suited to OSW deployments as it can accommodate sediment (and biological material) within experimental design. The University's Institute for Estuarine and Coastal studies has a strong track record in OSW research and consultancy, having been involved with over half of the UK OSW sites. Academic departments involved in this portfolio of work include; Logistics, Management, Economics, Politics, Law, Psychology, Sociology, Healthcare, Geography, Biology and others.

Within a wider economic / environmental / sociology focus, the University of Hull Logistics Institute is undertaking a three year study assessing the economic, environmental and social impacts of Green Port Hull, the offshore wind development initiated by ABP and Siemens. It will provide evidence, analytics and key performance indicators, on an on-going basis, to the stakeholders and to the public. (http://gia.hull.ac.uk/)

Market Conditions is a more applied area of work and intelligence that the University of Hull delivers to provide insights into market trends, needs and overall conditions. Studies delivered through this stream of work provide the evidence for investment in new offshore wind initiatives and research projects at an internal level and for collaborative partners. University of Hull staff have developed a wide ranging knowledge base across multiple fields of expertise to help justify areas of development and allow the university to act as a trusted source of market intelligence at a wide range of external events.

Specific areas of activity include: the development of 'Whole Life Supply Chain' modelling tools; SME innovation support activity; market readiness and proof of market assessment and supply chain assessment.

3.2.6 University of Liverpool

The University of Liverpool has extensive leading edge research in engineering and science that is both directly related to and aligned with the offshore renewable energy sector. These include:

The Schools of Engineering (SoE) and Electrical Engineering and Electronics and Computer Science (SoEEECS) have knowledge and experience in many areas of renewable energy – in particular in the area of tidal stream, tidal range, electrical machine and power electronics for renewable energy generation and integration and smart grid operation. Specifically related to offshore energy, there is considerable experience in experimental and theoretical research into many aspects of fluid mechanics in SoE, including aero and hydro dynamics and the influence of waves on the tidal flow. Research has included wave and current loading on offshore structures and other work includes offshore tidal turbine CFD modelling; large scale turbine farm energy resource and impact; offshore wind farm impact; structure vibration; antifouling marine coatings; laboratory experimental turbine design and performance assessment and advanced numerical predication of deep water mooring strand behaviour and failure.

In SoEEECS, there is significant expertise and research related with offshore renewable energy, including the design and testing of polymer insulation behaviour under HVDC stress for DC circuit breakers; advanced control of electrical machine and power electronic converters to improve energy conversion efficiency and apparatus reliability of offshore wind power generation systems; condition monitoring with advanced sensor technologies and data communication for high voltage apparatus such as transformers, power electronics and wind turbines. Moreover, smart grid technologies have been developed to integrate more intermittent offshore renewable generation.

The School of Environmental Science (SoES) has expertise in social science, marine biology and marine planning and management including specific work such as the health of coastal seas; accounting for seabirds in Marine Spatial Planning and newly developed coastal modelling tools to enable exploration of the adaptation and resilience of coastal energy supply through coastal response to storms and wave overtopping.

The University of Liverpool's flume facility is unique in the UK in its ability to conduct cavitation experiments and can generate water velocities up to 6 m/s, with the ability to develop velocity profiles and surface waves. Instrumentation includes Laser Doppler Anemometry (LDA) and Particle Imaging Velocimetry (PIV), as well as a variety of force measuring systems.

Established in 2010, the **Virtual Engineering Centre (VEC)** comprises a multi-disciplinary team including specialists in engineering, computer science, visualisation and manufacturing technology, and is underpinned by the University of Liverpool and specialist Centres of Excellence. Continuous Professional

Development courses on virtual engineering are available for industry. The VEC works across a range of sectors including Energy and has developed specific expertise in supporting renewable energy technologies and developing innovative simulation and modelling to support new technologies within the oil and gas industry.

The University of Liverpool has a strategic partnership with the **National Oceanography Centre (NOC)** which is based on campus creating a highly stimulating collaborative research community with shared facilities, close day-to-day interaction between NOC and university researchers and a world-class postgraduate training environment. This includes visiting professors and collaborations related to marine renewable energy (MRE) mainly based around coastal modelling and offshore energy opportunities. More specifically, the NOC capability is mainly in modelling the resource and environmental impacts of MRE, eg. current EPSRC project EcoWatt2050 looking at impacts of large scale tidal energy extraction on ecological systems, also taking into account climate change effects. This entails hydrodynamics and wave modelling of coastal and shelf seas and also includes sediment modelling, focusing also on coastal morphology. Other work includes observing changes in coastal morphology using X-band radar and looking at resource and impacts of NW barrages across 5 estuaries with plans to extend previous modelling of tidal barrages and lagoons to 3D and include sediments. Also limited case studies have been undertaken on managing coastal flooding using tidal energy infrastructure. A good interface between academia and industry has been built up via the NERC MRE Knowledge Exchange Programme.

Centre for Offshore Renewable Energy Research (CORER) is a virtual centre led by the National Oceanography Centre with the Universities of Liverpool and Southampton, the Ocean University of China and NERC. It unites academics, researchers and postgraduate students with ambition to produce novel and fundamental scientific research within the offshore renewable energy field and disseminate research to industry to reduce inherent risks and uncertainties in the offshore renewable energy sector.

3.2.7 Newcastle University

Newcastle University has a broad base of engineering and science expertise relevant to the offshore energy sector. This includes:

The School of Electrical and Electronic Engineering is involved in the development of electrical generators and power converters for the wave and tidal energy sector. As part of the EPSRC funded Supergen Marine programme, staff are part of an international consortium working towards an all-electric drive solution for wave energy, where there are no intermediate mechanical linkages between the moving parts of a device and its smoothed electrical output (see Edrive project case study in Section 3.3.1). This work focuses on the power electronic and electro-mechanical challenges of slow speed cyclic power production. The School is also involved in the development of large generators for tidal stream devices through a number of research projects.

The Design Unit at Newcastle University is a world-leading centre for gear research and has an extensive programme of activity relevant to offshore energy (see case study below).

The £20m EPSRC **National Centre for Energy Systems Integration (CESI)** is primarily funded by the Engineering and Physical Sciences Research Council (EPSRC) and Siemens. The aim is to reduce the risks associated with securing and delivering a fully integrated future energy system for the UK. This will be achieved through the development of a radically different, holistic modelling, simulation and optimisation methodology which makes use of existing high level tools from academic, industry and government networks and couples them with detailed models validated using full scale multi vector demonstration systems. CESI will carry out uncertainty quantification to identify the robust messages which the models are providing about the real world, and to identify where effort on improving models should be focused in order to maximise learning about the real world. This approach, and the associated models and data, will be made available to the energy community and will provide a rigorous underpinning for current integrated energy systems research, so that future energy system planning and policy formulation can be carried out with a greater degree of confidence than is currently possible. CESI is a unique partnership of five research intensive universities and underpinning strategic partner Siemens (contribution value of £7.1m to the centre) The Universities of Newcastle, Durham, Edinburgh, Heriot-Watt and Sussex have a combined RCUK energy portfolio worth over £100m.

Tyne Subsea – the National Centre for Subsea and Offshore Engineering at Newcastle University builds on a long tradition of applied engineering research focused on the marine, subsea and offshore sectors, drawing on strong engineering schools (Marine, Electrical, Mechanical and Civil Engineering). These research activities have always had an ethos of being linked to the needs of businesses reflecting strong, long-standing relationships. The Centre has world-leading capability in hyperbaric testing and autonomous robots for the subsea sector.

The School of Marine Science and Technology at Newcastle University is one of the largest and broadest based marine schools of its kind in Europe, covering the fields of marine engineering, marine biology, naval architecture, offshore engineering, coastal management and small craft technology, and enjoys a substantial international reputation. Research into offshore renewable energy technologies spans a range of areas through the design, operational and maintenance phases including: novel blade and turbine designs for tidal energy conversion, foundation design and scouring; power take-off systems and control for marine renewable energy devices, advanced condition monitoring and fault diagnosis; and marine robotic devices for underwater inspection and cleaning and maintenance strategies for marine systems.

The Sir Joseph Swan Centre for Energy Research is a multi-disciplinary activity focused on improving the efficient utilisation of energy and support end use energy demand. Research contributes to the global challenges of energy security, energy efficiency, including waste reduction, and de-carbonisation.

3.2.8 Offshore Renewables Institute (Aberdeen, Dundee, Robert Gordon)

The Offshore Renewables Institute (ORI) unifies the capability of three partner universities: University of Dundee; University of Aberdeen; and Robert Gordon University. It is becoming a recognised global authority on the delivery and implementation of offshore renewable energy. The ORI offers an interdisciplinary and integrated approach bringing together experts, researchers, and knowledge from different disciplines and all three university partners to confront challenges faced by Industry and

Government in delivering and managing the offshore energy industry. Expertise focuses on four thematic areas: in framing, consenting, managing, and deploying offshore projects.

3.2.9 Robert Gordon University

A small team of engineers in the **Centre for Understanding Sustainable Practice (CUSP)** has a history of working on a number of marine renewable projects in the Scottish waters and further afield.

The CUSP works with national governments, local authorities, NGOs, business, academics and indigenous communities. It supports and facilitates social and economic transformation by linking energy, food, and water resources to people and their environment through technology development, policy intervention and business case presentation.

3.2.10 University of St Andrews

The **Scottish Oceans Institute (SOI)** at St Andrews is an interdisciplinary research institute studying the marine environment which forms a key focus for research excellence in marine-related science. Research interests range from the deep oceans to the coasts, and from the people who use and interact with the sea, to the biological and physical processes that make the oceans function. SOI develops scholarship, commercialization of research and advanced-level teaching delivered through contributing Schools at the University of St Andrews.

3.2.11 University of Strathclyde

The expertise in marine renewables at the University of Strathclyde resides in Departments of Electrical and Electronic Engineering, Mechanical and Aerospace Engineering, Naval Architecture and Marine Engineering and with the School of Economics.

Most of the Wind Energy expertise resides in the **Wind Energy & Control group of the Institute for Energy & Environment**. The group is an international leader in wind energy and the control of wind turbines and wind farms. Current research activities examine the dynamic analysis of turbines, their modelling and simulation, control system design and their optimisation, along with resource assessment and condition monitoring issues. It also has a focus on the development of system engineering methods and practical algorithms for the control and optimisation of complex and nonlinear systems. This covers the whole cycle of control design including system analysis, modelling, real-time simulation, and implementation. In collaboration with industry partners, its control based research work is applied to power generation plant, water and environmental systems, marine systems, medical robotic systems and systems biology.

Wind Energy Systems Research Centre

The University of Strathclyde has been successful in securing a major funding programme for a new Industrial Doctoral Training Centre aimed at supplying the wind industry with a new generation of specialists in wind energy. Over the next five years, the Centre will produce 50 PhD-level engineers and scientists, bringing together pioneering research and advanced skills training to help the UK meet its ambitious renewable energy targets, as well as addressing the skills shortage in the sector. In the wind energy arena, a number of companies – some of which were spinouts from Scottish universities – have already produced advanced products and services, and others are involved in the further commercialisation of research projects to add to the body of work coming out of Scotland.

This group is also home to the **SUPERGEN Wind Hub**, described in more detail in Section 7.1.7, and the **DTC Wind & Marine Systems**.

The **department of Naval Architecture, Ocean and Marine Engineering (NAOME)** is a key provider of innovative and useful research for the maritime, oil and gas and marine renewables industries across the world. It is a world-leading centre of marine technology, by developing a sustainable research environment which supports continuous improvement and growth.

3.3 Project Case Studies

This sub-section presents details of particular research projects that were highlighted during the SIA process as being of particular impact (either within the SIA region or elsewhere in the UK). They represent only a small selection and of course there are many others of merit that could not be included for reasons of space.

3.3.1 EDRIVE-MEC: All Electric Drive Train for Marine Energy Converters

The EDRIVE programme is funded by the EPSRC 2016-2019, led by Prof Mueller (Edinburgh University) and colleagues from Newcastle University.

Conversion of energy from wave into electricity is ideally performed by a system that can convert motion in multiple directions, react large forces or torques whilst operating at low velocity, variable voltage and frequency, with high reliability, availability and efficiency over a wide range of loads. E-DRIVE proposes to fulfil this aim through the development of novel integrated low speed generators with speed enhancement and power converter topologies with associated control to replace hydraulic systems - mirroring developments in all/more electric systems in automotive and aerospace.

3.3.2 Greenport Impact Assessment (GIA) – Measuring the success and impact of renewable energy investments

The University of Hull Logistics Institute is utilising the Siemens blade manufacturing development at Green Port Hull (GPH) as a case study in the Greenport Impact Assessment (GIA) - gia.hull.ac.uk. This innovative three-year economic, environmental and social impact analysis is reviewing and evaluating GPH. It is providing evidence and analytics and evaluating key performance indicators on an on-going basis to stakeholders and to the public. Key amongst these is a 'real time' GVA analysis, which, together, can be used to inform policy and devise or adjust strategies to attract and develop businesses throughout the renewable energy value chain. The work has attracted significant international interest from the USA and Morocco, where a proposal to execute a similar study is now under review.

3.3.3 Human Factors in Offshore Wind Technician Transit

Technicians service offshore wind turbines through planned missions or in response to faults. Currently, there is limited information to judge if sea conditions will allow the crew transfer vessels (CTVs) to sail, ensuring the safety and wellbeing of the technicians as they perform complex and physically demanding tasks once transferred to the turbine. The University of Hull is collaborating with organisations active in the offshore wind sector to apply psychological and physiological methods and digital technology to create a decision-support tool. The wellbeing of technicians as they transit in different sea conditions is being assessed together with vessel motion and sea state measurements. When combined, these data are used to create a tool to support the authority that makes the decision to 1) launch, 2) not launch, or 3) to launch but only with certain control measures. Optimising how CTVs deliver technicians will improve O&M productivity and lead to increased turbine availability. It is estimated that this innovation will lead to a 0.7% reduction in LCOE; equivalent to additional revenue of more than €1.2m a year for a 500MW wind farm. Importantly, this innovation will not require substantial capital investment by the industry in order for it to have an impact. To make uptake as rapid as possible the 'model' created will be open access and will be promoted for use across the existing and future CTV fleet.

3.3.4 Wind Turbine Bearing Performance Research

One of the main problems faced by the offshore wind industry is high maintenance and repair costs of wind turbine mechanical systems. The predicted reliability of wind turbine designs of varying size is in the range 0.07 to 0.1 failures per year. Surveys over a total of 21,000 turbine years show that the actual failure rate is higher than expected and that gearbox, rotor blades and drive train cause the largest amounts of downtime, in spite of using best-design practices and expertise gained from other applications. The survey also identifies that the downtime per failure for European onshore wind turbines maybe as high as 10-12 days per failure.

Research within the Design Unit at Newcastle University is currently focused on performing component testing to improve the understanding of bearing failure modes prevalent in wind turbines. In parallel with this, new condition monitoring methods are being developed to identify the early detection of on-set of failure. Using developed instrumentation systems, the dynamic response of the rolling elements and the impact of this on resulting modes of failure initiation is now better understood, although more research is needed. The test facility is also being used to trial newly developed acoustic sensor technology and other NDE approaches, with the aim of establishing condition monitoring systems able to give early warning of failure initiation.

3.4 University Expertise Outside of the SIA Area

The data on publications above clearly illustrates that not all of the UK's leading expertise lies within the SIA geography. Plymouth University is a leading centre for wave and tidal research and also supports significant test facilities whilst Exeter University is also strong in these areas of research. The activities of both universities are well described in the South West England and South East Wales SIA report published in late 2016.

The University of Sheffield is connected to the SIA area through its participation in Aura. It has extensive capability in OSW research and innovation, especially around generators and drives. The Electrical Machines and Drives (EMD) Group is a world leader in the field of electrical machines, power electronics, controls, and energy conversion and storage. With over 120 personnel, it has an outstanding track record for innovation and for promoting the commercial exploitation of its research findings and hosts the

Sheffield Siemens Wind Power Research Centre (S2WP). The facilities within the group support the full prototyping cycle from initial design to manufacture and testing. The S2WP collaboration has led to a fully equipped wind power generator control test system with a value of £100k. The Dynamics Research Group (DRG) at the University of Sheffield comprises more than 60 members and is recognised as having globally unique capability based on execution of multiple projects in the wind industry. It currently holds a portfolio of grants totalling several million pounds from UK and EU industry and from EPSRC and ERDF.

3.4.1 Pile Soil Analysis (PISA) project

The PISA project is led by Dr Byron Bryne (Oxford University).

The Pile Soil Analysis (PISA) project is a joint industry project run through the Carbon Trust's Offshore Wind Accelerator programme, with an industry working group headed by DONG Energy and includes RWE, EDF, Statoil, Statkraft, SSE, Scottish Power, Vattenfall, Alstom and Van Oord. Over 70% of the total offshore wind projects in the UK are owned by the PISA partners. The academic working group is headed by the University of Oxford and includes Imperial College and University College, Dublin.

A new design methodology has been developed during this project which will provide greater confidence in the prediction of pile response under the lateral loading seen by offshore wind turbines. A more accurate method of design will allow monopiles to be installed in deeper waters than is currently possible using the existing standards, and potentially with larger turbines on top. This would make monopiles a suitable foundation solution for a number of the UK Round III projects.

3.5 Conclusions

The UK has a strong, broad academic standing in research associated with offshore renewable energy. Over the three research areas examined (offshore wind, wave and tidal), the UK performed consistently well – producing both high volume and high quality research. Overall, the quality of the publications within the SIA region as measured by citations per paper is in line with that of the UK as a whole and second internationally only to the USA. Academic specialism specific to offshore renewable energy tends to be focused on turbine technology or wave and tidal device technology. Balance of plant elements (e.g. Foundations, cables, installation) tend to be covered by multi-disciplinary or cross-cutting themes such as engineering, energy systems and environmental studies. This provides the benefit of capturing and incorporating the best related knowledge into offshore renewable energy, but also highlights a potential opportunity for increased specialism in these areas. Key strengths currently are in tribology, subsea engineering and environmental analysis.

4 Innovation in Offshore Renewable Energy

4.1 Introduction

The offshore renewable energy sector in the UK and SIA region benefits from a strong innovation ecosystem of core businesses and related supply chains, research institutions, business support and innovation intermediaries, training and skills providers, and investors. This chapter examines relevant innovation activities in the UK and SIA area, including a detailed patent analysis, identified technology development and innovation assets, as we all supply chain activity and innovation activity.

4.2 Patent Analysis: Offshore Wind

As part of measuring the innovation capabilities of organisations within the SIA area, a detailed patent analysis was undertaken by Technopolis on behalf of the SIA consortia. However, whilst useful to provide an indicative measurement of innovative activities, further data collection and analysis utilising a broader definition and metrics is required to provide a more holistic picture of the innovative nature and competencies of the sector. Along with expanding the patent analysis to include citations, this could include conducting research and analysis into R&D business expenditure, product/service design, process innovation, new/reconfigured business models, organisational innovation and excellence in marketing.

A patent analysis of offshore wind was undertaken based on the European Patent Office Worldwide Patent Statistical Database (PATSTAT). As detailed in Appendix 1 , the research methodology was not able to distinguish between offshore and onshore wind and therefore the patent analysis encompasses both forms of wind energy. The first part of the analysis focused on an international perspective and is based on patent applications made by applicants and inventors worldwide. The key findings were:

- The UK is in the top 10 countries based on patent applications for the period 2000-2015. This includes both patent applications by country of applicant and country of inventor (see Figure 14 and Figure 15).
- Germany, the US, and China dominate the international patent landscape.
- General Electric (US), Siemens AG (DE) and Vestas Wind Systems AS (DK) were the top ranked organisations. No company in the UK featured among the Top 30 (see Appendix 1).

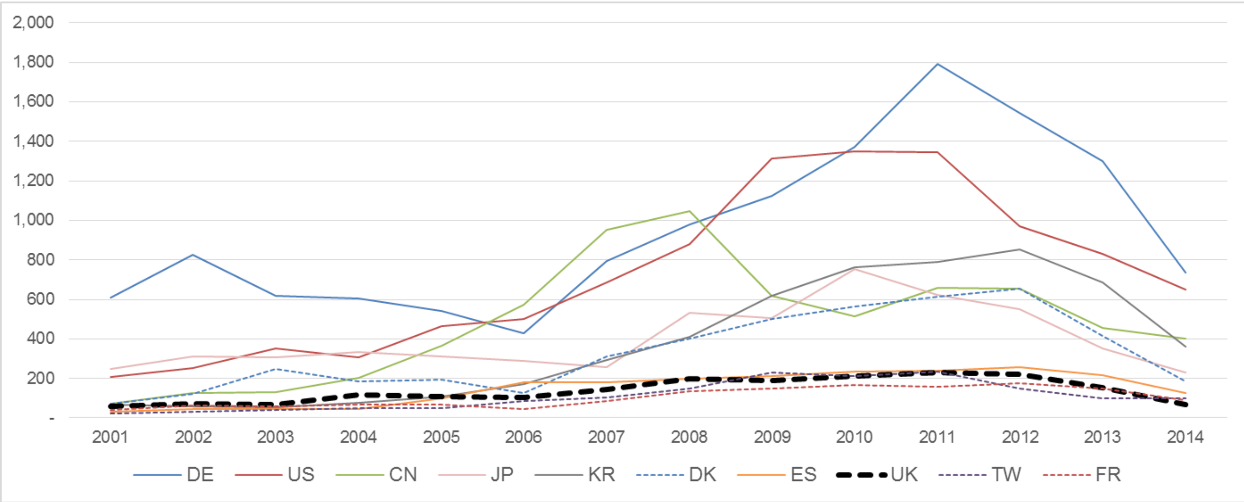

Figure 14: Offshore wind top 10 countries based on patent applications (by country of applicant) 2001 – 2014 (source: Technopolis, 2017)

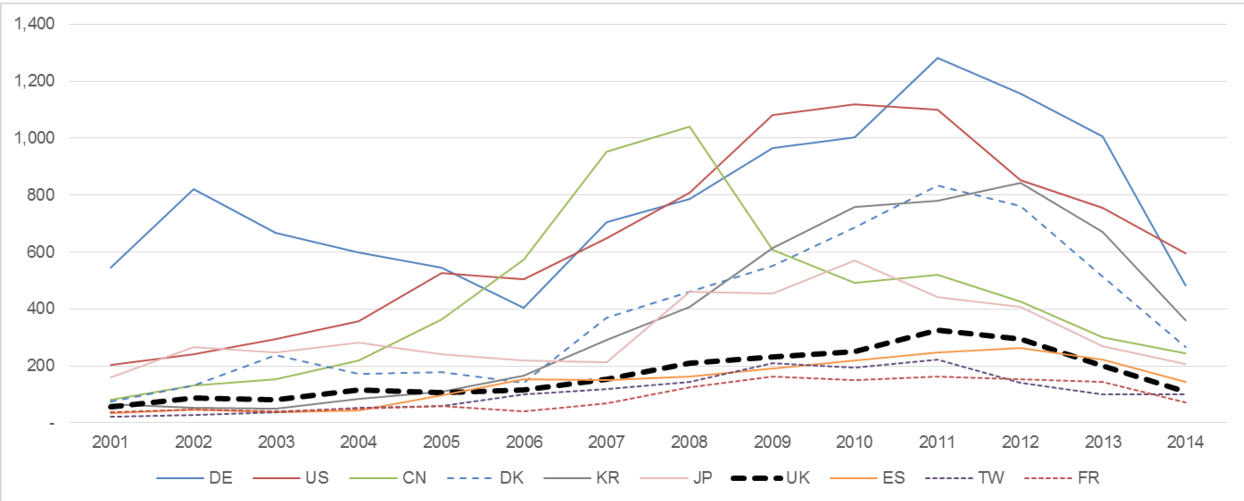

Figure 15: Offshore wind top 10 countries based on patent applications (by country of inventor) 2001 - 2014 (source: Technopolis, 2017)

The second part of the patent analysis of wind energy focused on the UK and SIA geography between 2004 and 2012. Despite limitations in the data - highlighted in Appendix 1 - the key findings from the analysis were:

- Inventors located in the SIA region had accounted for 28% of UK patents applications
- While the number of UK patents appears to have peaked in 2011, the upward trend within the SIA region continues in 2012, as shown in Figure 16 demonstrating a high level of innovation activity relative to the rest of the UK.
- The top UK companies that applied for a patent during the period were Romax Tech and Blade Dynamics
- The top ranked organisations in the SIA region by applicant or inventor included Artemis Intelligent Power Ltd, ITI Scotland Ltd and IHC Engineering Business (see Appendix 1)

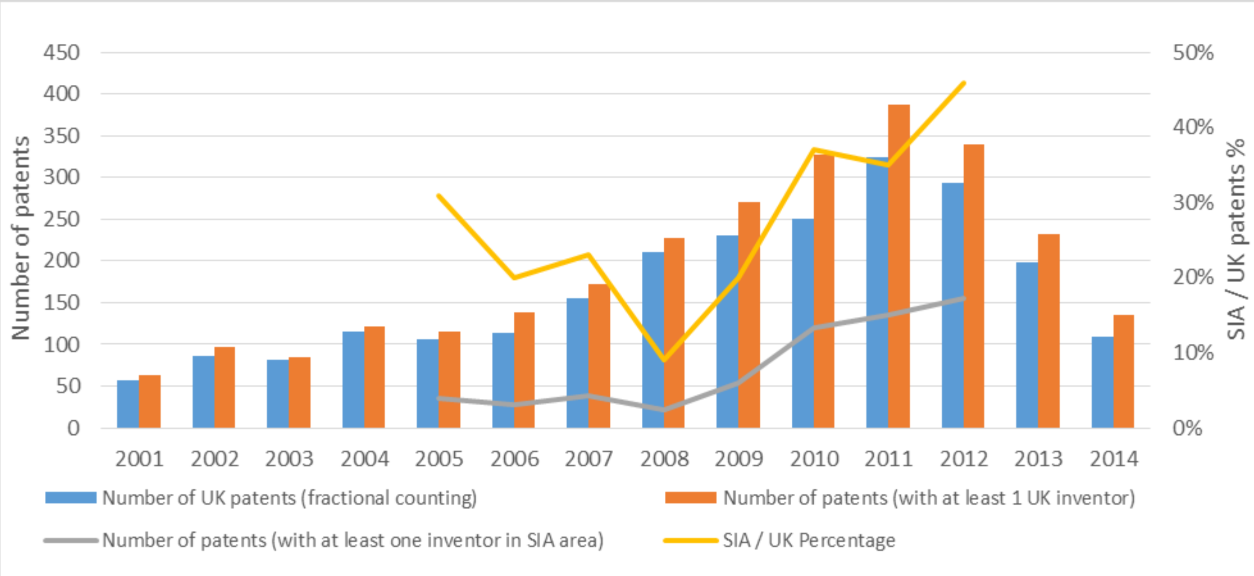

Figure 16: UK and SIA region offshore wind patents 2001 – 2014 (source: Technopolis, 2017)

4.3 Patent Analysis: Wave and Tidal

Applying an identical research methodology to wave and tidal energy, the patent analysis identified the following patterns:

- The UK is amongst the top 10 countries worldwide based on patent applications for the period 2000-2014. The UK is ranked second based on the total number of patents filed in that period.
- The data shows that the relative position of each country changes year to year, mostly because the number of patents filed annually is very small (between 20 and 80 patents).

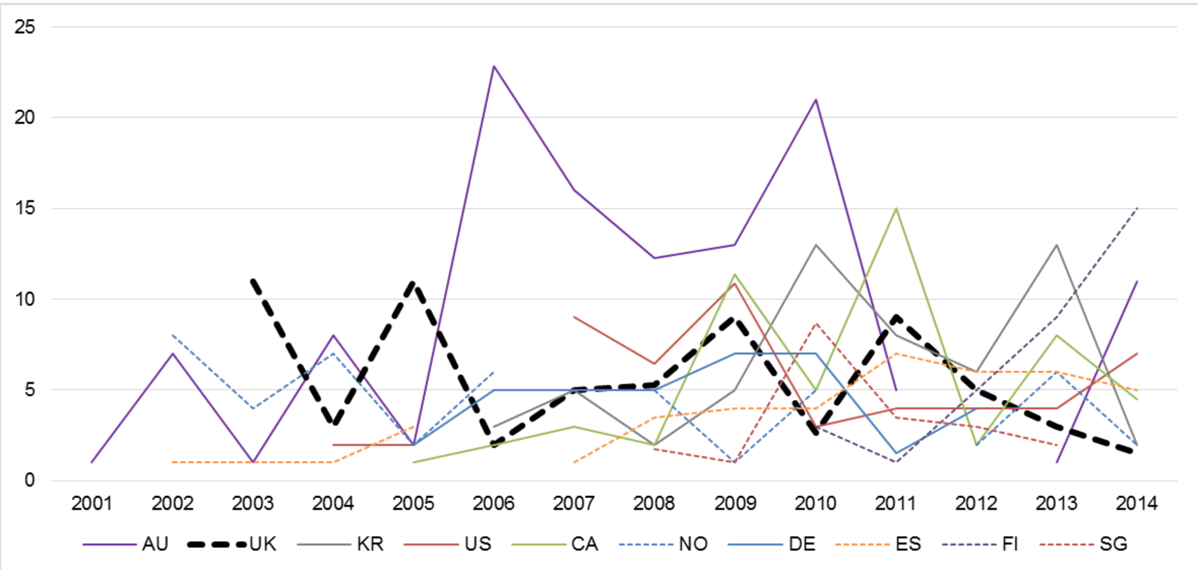

Figure 17: Wave and tidal energy top 10 countries based on patent applications (by country of applicant) (source: Technopolis, 2017)

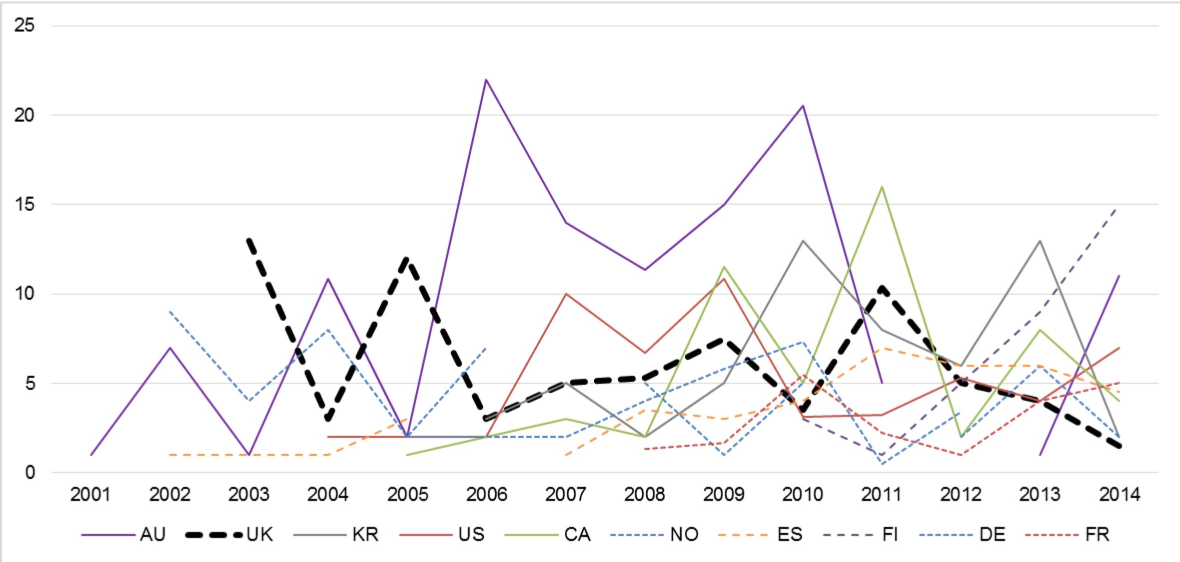

Figure 18: Wave and tidal energy top 10 countries based on patent applications (by country of inventor) (source: Technopolis, 2017)

The second part of the patent analysis focused on the UK and SIA area. The key trends from the analysis of wave and tidal energy were:

- Aberdeen's Robert Gordon University, Verdberg Ltd and Tidal Energy Ltd are in the top 30 ranked organisations in the world by patent filing (see Appendix 1).
- The top UK companies are Atlantis Resources Corp. and Verderg Ltd, which are located in the SIA area (see Appendix 1 , Table 8). In fact, the top UK companies active in the 'Tidal and Wave' energy patents (applications) are located on the SIA area.

The geographical spread of these UK patent applicants is shown in Figure 19, highlighting some clustering of activity in the Edinburgh and Aberdeen areas in Scotland.

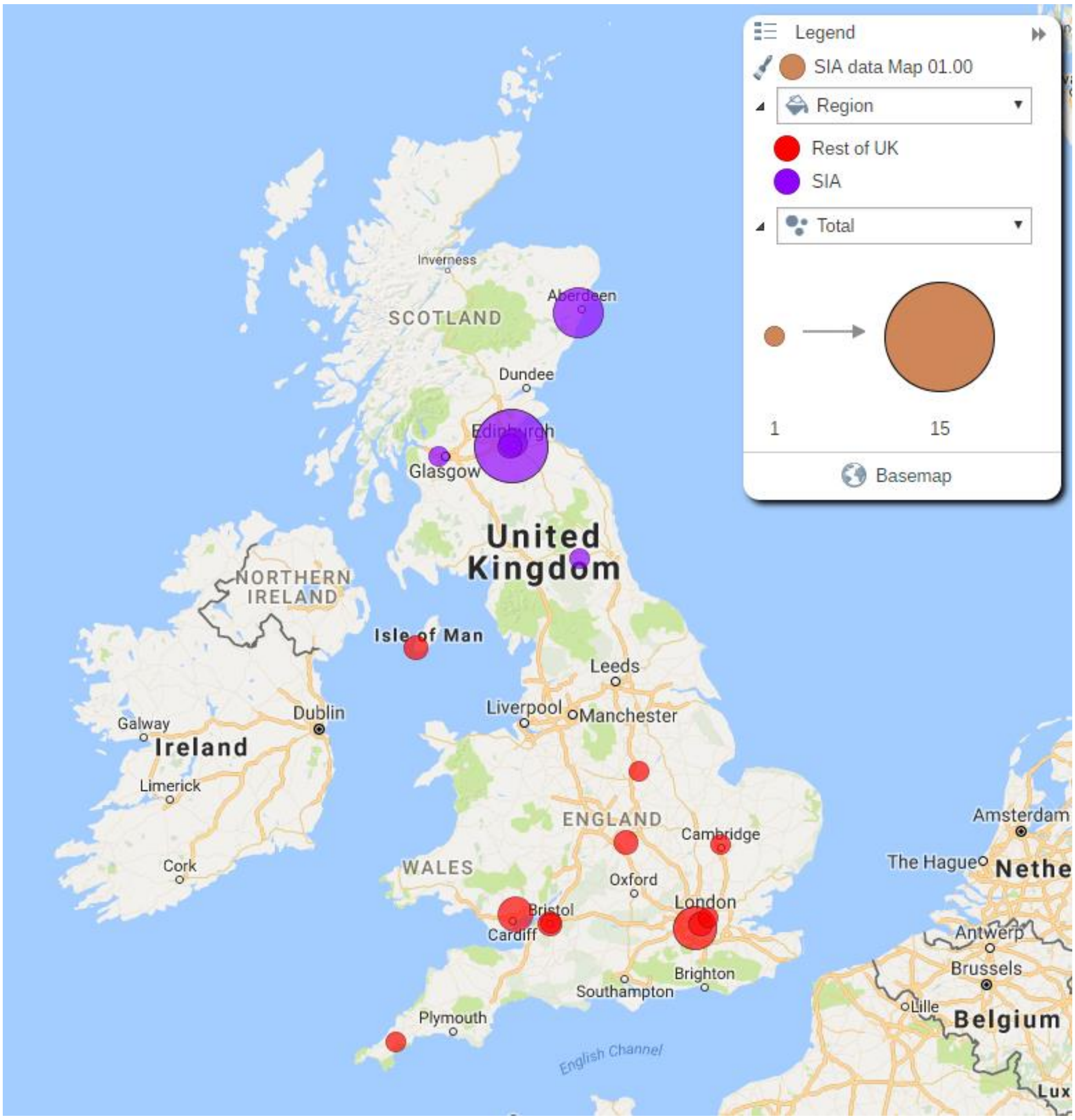

Figure 19: Wave and Tidal patent inventors by location (source: ORE Catapult and Technopolis analysis, 2017)

4.4 Patent Analysis: Summary

In summary, the patent analysis shows clear challenges to the UK – particularly in wind energy - where the UK demonstrates a low level of intellectual property ownership compared to global competitors. Primary data collected throughout the SIA process did identify important examples of UK companies which had developed intellectual property in particular niche technology areas (see, for example, the case study on GEV Wind Power). For example, one area of opportunity identified by the SIA - and based on existing research capabilities, testing and demonstration facilities and business base within the SIA geography - has been in the technical design, innovation and application of foundations for offshore wind structures. In particular, innovation into emerging screw and floating foundations presents a significant opportunity for the UK to reduce weight, save on material costs and support the deployment of offshore wind turbines in deeper waters. As highlighted in Section 4.7.4, following, the SIA area is host to relevant industrial research and innovation projects, showing that work is already underway to address this gap.

The UK and SIA region's innovation output in wave and tidal energy - as measured by patent applications - is more advantageous to the UK where it is clear that the UK represents a much higher proportion of the world-wide innovation. This may reflect the much less mature nature of wave and tidal compared to offshore wind but is nonetheless a promising opportunity for the UK. It is crucial that the UK should work proactively through fostering innovation activities in order to maintain this position as the sector moves towards commercial maturity.

4.5 Innovation Case Studies

This section presents a number of brief case studies of examples of UK innovation that were highlighted during the SIA process.

4.5.1 BiFAb

BiFab specialises in the transfer of oil and gas jacket substructure technology to the offshore wind market. Based on experience gained from recently completed offshore wind farm projects, BiFab partnered with Atkins to develop a unique jacket substructure. This design is jointly 50:50 patented and capable of supporting a range of turbines from 3MW to 8MW in water depths 15metres down to 80 metres. This is a lightweight structure, with potential savings in both weight and manufacturing costs, along with the potential to loadout more structures per barge due to the reduced foot print at the base of the jacket.

4.5.2 GEV Wind Power Ventura Habitat

GEV Wind Power (part of the GEV Group) is a Hull based company offering services to the Offshore Wind industry. The Company was established in 2012 and currently employs over 100 experienced blade technicians across sites in the UK, Europe, America and Asia. GEV Wind Power has developed and patented a revolutionary system for completing field blade repairs (the Ventura Habitat), combining a blade access platform and an in-house habitat structure. The new technology is set to revolutionize blade repairs, enabling faster return to service of turbines and contributing to a lower LCOE.

Figure 20: GEV blade repair system

4.5.3 IHC Engineering Business (IHC EB)

IHC designs, builds and supplies specialist equipment for offshore oil and gas, submarine telecoms, and renewables industries. Projects typically include the design, manufacture and supply of bespoke offshore systems - including pipe and cable-lay equipment, subsea trenching machines and complete integrated ship systems. With a prime location at the Port of Blyth, the Support Base is the central hub of IHC EB's production activities. In addition to this, IHC EB offers a wide range of support base services to its offshore clients - from commissioning, mobilisation and demobilisation, conversion activities and hire of certified equipment, through to hydraulic, electrical and mechanical testing. The company's headquarters are in Stocksfield, Northumberland.

4.5.4 JDR Cables

JDR Cables is one of the world's leading suppliers of subsea power cables and umbilicals to the global offshore energy industry. Headquartered in Hartlepool, JDR designs, engineers and manufactures subsea power cables, production umbilicals, intervention workover control systems and end terminations and accessories for the world's major energy companies and subsea service providers operating in the oil & gas and renewable energy markets. JDR has invested heavily in product innovation to design, develop and commercialise the world's first 66kV subsea power cable. Developed in partnership with the ORE Catapult's UKAS accredited High Voltage (HV) Electrical Laboratory in Blyth, Northumberland, the 66kV inter-array and export cable completed a qualification and type testing programme to leading international standards, including cable development, high-voltage and full-scale accelerated wet ageing testing, cable splicing, joints and connectors. In the future, the shift from 33kV to 66kV inter-array electrical systems is expected to have a significant impact upon the offshore wind sector, enabling increased power density, lower operational losses, fewer offshore collector substations and ultimately a reduction in the LCOE. The company has recently secured the industry's first commercial 66kV array cable contract with VBMS (UK) Ltd to supply 155km of intra-array cables for Scottish Power Renewables' East Anglia One (EA1) offshore wind farm.

Figure 21: JDR 66kV inter-array and export cable

4.5.5 Pipeline Coil Technology (PCT)

PCT designs and builds equipment for coiling, storing and handling a wide range of flexible products. These include small to medium bore plastic pipes, higher pressure reinforced pipes and 'wireline' products, for use in factories as well as on land and offshore installations. The Reece Group acquired Pipeline Coil Technology in 2013. PCT have a 2,500m^2 product assembly area that has a 40 tonne lift capacity and a working height beneath crane beams of 12m. In their Newcastle-based engineering office they utilise the latest 3D modelling systems for overall machine design and have programming tools and expertise to develop operating software for PC based or PLC based control systems.

4.5.6 Siemens Subsea Connectors

Siemens Subsea is a world leader in the subsea connector field and has established a global reputation over the last 35 years for the manufacture and delivery of world-class subsea connector and measurement technology. The Subsea Excellence Centre, an 11,000 square foot purpose-built facility in Ulverston, Cumbria is home to the manufacture of high integrity power and data connection systems for the subsea, offshore and ocean energy sectors.

Siemens Subsea has developed and qualified subsea connectors with the capability to meet the requirements for 33kV AC offshore wind inter-array connectivity and in February 2017 launched into the market the world's first wet-mate DC electrical connector to support subsea power conversion from ocean energy devices. Innovative improvements in electrical field control, cable termination and methods to reduce mating forces have contributed to a reduction in connector size, enabling modularity and reduced cost thereby increasing the flexibility of the customer's operations. These developments and the associated intellectual property provide the basis for Siemens continued innovation and support of a growing offshore renewables sector.

Figure 22: 45kVac 1250A subsea connector (wet mate/dry mate configurable)

4.6 Technology Development and Innovation Assets

The UK and SIA region has a number of physical research, innovation, testing and demonstration facilities to support businesses to commercialise new products, services and bring down the cost of producing energy from offshore renewable energy sources. This sub-chapter illustrates a number of these technology development and innovation assets.

Offshore Renewable Energy Catapult

The ORE Catapult provides a number of advanced test facilities to de-risk technology development for, including:

- ORE Catapult – Levenmouth 7MW offshore turbine. Working with the Energy Systems and Digital Catapults, ORE Catapult will create a smart energy demonstration zone around its Levenmouth turbine. This environment will allow companies to trial new technologies in storage, demand side management, cyber security, heat and transportation
- ORE Catapult – Blyth. 15MW wind turbine drivetrain test rig (Fujin); 3MW tidal turbine drivetrain test rig (Nautilus); Electrical component testing up to 66KV (Parsons Laboratory); 50m and 100m Blade Test Facilities; Marine test facility; onshore wind training tower.
- ORE Catapult – Blyth. NOAH Met mast. The offshore anemometry hub is installed three nautical miles off Blyth, Northumberland. It provides wind resource and environmental data to validate turbine demonstrations, with the instrumentation and data management capability to be made available for future research collaborations.

Hunterston Test Centre for Offshore Wind

Scottish and Southern Energy (SSE) and Scottish Enterprise (SE) have invested £20m to create an offshore wind turbine test centre capable of hosting three full scale wind turbines designed for offshore deployment. Siemens are currently testing their new 6MW direct drive turbine and Mitsubishi Heavy Industries are testing their 7MW, SeaAngel hydraulic drive turbine. The test centre is located at the port of Hunterston on the coast of North Ayrshire. Hunterston's wind resource, which replicates offshore conditions, coupled with its existing grid connection, make it an ideal site for the testing facility which has a key role in developing Scotland's offshore wind supply chain. The advantage of testing turbines on land is that it permits the manufacturer 24-hour access to make modifications and repairs, which is critical, particularly for early series prototype turbines.

Scottish Energy Laboratory

The Scottish Energy Laboratory is a network of Scotland's leading test and demonstration facilities and provides a clear offering of Scotland's capabilities to national and international companies.

The network has a combined investment value of over £250m across all key energy sectors and includes the European Marine Energy Centre in Orkney, the Energy Technology Centre and the Myers Hills Wind Turbine Test site, both near Glasgow, and the European Offshore Wind Deployment Centre in Aberdeen.

The Offshore Renewables Institute

The Offshore Renewables Institute is a research partnership between the University of Dundee, the University of Aberdeen and Robert Gordon University, focused on developing and delivering solutions to the offshore wind industry. The institute offers an interdisciplinary and integrated approach, bringing together experts, researchers, and knowledge from different disciplines to confront challenges faced by the industry.

Aura

Aura (www.aurawindenergy.com) is a multidisciplinary, multi-stakeholder offshore renewables initiative led by the University of Hull. It focuses on three inter-dependent strands of activity: research, development and innovation (RDI); talent pipeline for skills development (TP) and industry engagement and enterprise (IEE) to support sector development. The Aura RDI coalition comprises the Universities of Hull, Durham and Sheffield, Siemens Gamesa Renewable Energy, DONG Energy UK and the ORE Catapult. Their combined expertise and capabilities are being harnessed to identify and solve key technological challenges in the offshore wind sector. With national and international reach, Aura is focusing initially on nine innovation areas in which it will gain early traction, and has secured over £10m of offshore wind research funding in the last year.

Blyth Offshore Demonstrator (EDF Renewables)

EDF has begun construction of a 41.5MW offshore wind demonstration site off the coast of Blyth in North East England to demonstrate the effectiveness of self-floating and submersible gravity-based foundations. The project consists of five 8.3MW turbines mounted on concrete foundations, each weighing approximately 15,000 tonnes. The project will also be the first to use 66kV cables to connect the windfarm to the onshore substation. The project marks an important milestone in unlocking the potential to deploy offshore wind on further seabed types as well as capitalising on local construction capabilities. At the peak of construction, there will be 200 people working on the project.

Dounreay-Trì

Dounreay-Trì is a floating offshore wind demonstration project located 6km off the coast of Caithness. Granted planning consent in March 2017, the Dounreay-Trì project will consist of a single semi-submersible platform supporting two 5MW turbines, a single export cable to bring the power to shore at, or near, Sandside Bay, and onshore electrical infrastructure to connect the project at or near the existing substation at Dounreay.

Kincardine Offshore Wind Project

Kincardine Offshore Wind Project is a floating wind turbine array demonstration proposed by Kincardine Offshore Windfarm Limited (KOWL); a joint venture between Pilot Offshore Renewables and Atkins. Also granted planning consent in March 2017, the project consists of eight 6MW floating wind turbines on floating semi-spar foundations located 15km off the coast of Dog Hole, Aberdeenshire.

Hywind Scotland Pilot Project

Hywind Scotland Pilot Project is an offshore wind array consisting of five 6MW turbines on spar floaters. Developed by Statoil, the turbines will be deployed 25km off the coast of Peterhead and connected to the Batwind energy storage project; a 1MW lithium ion battery facility.

FloWave – University of Edinburgh

FloWave was conceived for academic research into wave and tidal current interactions. It is now also used by commercial developers to ensure their technologies and projects perform 'right first time' and are de-risked as much as practical before cutting steel or going offshore.

European Marine Energy Centre (EMEC)

Established in 2003, the European Marine Energy Centre Ltd is the world's first and only multi-berth, purpose-built, open sea test facility for wave and tidal energy convertors. The centre's fourteen full-scale test berths are connected to an onshore substation by 11Kv sub-sea cables, which connect to the national grid. The sub-sea cables also contain fibre optics, which transmit information back to the EMEC data centre in Stromness and allow developers to communicate with their devices. The centre's two smaller scale test sites – one for wave in Scapa Flow and one for tide in Shapinsay Sound — allow developers to test prototype devices and components in less challenging sea conditions, serving as a stepping stone from tank testing to full scale device testing.

MeyGen

Located in the Pentland Firth off the coast of Caithness, MeyGen is an up to 398MW tidal stream array being developed by Atlantis Resources. The first 6MW phase of MeyGen, Phase 1A, was completed in 2017 and comprises four 1.5MW turbines. The project is presently the world's largest operational tidal stream array.

4.7 Supply Chain Activity

4.7.1 Supply Chain Analysis Approach

The purpose of the supply chain analysis is to identify areas of particular strength or gaps in provision. This is analysed, both from the point of view of which geographic areas have high or low levels of activity, and also considering which parts of the value chain are over or under-represented. The analysis also seeks to link these findings with the level of engagement of companies in the SIA region in offshore renewable energy research and innovation projects.

A number of sources have been used in order to describe the offshore renewable energy supply chain within the SIA region. At the SIA region-wide level, a shortlist of companies, for whom offshore renewables is a core or significant part of the business, has been defined based on lists from relevant trade bodies and existing supply chain analysis. These companies have been classified by the most relevant supply chain sub-sector

At a local level, each LEP and Scottish Enterprise has provided lists of companies known to be active to some extent in the sector – for some companies this is their core business, but for many others, engagement in the sector is on a marginal or ad hoc basis. As each LEP uses different categorisations, the analysis has grouped companies into four categories which can be viewed as common across all LEP's: development and consent; turbine and balance of plant; Installation and commissioning; and support functions (including O&M). The type of information available on these companies also varies by LEP and so the following analysis will highlight different elements in different areas depending on availability of data. This local-level gives the broadest view of supply chain companies engaged in the sector and shows the broad range of cross-over between offshore renewable energy and other industries.

Finally, ORE Catapult's database of awarded research and innovation grants has been used as an indicator of supply chain engagement in industrial or academic collaborative research and innovation.

4.7.2 SIA Region View

The analysis identified 186 companies in the SIA region with offshore renewables as their core or significant part of their business.

The highest concentrations are found in the Humber region (48), North East England (35), North East Scotland (27), followed by Liverpool and East Scotland (23). As well as reflecting proximity to offshore renewables activity, this is also a sign of companies diversifying or transitioning from an oil and gas focus, leveraging transferrable skills, equipment and processes. The lowest representation is in West of Scotland, most of whose companies are based in Glasgow and this low number reflects the lack of proximity to major offshore activity. Table 2 illustrates the location and area of specialism of the companies identified.

	NE Scotland	West Scotland	East Scotland	Tees Valley	NE England	Liverpool	Humber	Total
Blades and turbines	1	3	3	0	2	1	3	**13**
Cables	4	0	2	1	4	2	1	**14**
Operation and maintenance	13	4	8	1	12	4	40	**82**
Drive Train	0	2	2	0	2	0	0	**6**
Tower	2	2	1	1	2	1	0	**9**
Foundations	0	1	1	1	2	0	0	**5**
Substations	5	2	1	4	6	0	0	**18**
Ports	2	0	5	8	5	15	4	**39**
Total	**27**	**14**	**23**	**16**	**35**	**23**	**48**	**186**

Table 2: Location and specialism of companies active in offshore energy (renewables as core activity) (source: ORE Catapult and Technopolis analysis, 2017)

In terms of segments, there is significant activity for O&M providers (82) and ports (39), with the next most activity in substation manufacture (18) and cable-related fields (14). Interestingly, there are more companies engaged in some element of turbine supply (13) than directly involved in foundation fabrication (5). However, the majority of these turbine-related companies are mainly engaged in supply of turbine parts or turbine O&M during the operations phase rather than supply of turbine blades or nacelles. The lack of foundation fabrication in the UK reflects the fact that, to date, project developers have opted to use existing, proven facilities in Germany and Denmark or have used engineer-procure-construct (EPC) contracts where the fabrication location is decided by the lead contractor. The bulk of offshore wind foundation work won in the UK to date has been for transition pieces. However, this may well change over time if serial production methods can be fully developed for jacket foundations, as well as having the potential to take the lead in design and fabrication of floating wind foundations.

The picture from this analysis backs up previous analysis[18] that there is substantial activity in areas where it makes logistical sense, eg. Ports and O&M together account for 65% of the business identified, but

[18] ORE Catapult - The Economic Value of Offshore Wind: Benefits to the UK of Supporting the Industry

companies in the SIA region, similar to the rest of the UK, are capturing only a limited share of the available market.

4.7.3 Local View

Data collated by LEP's within the SIA consortium identifies more than 500 companies which have been involved to any extent in offshore renewable energy. This includes companies engaged in many forms of steel fabrication, mechanical, electrical and structural engineering and design work. This demonstrates both the potential synergies with other forms of construction and infrastructure development and the fact that the volume of offshore renewables work won by UK companies is very often not significant enough to sustain an entire business. In many ways, these companies rely on utilising existing facilities, skills and resources rather than being able to make the business case for investing at the scale needed to specialise in the sector, particularly in the cases of construction and installation. Where available, regional mapping showing supply chain locations is shown in Appendix 4.

4.7.4 Supply Chain Engagement in Research and Innovation

ORE Catapult maintains a database of research grants awarded to universities, companies and collaborations between the two. This database has been used to give an indication of the number of companies involved in industrial or collaborative research and innovation projects and the segments of the value chain being focused on. This identifies 109 individual companies in the SIA region currently involved in 124 projects, worth an estimated £72 million[19] (£34 million in research funding plus £38 million internal or match funding), involving industrial lead or partner organisations, with 91 involving purely industry and 33 being industry-academic collaborations. A summary of this activity is shown in Table 3.

Total Funding in £m	Offshore Wind	Tidal	Wave	Total
Blades	-	4.3	-	**4.3**
Cross-cutting	1.0	21.0	26.6	**48.7**
Drivetrain	4.9	-	0.1	**5.1**
Electrical Infrastructure	2.8	-	-	**2.8**
Foundations & Substructures	7.4	-	0.3	**7.7**
Installation & Decommissioning	0.1	1.4	0.1	**1.7**
Operation & Maintenance	0.8	-	-	**0.8**
Other	0.3	-	-	**0.3**
Wind & Ocean Conditions	0.8	-	-	**0.8**
Total	**18.0**	**26.7**	**27.2**	**71.9**

Table 3: Supply chain engagement in innovation activity – funding value per area £m (source: ORE Catapult R&D funding database, 2017)

[19] The total funded value for each project has been split evenly by the number of project partners where the partner-specific value is not known

The majority of projects (60) are in offshore wind, but with also a large number in wave energy (36) and the remainder in tidal energy (21) and projects cutting across all three sectors (7). The single biggest area of project value is cross-cutting research within wave energy, reflecting the early stage of the technology. Within offshore wind, the largest area by value of projects is foundations and sub-structures, which includes floating foundation projects. In tidal energy, the largest number of projects is in cross-cutting areas, again reflecting the need to find solutions across the entire value chain from turbine to electrical infrastructure.

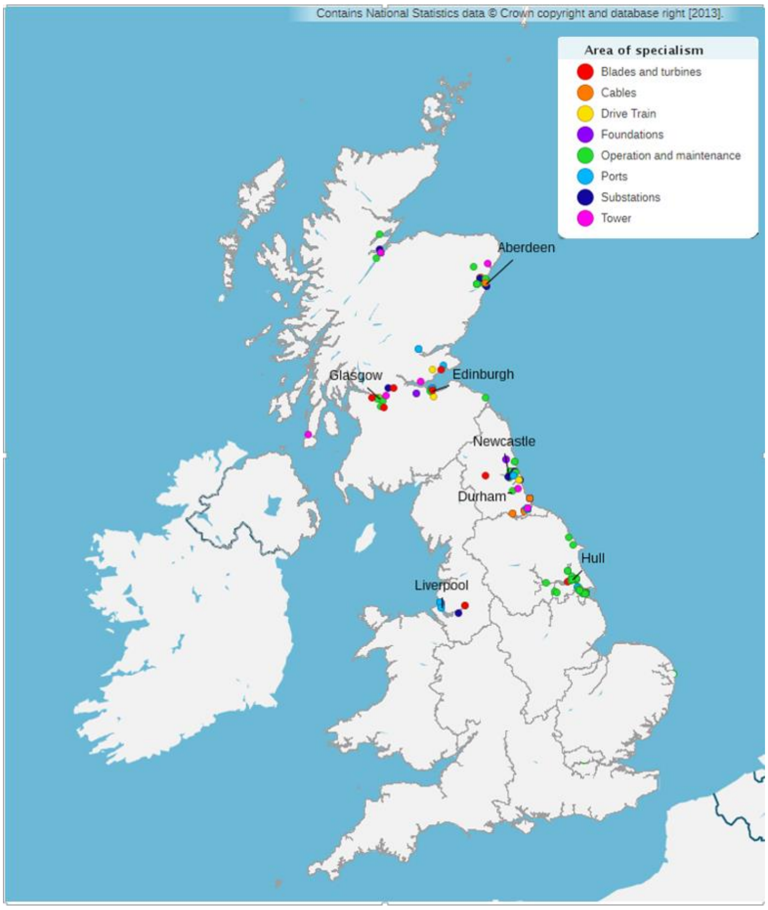

Figure 23: SIA area-based organisations engaged in publicly-funded innovation projects (source: ORE Catapult R&D funding database, 2017)

These companies are accessing innovation funding from a wide range of UK and European sources. As shown in Figure 24, Scottish government, the Carbon Trust and UK central government form the most significant sources of funding.

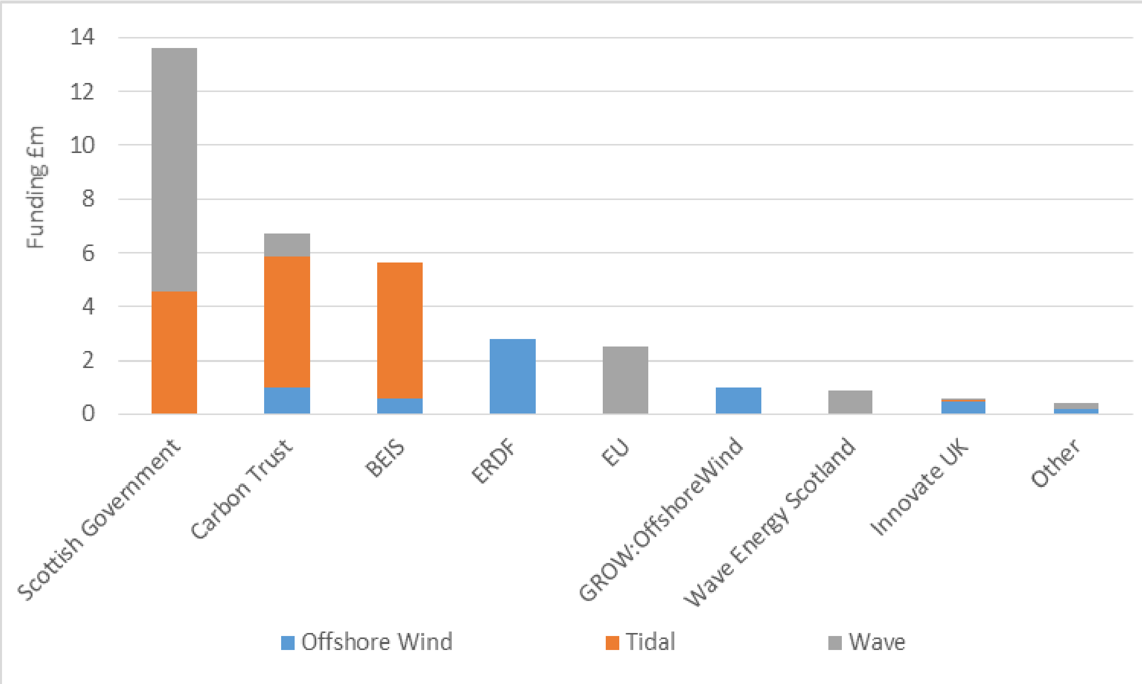

Figure 24: Sources for SIA area companies currently receiving innovation funding (source: ORE Catapult R&D funding database, 2017)

There is substantial cross-over between the 109 companies identified as being engaged in offshore renewable energy research and innovation projects and the 186 supply chain companies identified as having this as their core business. The high number engaged in publicly-funded research and innovation projects reflects:

- There is a high number of companies in the SIA region actively engaged in innovation
- Much of this innovation is being conducted by companies for whom offshore renewables is their core business
- 27% of these projects are industry-academic collaborations, highlighting the already strong links and use being made of the facilities and expertise highlighted throughout this report (though it must be noted that collaborations in some cases are with universities outside of the SIA region or even outside the UK). However, this also suggests there is a large amount of scope for increased joint activity.

Figure 25 shows the locations of the offshore supply chain companies as well as those engaged in relevant, publicly-funded innovation projects. This mapping illustrates clear clustering of supply chain and innovation activity around the geographies covered by the SIA.

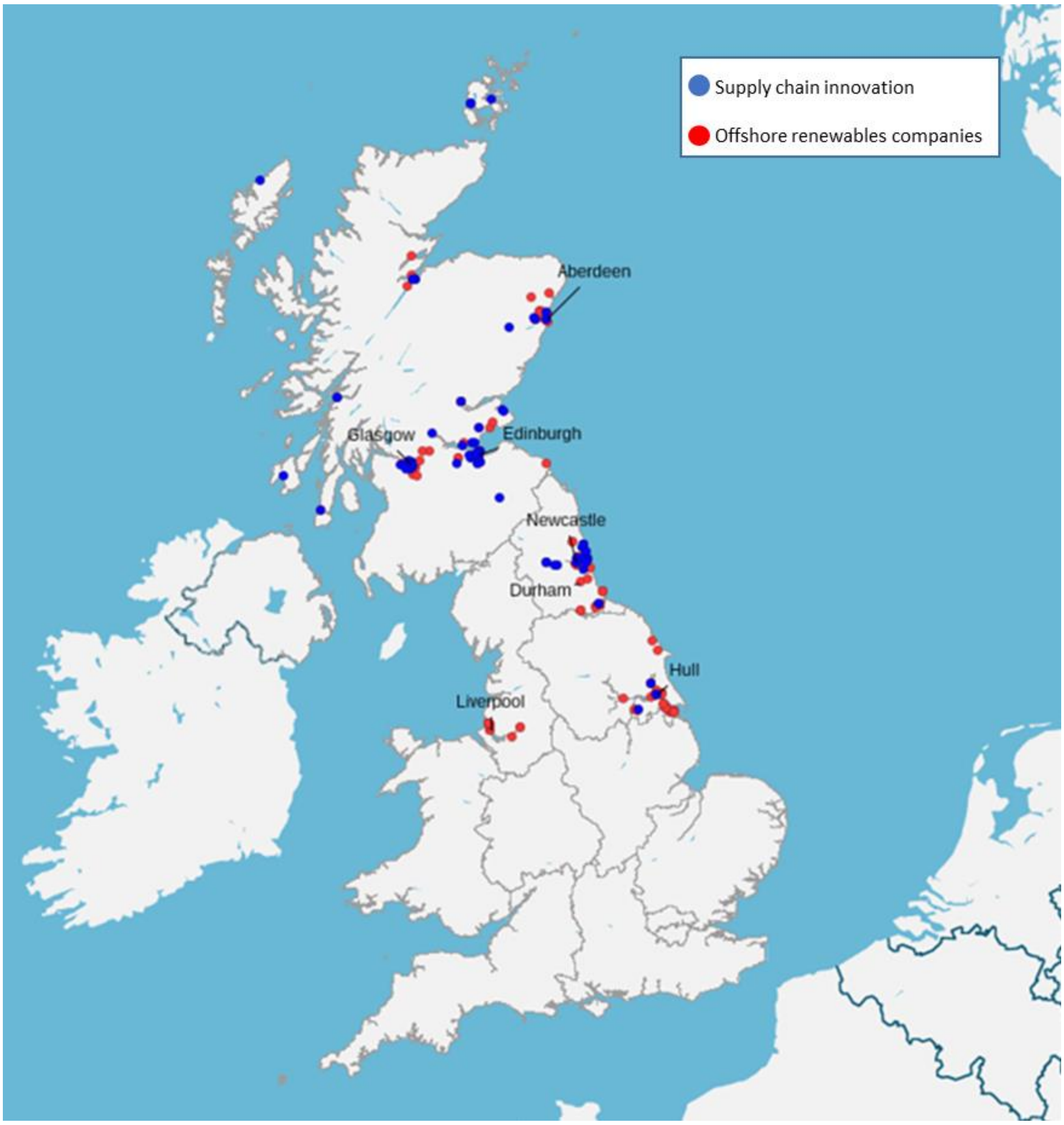

Figure 25: Offshore renewable energy and innovation companies in the SIA region (source: ORE Catapult and Technopolis analysis, 2017)

4.8 Conclusions

Analysis shows an ongoing year-on-year increase in wind energy related patents in the SIA region, but it is clear that this is only one measure of innovation. The SIA area is home to a range of organisations, which are actively engaged in research, development and innovation and there are strong bonds between industry and academia. The region has pioneered some of the most disruptive technology that is supporting cost reduction across offshore wind, wave and tidal. It is also worth noting that, while this SIA is naturally focused on innovation within offshore renewables, there is a substantial amount of innovation imported into the industry from other relevant sectors.

5 Offshore Renewable Energy and Skills in the SIA Area

5.1 Education and Skills

As with most industries, skills are vital for the offshore renewable energy sector and as with other areas there is a shortage of skilled employees. This shortage is exacerbated by the additional technical and safety certification regiments required by some roles in the sector.

The sector requires skilled people drawn from many different disciplines, from design and environmental services to work on the viability of potential generation sites, through fabrication, materials, electrical and mechanical design and manufacturing skills for the design and manufacture of components, structures, blades and towers, through to offshore engineering skills for the installation, operation and maintenance of the generating devices and sites.

In terms of human capital and talent, 5.3% of the consortium area's workforce is employed in science, research, engineering and technology professions[20] (very slightly lower than the UK average of 5.4%) and 1.9% is employed in associated professions[21] (very slightly higher than the UK average of 1.8%). In areas such as the City of Edinburgh (11.5%) and Aberdeen City (10.9%), the percentage of the workforce employed in science, research, and engineering and technology professions is more than twice the national average. Again, as shown in Figure 26, the picture varies greatly across the SIA region.

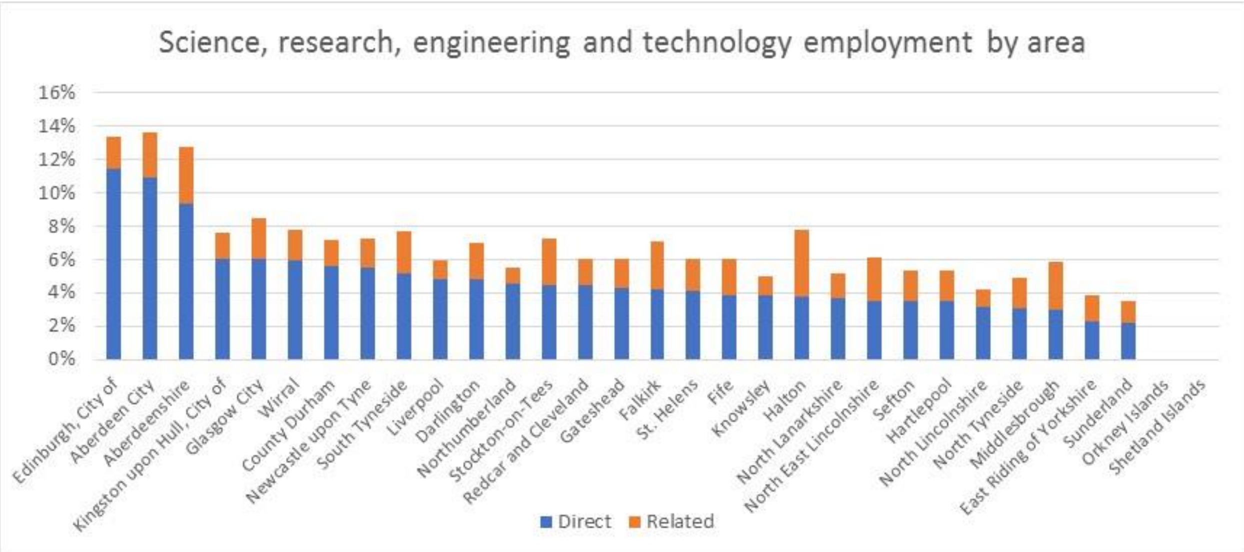

Figure 26: Employment in relevant subjects by area within the SIA (source: Technopolis, 2017)

On average across the whole SIA area, the qualifications of the consortium area's workforce to NVQ4+ and NVQ3+ levels are slightly lower than the UK averages (35.1% vs 37.1%, and 54.4% vs 55.8%, respectively). The consortium area also has a higher proportion of its workforce with no qualifications, 10.0% compared to 8.6% in the UK (ONS Annual Population Survey).

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[20] ONS SOC2010 code 21 https://www.ons.gov.uk/methodology/classificationsandstandards/standardoccupationalclassificationsoc/soc2010

[21] ONS SOC2010 code 31 (ONS methodology available at above website)

The region covered by this SIA has a strong heritage in offshore engineering and manufacturing, especially for the oil and gas sector; this has created a training ecosystem which is now adapting to the new opportunities created by offshore renewables. The training provision can generally be grouped into four main areas:

i) University provision – aimed at graduate and post graduate training to provide the skilled engineers, scientists and managers needed by the sector. Universities are also increasingly offering apprenticeship programmes, especially degree apprenticeships. The SIA area includes a number of world-leading universities and research centres, as highlighted in Section 3.2 of this report.

ii) Further Education (FE) college provision - aimed at the apprentice and NVQ3, 4 and 5 level training requirements

iii) Industrial training providers - delivered by both FE colleges and specialist training providers, often as short courses, this provision addresses the needs for certification of competence around safety, e.g. helicopter escape training, safe working practices, such as working at height, rope access, and inspection technologies such as non-destructive testing of structures

iv) Apprenticeships – being reintroduced particularly through the National Apprenticeship scheme.

Examples of key university training for the offshore renewables sector[22] include:

University	Course areas
Aberdeen	Renewables, subsea engineering
Dundee	Energy industries and renewable energy
Durham	Energy industries and renewable energy
Edinburgh	Sustainable Energy systems
Edinburgh Napier	Supply chains and offshore renewables
Glasgow	Sustainable Energy
Heriot Watt	Renewable energy, marine planning
Highlands and Islands	Energy Engineering, Sustainable energy
Hull	Energy Markets, Renewable energy, Energy engineering
Liverpool	Sustainable civil engineering, energy generation
Liverpool John Moores	Marine and offshore engineering
Maculay Institute	Sustainable natural resources use
Newcastle	Offshore engineering, marine offshore and power systems, renewable energy, subsea systems
Northumbria	Renewable and sustainable energy, electrical power systems
Robert Gordon	Energy management, subsea engineering offshore renewables
Stirling	Energy Management
Strathclyde	Renewable energy, sustainable energy, marine technology
Tees Valley	Energy and environmental management

Table 4: Universities Offshore Renewable Energy training courses (source: RenewableUK)

[22] Source - RenewableUK

Training ranges from basic access, safety and offshore survival training, through to specific technical competence courses, to advanced graduate and post graduate technical courses. The skills training base includes FE colleges focused on offshore and marine training, e.g. the Marine Centre in South Tyneside, Hull College, Grimsby Institute for Further and Higher Education, Middlesbrough college, Newcastle college, Tameside College and James Watt College, the Shetland School of nautical studies and the Scottish Marine Academy, to specialist safety and offshore training centres (eg. HOTA and CATCH) and world leading technical training activities including underwater inspection technologies. Examples include Falck, Maersk AIS training, PetrofAC, Professional Diving Academy, the Underwater Centre at Fort William and The Welding Institute. Another initiative is the Energy Skills Partnership (ESP) collaboration of colleges aiming to increase Scotland's capacity to deliver skills for the energy sector. Through this consortium approach, Scotland's colleges will ensure the right skills are being delivered and raise industry awareness to ensure Scotland has the workforce, skills and competencies required by the energy sector in the future.

There are a number of examples of specific training providers offering highly relevant provision:

- **University of Strathclyde Wind Energy Centre for Doctoral Training (CDT)** - Strathclyde University hosts a doctoral training centre for PhD students in wind energy – Wind Energy CDT. The overall aim of the Research Centre is to meet the needs of the fast growing wind energy industry by providing high calibre PhD graduates with the specialist, generic and leadership skills necessary to lead future developments in wind energy systems. The objectives are to ensure all students from different disciplines gain competencies in core aspects of wind energy systems engineering and understand the socio economic impact of wind energy systems.

- **Industrial Doctorate Centre in Offshore Renewable Energy (IDCORE)** is a partnership of the Universities of Edinburgh, Strathclyde and Exeter, the Scottish Association for Marine Science and HR-Wallingford. IDCORE was set up by the Energy Technologies Institute (ETI) and is funded by the ETI and the EPSRC RCUK Energy programme. This multi-disciplinary Centre brings together diverse areas of expertise to train engineers and scientists with the skills, knowledge and confidence to tackle current and future offshore renewable energy challenges. The strategic direction of the programme is guided by an Industrial Steering Board comprising representatives from professional bodies, employers and regulators. EngD students on the programme (called Research Engineers) undertake advanced training in technical skills and competencies as well as transferable skills such as project management, innovation management, and team working. Alongside this they undertake a challenging and original research project at PhD level.

- **AIS training**, one of the UK's leading suppliers of skills and competency training to the offshore wind market, offers over 300 industry-approved courses and has the capacity to train up to 75,000 delegates annually, in areas such as Working at Height, Sea Survival, Technical, Hydraulic and Mechanical and Electrical Courses for industry. They have developed specific renewable sector approved courses and leverages assets at the ORE Catapult in Blyth to provide industry specific training. The organisation trains international delegates from all over the globe, bringing in substantial economic benefits for local communities.

- **The TWI centre** in the Tees Valley is the UK's centre for training underwater inspection technologies, including certification training for divers and remote operated vehicle (RoV) inspection operators. Most of the inspection divers or RoV inspectors operating in the North are trained by TWI in the Tees Valley, where they are certified to inspect underwater structures. Many of the students are international and travel to the region to study for their inspection qualifications.

- **The Humber Energy Campus[23],** a virtual campus, has been created to bring together the best training, knowledge, experience and facilities to become a centre of excellence for energy skills. It provides a single gateway for learners and employers offering advice and guidance, finance and support, course and provider information and a complete directory of all energy related training on offer in the region to drive a skilled Humber workforce driven by the needs of business.

Some providers have partnered with wind farm operators to deliver bespoke training:

- DONG Energy has partnered with the Grimsby Institute to offer new offshore wind turbine technician apprenticeships. Three-year apprenticeships comprise of one year of classroom based learning at the Grimsby Institute followed by two years working on site with DONG Energy. Students will be taught in a new virtual training centre opened by the Grimsby Institute this year. The new apprentices will start in September 2017 and study as a maintenance & operations engineering technician (MOET) with an emphasis on turbine technology. They will undertake a BTEC Level 3 in Engineering, and if they successfully complete the programme will become full-time employees at DONG Energy.

A lot of the skills required within the sector are similar to those existing within other sectors such as general manufacturing or the offshore oil and gas sector. The SIA region has a strong tradition of delivering these types of skills at all levels from apprenticeships to post graduates and this forms part of the industrial base of the region. There is also an emerging training provision focused on the specific training needs of the sector and at re-training skilled oil and gas operatives for the renewables sector. The academic and specialist training offering attracts significant numbers of overseas students who can travel to the region for a few weeks to attend specific industrial training courses or a few years for more in-depth academic studies. These activities are part of the region's strong export base.

Aberdeen is an interesting case study of the importance of a skilled workforce to the development of a world-leading offshore energy cluster. The area has clearly done well in education and training but also in attracting talent drawn largely to well-paid employment. There is also evidence that this effect has spilled over to a large number of contracting staff who commute from other parts of Scotland and the North-East coast of England to Aberdeen – highlighting the integrated nature of the offshore energy cluster within the SIA area. However, Aberdeen companies have long reported concerns about the availability of skilled staff (particularly with STEM skills)[24].

5.2 Skills Challenges

The issue of skills for the offshore energy sector is of significant concern – highlighted in 2013 by Renewable UK's skill manifesto[25]. This approach, developed in consultation with the whole industrial

[23] http://energy.bridgingthegaphumber.co.uk/courses/index.asp
[24] https://issuu.com/subseauk/docs/subseauk-news-feb13-issuu
[25] http://www.renewableuk.com/news/309150/Skills-Manifesto.htm

community, sets out a clear challenge to the UK government to address the need for national skills programs. Recent surveys have confirmed that young people still perceive the offshore energy industry to be an attractive employer[26] but the UK's lack of a national strategy for skills means that education provision remains fragmented and un-coordinated. Sector bodies, spurred on by industrial concerns about skills provision, have developed initiatives that do address these issues, e.g the SUBSEAUK led initiative *Subsea Target*[27] which focuses on attracting new talent into the industry whilst industry sponsored MSc programs provide higher level education in a relevant context[28]. However, industry working with education institutions can only solve so much of this problem and there is a clear need for co-ordinated action on skills provision for the offshore energy industry. As part of the UK's industrial strategy, the offshore renewable energy industry presents a golden opportunity to align national skills development with local spatial skills development.

Data sourced from the UK Commission for Employment and Skills (UKCES) Working Futures 2014-2024 bear out the above concerns. For the combined regions[29] of Scotland, North East and North West England, Yorkshire and the Humber, while there is forecast to be a contraction in the engineering and "rest of manufacturing" industries (See Appendix 5 for SIC codes included in this analysis[30]), replacement demand means there will still be a net demand for engineering and manufacturing skills to the tune of hundreds of thousands of workers. Within these industries, the roles forecast to experience the greatest contraction are machine operatives and skilled trades and occupations, while professional occupations and managers are set to experience some growth. It is worth noting that, based on the future deployment projections, offshore renewable energy is a growing subsector within these wider industries and provides a real regional opportunity for growing skilled employment.

The UKCES data (Appendix 5 , Figure 46 and Figure 47) also highlights the education challenges, with increasing demand for higher-level qualifications. Looking at expansion demand, there will be a decline in the number of jobs requiring no, low or intermediate level qualifications, but an increase in the number requiring higher level qualifications. There is forecast to be replacement demand for all qualification levels.

[26] http://www.subseauk.com/8296/oil-and-gas-still-an-attractive-draw-for-now-warns-skills-body
[27] http://www.subseauk.com/4979/subsea-target
[28] http://www.subseauk.com/6392/subsea-uk-sponsored-mscs
[29] This is not a perfect match for the SIA area, but is used to illustrate the jobs and skills situation
[30] Note that the SIC codes you used in this analysis sit within these broad categories – but in each case only account for a small proportion of total employment within them

5.3 Offshore Wind Employment

The importance of offshore wind to the SIA region is borne out by work commissioned for Project Aura from Cambridge Econometrics. The study found that UK employment in the sector will double from approximately 10,000 direct FTE in 2017 to an estimated 21,000 direct FTE by 2032. In addition, the study estimates an additional 37,000 indirect and induced jobs, with the sector supporting a total of almost 60,000 by 2032. Crucially, the SIA area is projected to be at the forefront of this increase in employment.

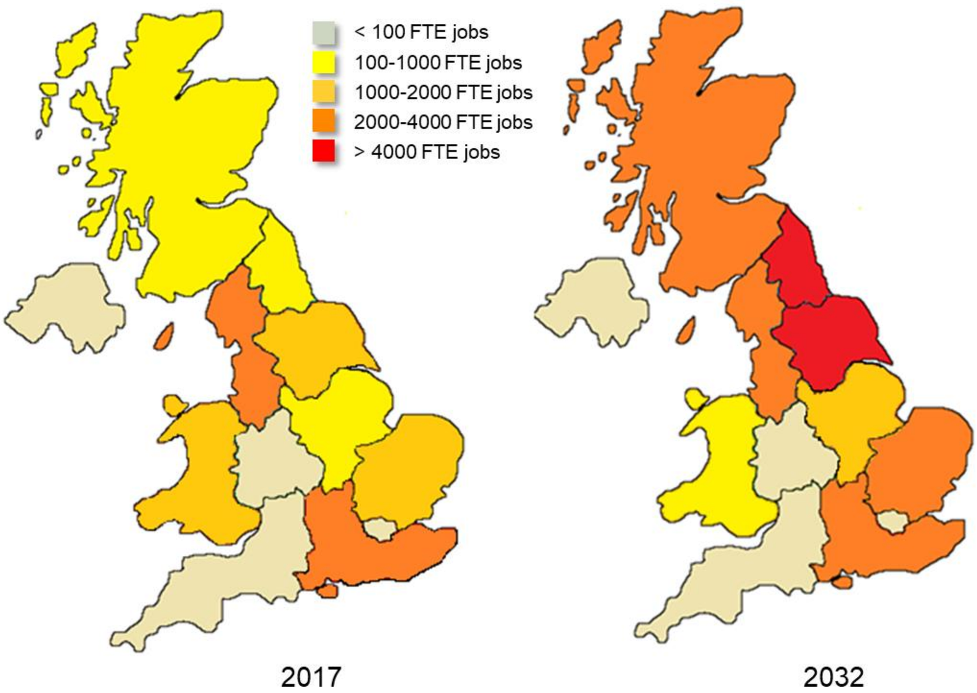

Figure 27: Projected UK Offshore Wind Employment 2017 vs 2032 (source: Cambridge Econometrics)

The scale of this opportunity in terms of employment and resulting economic value makes the co-ordination of skills supply and demand an imperative for the SIA region.

5.4 Conclusions

Developing the right balance of specialist skills will be essential to continue the SIA region's strong presence at the forefront of innovation. However, the area suffers from a shortage of skilled engineers. The skills required within the sector are similar to those existing within other sectors such as general manufacturing or the offshore oil and gas sector. The SIA region has a strong tradition of delivering these types of skills at all levels from apprenticeships to post graduates and this forms part of the industrial base of the region. Offshore renewable energy presents a significant economic opportunity, but the ambition will only be realised with joined-up thinking on skills and talent development.

6 Offshore Renewable Energy in the SIA Area

6.1 Introduction

The constituent parts of the SIA geography contain significant clusters of activity in offshore renewable energy. Many companies operate across a number or all of the geographical sub-areas and there are strong collaborative links and networks that support the industry as a whole. The following sections highlight the main strengths of each area.

The SIA is closely aligned to the relevant strategies of the four LEPs directly involved and that of Scottish Enterprise.

6.2 Humber

The Humber LEP has identified energy and renewables as the major economic opportunity for the Humber region, with a particular focus on maximising the impact of substantial investments in offshore wind around the Humber estuary. Offshore wind is considered to have potential to create an entire industry for the Humber which could create in the order of 7,000 new direct jobs across the major ports at Hull, Immingham, Killingholme and Grimsby.

The Humber Estuary is connected with around 25% of the energy production in the UK. Until recently, this energy production has been exclusively through conventional, fossil fuel sources, which have provided and still provide a strong basis for the local economy. However, there is now a new and significant potential for endemic economic growth in renewable energy driven, in part, by Government statutory targets. The key renewable power form of generation which offers major opportunity to the Humber is offshore wind with circa 20GW of capacity planned for installation within a close proximity to the Estuary. In addition, significant opportunities arise from bio-energy and carbon capture and storage.

Humber LEP's Strategic Economic Plan set out the Humber's ambition to become a renowned national and international centre for renewable energy. The Humber LEP is supporting the development of an Innovation Strategy focused on driving down the cost of energy with focused effort across entire project lifecycles and supply chains.

The strategy builds on recent major investments such as Siemens' blade manufacturing facility in Hull and the growing cluster of O&M businesses at the Port of Grimsby.

6.3 Liverpool

The inclusion of Liverpool makes this SIA a true East-West collaboration across the breadth of the Northern Powerhouse, with the significant research, innovation and natural assets that the City Region brings to bear, while the EU Motorways of the Sea programme offers opportunities for a new Trans-European corridor from Ireland – Liverpool – Hull – Scandinavia.

Liverpool City Region (LCR) LEP has marine energy (principally offshore wind & tidal) as an investment priority, while "Blue/Green" is one of the four focal smart specialisation areas identified in the LCR Innovation Plan, where offshore energy is a key sub-component. The Liverpool City Region has identified tidal energy as a focus as part of the recent devolution deal, which states “a next step in the river's (Mersey’s) recent evolution could be to harness its huge tidal range to produce power for the City Region's businesses and citizens”. Technology is in development that could deploy a large tidal energy system into the river that could have the potential to produce significant volumes of clean and predictable energy well into the next century. The Liverpool City Region estuary has one of the largest tidal ranges in the UK and the Liverpool City Region considers it to be one of the best locations in the UK for a tidal power scheme. The government recognises that the River Mersey and Liverpool Bay area is a key asset that has the potential to drive growth within the Northern Powerhouse and the government commits to supporting Liverpool City Region by providing guidance to support Liverpool City Region’s development of a cost effective tidal power scheme proposal for the River Mersey or Liverpool Bay that could generate low carbon energy for businesses and consumers”.

6.4 North East LEP Area

The North-East Strategic Economic Plan highlights four key areas of opportunity for high productivity growth in the region including a range of sub-sea, offshore and energy technologies, strength in depth in advanced manufacturing in energy and a vibrant digital cluster, which is the fastest growing in the UK. It hosts assets from four Catapult Centres (High Value Manufacturing, ORE, Digital and Satellite Applications), with a fifth investment from the Energy Systems Catapult imminent. It hosts a number of key National Innovation Centres relevant to this SIA including the new National Centre for Energy Systems Integration and the National Centre for Innovation in Data.

The North East LEP area continues to have a demonstrable competitive advantage and substantial business base within the offshore sector, with a particular emphasis on subsea technology. It is estimated that more than 50 companies, with over 15,000 employees generate £1.5bn turnover. There is a good mix of ownership (inward investment, privately owned, private equity, foreign owned subsidiaries) and a long history of entrepreneurial activity. Drawing on the region’s long history of providing solutions for extreme environments and hazardous conditions, the region has particular strengths and expertise in the technologies that enable subsea operations in ever deeper and more challenging waters, with excellent engineering and manufacturing capabilities in the LEP area. In addition to energy, these have potential applications in a range of other sectors including defence and communications. Products and services within the subsea and offshore technology ‘sector’ can be broadly broken down into the following five groupings:

- Products and components to operate subsea and offshore;
- Vehicles and machinery used subsea;
- Equipment for vessels used to install products and deploy and recover vehicles/machinery;
- Subsea and offshore installation, seabed intervention, inspection, maintenance and repair (IMR), and decommissioning activities;
- Engineering Design and Knowledge Intensive Business Services.

The business base is clustered around the River Tyne and the North East ports and includes Bel Valves, GE Oil and Gas, SMD and Technip Umbilical Systems. The North East has excellent access to UK offshore wind areas. The area is located close to the largest development zone, Dogger Bank, and centrally located to service the other wind farms making the area ideally placed for manufacturing equipment and providing services.

In addition to established, locations, since 2012 the North East Local Enterprise Partnership has invested in 115 hectares of new Enterprise Zones sites across the region three locations with a particular focus on supporting businesses to start, grow and expand in advanced manufacturing, energy and renewables sectors. The North Bank of the Tyne is hosting cluster growth offshore and marine engineering industries and the Port of Blyth in next-generation renewables. Ten new sites will become active in round 2 during 2017 including additional capacity in these sectors.

Linked to these developments, the new National Centre for Sub-sea and Offshore Engineering has recently opened, providing a focus for both bringing together industry and academia to create a world-class engineering research facility, and developing highly skilled graduates through project work and addressing the UK-wide skills shortage in the key disciplines underpinning offshore and subsea technology. The centre will provide crucial infrastructure for emerging research opportunities in high pressure materials, extreme environment electronics, underwater communications and pipeline engineering. Partners from the established manufacturing cluster include GE Oil and Gas and Bridon International.

Through the North East Strategic Economic Plan, the North East LEP has developed a strong open innovation and smart specialisation strategy and the region is increasingly recognised nationally and internationally as an exemplar innovation eco-system. This is supported by the North East Innovation Board which provides a collaborative multi-level leadership drawing together business, academic and political leaders working with Innovate UK and its agencies. The Innovation Supernetwork provides a systemised network eco-system to support open innovation delivery and includes Venturefest North East working with the Knowledge Transfer Network (KTN) and Innovate UK and a number of spin off activities.

6.5 Tees Valley

Tees Valley is centrally located on the UK's east coast and is an ideal location to access the North Sea. Tees Valley's main strengths are its ports with nine deep water sites, including the east coast's deepest port, twelve Enterprise Zones and its world-leading supply chain. There are also over 16GW of offshore wind developments within 90 nautical miles.

Tees Valley has a critical mass in advanced engineering and manufacturing businesses, particularity in relation to offshore energy subsea engineering. Key local companies include Offshore Structures Britain who supply many of the offshore wind farms around the UK, Wilton Engineering, JDR Cables, one of the world's leading suppliers of subsea cables, Subsea Innovation, Deepocean, SMD, and Modus. In addition, the TWI centre on Teesside is the UK's centre of excellence for training in underwater inspection technologies, including certification training for divers and remote operative vehicle inspection operators.

Tees Valley is the location of one of the largest oil and gas clusters in the UK. The oil and gas supply chain in Tees Valley is made up of over 400 direct and 3,000 indirect companies employing over 4,250 people.

Although there is a high proportion of micro and small enterprises in the sector, they are highly integrated into national supply chains. In addition, the region hosts leading industry names including BP Cats, Conoco Phillips, SABIC, Lotte, Huntsman, and Heerema.

6.6 Scotland

Scotland is a leading location for the test and demonstration of offshore renewable technologies, home to internationally renowned facilities like the European Marine Energy Centre (EMEC), the Hunterston Test Centre for Offshore Turbines, and the Offshore Renewable Energy Catapult's Levenmouth Demonstration Turbine. A world leader in marine energy, Scotland hosts more operational wave and tidal stream devices than the rest of the world combined, with notable projects including Nova Innovation's Shetland Tidal Array — the world's first grid-connected, community owned offshore tidal array and Atlantis' MeyGen project — the world's first large-scale tidal stream project. Wave energy remains a pre-commercial technology, but Wave Energy Scotland, EMEC, FloWave and other T&D facilities help position Scotland at the forefront of this emerging sector. In total there are over 1GW of tidal stream projects at various stages of development around Scotland's coast and several wave energy devices undergoing testing at EMEC.

The country is also playing an important role in pioneering a new generation of offshore wind technologies, particularly floating offshore wind. The world's first floating offshore wind farm, Hywind Scotland, is currently under construction off the coast of Peterhead and a further two floating projects, Kincardine and Dounreay Tri, are planned for construction in 2018. In total there are around 700MW of projects under construction in Scottish waters — Beatrice, the European Ofshore Wind Deployment Centre (EOWDC) and Hywind Scotland — and a further 3.5GW of projects with full offshore planning consent.

Scotland's long history of oil and gas exploration and recovery has helped the country to build a strong, diverse energy supply chain. As the offshore renewables industry continues to grow in the UK, Europe and elsewhere in the world, an increasing number of supply chain companies have diversified to service the sector. Key Scottish companies active in offshore renewables include: EPCI contractor SubSea 7; subsea contracting and engineering service providers Canyon Offshore and Ecosse Subsea; offshore installation specialists Bibby Offshore and Briggs Marine; offshore grouting specialists FoundOcean; foundation and substation fabricators Babcock, BiFab and Global Energy Group; tower fabricators CS Wind; and ROV suppliers ROVOP and Cyberhawk.

6.7 Infrastructure and Investments

6.7.1 Energy Parks

The SIA area has a number of energy parks which provide an enabling environment to support emerging and established clusters of energy business and wider support organisations. These include:

Neptune Energy Park

The Neptune Energy Park, in Newcastle upon Tyne, is an offshore and marine cargo handling terminal with a world-class reputation in service, cost effectiveness, efficiency and flexibility. Neptune is a major redevelopment of the former Neptune shipyard, creating a clean 80 acre site with 700m of operational quay edge, deep-water access and heavy load-out capability up to 700 tons. The site incorporates a fully functioning 218m long dry dock facility and is available for specific short and long term projects. The site incorporates a manufacturing cluster of established companies such as GE Oil and Gas, Fraser Hydraulic Power and Bridon International.

Nigg Energy Park

The former oil and gas fabrication yard at Nigg on the Cromarty Firth was successfully purchased by Global Energy Group (GEG) in October 2011, following which a £1.8m funding package from Highlands and Islands Enterprise (HIE) was awarded to help transform the largely dormant site into a multi-use modern energy park. HIE invested a further £6.5m in Nigg in May 2014 as part of a £40.5m quayside development at the site. GEG has since signed a contract with Siemens securing the use of Nigg Energy Park during the construction of the Beatrice offshore wind farm project.

Green Port Hull (GPH)

Green Port Hull is a partnership between the East Riding of Yorkshire Council, Hull City Council, Associated British Ports and the University of Hull. Its purpose is to work jointly to optimise the co-location advantages of the offshore wind supply chain in the region, catalysed by the transformational investment of £315m in the Siemens Gamesa Renewable Energy offshore wind turbine blade manufacturing, assembly and servicing facilities. Strategically located within 12 hours' sailing time of three major Round 3 wind farm zones, GPH aims to establish Hull and the East Riding of Yorkshire as a world-class centre for renewable energy. To this end, it is investing in skills and employment, business support, and research, development and innovation. GPH offers over 500 hectares of employment land, some with direct quayside access, a programme of investment totalling £1 billion underway in Hull, Enterprise Zone status, extensive infrastructure and logistics capability and committed civic leadership.

Port of Grimsby

The Port of Grimsby is home to a growing cluster of operations and maintenance companies. DONG Energy, Centrica, Siemens, E.On and RES, amongst others, have established operations within the port, which forms an established centre of excellence for Round 1 and 2 O&M activities.

6.7.2 Enterprise Zones

The SIA area has a number of UK Government-supported Enterprise Zones supporting low carbon energy businesses with a combination of discounted business rates, skills and training support, simplified planning processes and tax relief on capital investments. Some of the Enterprise Zones include: Humber, Hatston and Lyness, Orkney; Blyth Estuary, Blyth; North Bank of the Tyne, Newcastle; Port of Sunderland, Sunderland; New Energy and Technology Park, Hartlepool; Arnish – Western Isles;

Hartlepool Port Estates, Hartlepool; Nigg and Scrabster – Highland, Dundee; and Mersey Waters Enterprise Zone, Liverpool. In addition, the Humber Enterprise Zone[31] is the largest in the UK.

6.7.3 Port Infrastructure

The area comprising the SIA geography is well served by existing and continued investment in port infrastructure to support the offshore energy industry. This includes deep-water ports and land at Green Port Hull, Port of Grimsby, Teesport, Hartlepool, Port of Tyne, Port of Blyth, Liverpool Peel Ports, Aberdeen Harbour, Cromarty Firth, Port of Hull, Port of Grimsby, Killingholme and others.

6.8 Conclusions

Strategic Economic Plans enable LEP's to frame opportunities and growth plans for offshore renewable energy in the wider context of local economic plans. A number of key sites within the Enterprise Zone portfolio have been designated for offshore and sub-sea energy cluster development. In the North East, these include seven sites around the North Bank of the Tyne and the Port of Blyth in the Round 1 Enterprise Zone and sites within the Round 2 Zone.

[31] http://www.humberlep.org/wp-content/uploads/2015/03/Humber-Enterprise-Zones-AH-Digital-Brochure-With-Links2.pdf

7 National and Regional Collaboration and Funding

7.1 Collaboration Structures

The Offshore energy sector is a well-connected sector with strong links both across the UK and internationally. These connections exist at every level – through individuals moving between companies and through company to company links as part of projects undertaken and through trade bodies and members societies. RenewableUK plays a key role as the most prominent UK trade body covering the whole renewable energy field. Offshore energy (of all forms) features strongly in the activities of RenewableUK which plays a key role in UK policy discussions and other sector groups, but it is not dedicated to offshore renewables and so is not detailed further here.

7.1.1 Offshore Wind Innovation Hub (OWIH)

The purpose of the Offshore Wind Innovation Hub (OWIH) is to coordinate across the entire innovation landscape for offshore wind in the UK. The Hub is funded by the Department for Business, Energy and Industrial Strategy (BEIS) and delivered jointly by ORE Catapult and the Knowledge Transfer Network. The Hub will provide a coordinated UK approach to offshore wind innovation. The Hub's first programme will be the Offshore Wind Innovation Exchange (OWIX). This cross-sector scheme will aim to accelerate the cost reduction of offshore wind by matching industry challenges with innovative solutions adapted from other parts of the economy. It will also provide new opportunities for UK business across industries.

7.1.2 Offshore Wind Industry Council (OWIC)

OWIC is a senior Government and industry forum established in May 2013 to drive the development of the world-leading offshore wind sector in the UK. OWIC is responsible for overseeing implementation of the Offshore Wind Industrial Strategy, and is the sponsoring body of the Offshore Wind Programme Board - a joint government / industry body responsible for driving cost reduction in offshore wind. Membership comprises of government and public body representatives alongside senior executives from the development and supply chain community.

7.1.3 Offshore Wind Programme Board (OWPB)

The OWPB has been established following the recommendations in the Offshore Wind Cost Reduction Task Force report. The board brings together senior representatives from industry (including developers and supply chain), UK government, The Crown Estate and Statutory Nature Conservation Bodies. It is based on successful models used in other sectors such as PILOT (the oil and gas taskforce). The Board's objective is to implement the Task Force's recommendations to drive cost reduction, to treat the UK's offshore wind sector as one business by assessing risks and barriers and tackle these by helping to find and implement solutions in partnership with the wider industry.

7.1.4 ORE Catapult

The ORE Catapult also plays a key role as an innovation connector though a number of mechanisms across the whole offshore energy space. Head-quartered in Glasgow, the ORE Catapult also has significant activities in Blyth, Northumberland (at which large scale test facilities are based) and at

Levenmouth in Fife. The ORE Catapult runs an extensive programme of joint industry projects, collaboration initiatives and innovation programs.

7.1.5 MaRINET

There is strong evidence of connectivity between UK offshore energy activities and European centres of excellence. Many UK centres are prominent in MaRINET - a European Commission-funded network of world class research centres that have come together in order to accelerate the development and commercial deployment of marine renewable energy technologies – wave, tidal and offshore-wind. MaRINET has recently been renewed until 2021 by the EU Commission and will be coordinated from Ireland.

Through facilitating access and streamlining the testing process, these research centres aim to advance marine renewables research and innovation at all scales - from small-scale model and laboratory testing, through to prototype and open-sea trials. In order to do this, the network partners are offering periods of Free-of-Charge access to their testing facilities and conducting joint activities in parallel to standardise testing, improve testing capabilities and enhance training and networking in the industry. UK centres included in MaRINET receive EU funds to keep facilities running and then to subsidise access for researchers and companies testing new technologies.

7.1.6 Project Aura

Born of the Green Port Hull partnership, Aura's vision is to create a world-leading, multidisciplinary offshore wind talent and innovation hub, supporting the establishment of a vibrant industry for Hull, the Humber, the UK and globally (www.aurawindenergy.com). Aura's mission is to identify and address key technical, operational and economic barriers to drive down the cost of offshore wind energy, support the growth and development of the supply chain for the offshore wind sector and promote and sustain the UK's status as a world leader in offshore wind. Led by the University of Hull and the Humber LEP, Aura is a collaboration with global offshore wind industry players (Siemens Gamesa Renewable Energy, DONG Energy), leading UK research institutions (the Universities of Sheffield and Durham), Government organisation (ORE Catapult) and skills organisations (HCF Catch). By bringing together this critical mass of offshore wind organisations in an area that is geographically well-placed as a long term base for service of UK Round 3 offshore wind farms, Aura is co-ordinated across three 'strands' to create a seamless offer:

Industry Engagement and Enterprise: Placing industry at the heart of the Aura programme of activity, supporting the development of the offshore wind supply chain, providing a direct route for exploitation of innovation and adoption of best practice from upskilled workers.

Research, Development and Innovation: Creating a multi-disciplinary innovation hub with world-leading capability in its focus themes. The combination of research capability and close collaboration with industry across the TRL scale is unique. The investment in innovation is the step change from earlier programmes in scale, scope and ambition.

Talent Pipeline. Establishing the 'go to' framework that spans the different education stages from UTC (age 14) through apprenticeships to degree apprenticeships, degrees and higher degrees (University of

Hull), CPD and executive education for demand-led high quality education and training, to meet the skills needs of the offshore wind industry.

Based in the Humber and with a regional focus, Aura is integrated into wider UK, European and Global innovation and skills networks, offering national and international reach.

7.1.7 SUPERGEN Wind

Collaboration within the UK sector is nurtured through the establishment of the Supergen programme that was initiated by the EPRSC in 2004. In 2014 The Supergen activities in Wind Energy (which encompass both onshore and offshore) were successfully renewed as part of Phase 3 Hub funding from RCUK. The Supergen Hub takes a leadership role in bringing together the underpinning research efforts in Wind Energy in the UK and linking them more strongly to the development research being supported by other funding organisations. The SUPERGEN Wind Hub currently includes the Universities of Strathclyde (co-ordinator), Durham, Loughborough, Cranfield, Manchester, Oxford, Surrey, Bristol, Imperial and Dundee alongside STFC Rutherford Appleton Laboratory, DNV GL and the Offshore Renewable Energy Catapult. The Hub is funded for five years to 2019. The aim of the Hub is to continue to develop the important academic, industrial and policy linkages that were established during the earlier phases of the SUPERGEN Wind programme (2006-2014), and to lead the technology strategy for driving forward UK wind energy research and for exploiting the research outcomes.

7.1.8 SUPERGEN Marine (UKCMER)

The first phase of the SuperGen Marine Energy Research Consortium commenced in October 2003 following the award of £2.6 million under the EPSRC's SUPERGEN Programme. The award funded research into marine renewable energy conversion and delivery. Phase one resulted in 133 publications at the end of the programme. This success led to the creation of the second phase SuperGen Marine Research Consortium, a four-year, £5.5 million project which commenced in October 2007. Five core academic institutions are involved in the second consortium - The University of Edinburgh, Heriot Watt University, Lancaster University, Queens University Belfast and the University of Strathclyde - along with a number of affiliate institutions being awarded PhD studentship funds. A new research phase has been awarded, subsequent to the success of phases one and two, which commenced in October 2011, with SuperGen Marine being renamed the SuperGen UK Centre for Marine Energy Research (UKCMER). SuperGen UKCMER will broaden the level of collaboration within SuperGen to recognise the growing interest in marine renewable energy research by operating with a structure of four core institutions in addition to a further seven associate universities.

7.1.9 SUPERGEN Offshore Renewable Energy

The Supergen Wind and Marine activities have now been combined under a single Supergen Offshore Renewable Energy programme following the 2016 Supergen strategic review, which favoured clustering related disciplines into a single programme. The official announcement of consortium leader is expected in July 2017, with the call for building the hub to follow. The hub will be expected to work very closely with other key bodies, including ORE Catapult and the KTN.

7.2 Innovation Initiatives, Infrastructure, Funding and Networks

As part of the SIA, a number of key investments and activities have been identified that are playing a prominent role in supporting businesses to innovate in the sector. This sub-chapter identifies some of the key enterprise and business support initiatives, physical and enabling infrastructure, finance and networks that stimulate and support the offshore renewable energy industry.

7.2.1 Innovation Initiatives

Offshore Wind Innovation Hub

Described in Section 7.1.1 on Collaboration Structures.

Carbon Trust Offshore Wind Accelerator (OWA)

The Carbon Trust Offshore Wind Accelerator (OWA) is a collaborative research, development and demonstration (RD&D) programme between the Carbon Trust and nine international energy companies, including DONG Energy, ENBW, E.ON, Scottish Power Renewables/Iberdrola and Vattenfall. Together, the OWA partners account for 76% of Europe's offshore wind installed capacity.

The aim of the OWA programme is to identify and support industry-led innovative projects which impact on the LCOE from offshore wind by reducing costs and improving efficiency and availability of existing and future offshore wind farms. As part of the programme to drive down costs, technical challenges are identified by the OWA partners and fall into six technology areas: (i) turbine foundations and installation techniques; (ii) facilitation of access to distant turbines for maintenance; (iii) finding the best wind farm array layouts to optimise yield (through the study of wake effects); (iv) researching ways to reduce electricity transmission losses and increase reliability; (v) improving cable installation methods; and (vi) studying the environmental impact of constructing and operating offshore wind farms.

In partnership with the OWA partners and wider supply chain, the most promising projects are selected and targeted with grant funding to support businesses undertaking RD&D of new technologies and innovations. Some example projects supported by the OWA programme include: improving fatigue life of welded jacket connections; estimating soil damping from cyclic testing of piles; developing a new active ride control system for crew transfer vessels and a floating LIDAR demonstration project.

Over the next four years the commercial partners in the OWA programme have committed to invest at least £6.4 million, supported by a further £1.5 million from the Scottish Government, to bring new innovations to the offshore wind market.

ORE Catapult Innovation Technology Challenges

Working with industry, the ORE Catapult develops collaborative innovation challenge programmes that draw upon technical capabilities and leverage public and private sector funding. These programmes are particularly focused around cost reduction and removing barriers to progress. The ORE Catapult Innovation Technology Challenges are designed to accelerate the time to market for new innovations, reduce the LCOE, de-risk offshore renewable energy deployment and drive economic growth.

Offshore Wind Expert Support

Offshore Wind Expert Support[32] helps Scottish companies that have not traditionally been involved in the offshore wind sector to consider and build diversification strategies. The aim of the support is to identify and explore appropriate revenue streams for companies seeking to enter the offshore wind sector. The support culminates in the production of a company-specific action plan with key milestones to help companies take forward their offshore wind ambitions.

Wave Energy Scotland

Wave Energy Scotland (WES) is supporting and accelerating the development of wave energy technology in Scotland and was established in 2014 as part of Highlands and Islands Enterprise. WES brings together the best engineering and academic minds to deliver a range of projects aimed at resolving the issues that have hindered the development of wave energy technology. In particular, WES has been created to address the challenges encountered by developers in Scotland. WES has already awarded a number of contracts for the development of innovative technologies to produce low cost, efficient and reliable components and subsystems which can form the basis of the cost effective generation of wave energy in Scotland. WES is currently running over 56 projects and working with over 150 separate organisations, across 11 different countries. Key to this is driving convergence in the sector and ultimately reducing the costs attached to commercialisation.

The ultimate aim is to enable at least one wave energy device to reach the point where it has been rigorously tested and demonstrated, shows clear potential to be cost competitive with other offshore renewables, and is ready to be commercialised by the private sector.

7.2.2 Sector Networks

Across all of the SIA area, the offshore renewable energy sector is well served by cluster organisations and other membership bodies which promote connectivity in the sector. Some of these organisations include:

- **Subsea UK** - Subsea UK is the industry body and focal point for the entire British subsea industry and aims to increase business opportunities at home and abroad for the sector. The body acts for the whole supply chain bringing together operators, contractors, suppliers and people in the industry. Subsea UK was established by the industry and acts on behalf of the industry.
- **NSRI** - The National Subsea Research Initiative (NSRI) is the research arm of Subsea UK. It has been set up to bring academia and industry together to collaborate on getting technology to market much more quickly. The NSRI aims to be the focal point for the co-ordination of research and development activities for the UK's subsea sector.
- **Offshore Wind Programme Board** – BEIS-supported industry group that includes representatives from major industry players in offshore wind, representation from RenewableUK and the ORE Catapult.

[32] http://www.scottish-enterprise.com/offshoreopportunities

- **Energy Innovation Board** – with a role to to identify opportunities for enhanced collaboration on both UK and international energy innovation priorities. The Board has replaced the LCICG, which developed the Technology Innovation Needs Analysis (TINA's) to identify where the sector supply chain needs to focus development.
- **Academic Research Hubs** – The ORE catapult has developed key relationships with academic experts/institutions to provide deep reach into technical areas and provide the flexibility to tune expertise to an evolving sector and client demand.
- **Subsea North East -** Established in 2006, Subsea North East brings together key players in the sector. Subsea North East works across four themes: global prominence, business development, skills and resources, and technology. Subsea North East works in partnership with Subsea UK (based in Aberdeen), the membership organisation for the industry in the UK and NOF Energy, the North East-based national business development organisation working on behalf of companies in the oil, gas, nuclear and offshore renewable sector.
- **Team Humber Marine Alliance –** Represents over 200 companies offering wide-ranging supply chain capabilities in the marine engineering and offshore energy sectors, facilitating joint bidding for major contracts and trade missions.

7.2.3 Financial Support

Wave and Tidal Energy: Research, Development and Demonstration Support

The Wave and Tidal Energy: Research, Development and Demonstration Support (WATERS) is a collaborative programme that supports wave and tidal companies to build and demonstrate full-scale prototypes in Scottish waters. To date, Scottish Enterprise has committed £12m of investment in WATERS, investing £10.7m in 8 firms.

Renewable Energy Investment Fund

The Renewable Energy Investment Fund (REIF) is delivered by the Scottish Investment Bank - the investment arm of Scottish Enterprise. REIF provides financial assistance for renewable energy projects, including providing £19.6m investment in the MeyGen project - the largest planned tidal development project in the world (see MeyGen case study).

Prototyping for Offshore Wind Energy Renewables Scotland

The Prototyping for Offshore Wind Energy Renewables Scotland (POWERS) fund is designed to support the manufacturing of next generation offshore wind turbines and major turbine components, including gearboxes, nacelles, blades, and towers in Scotland.

The Scottish Innovative Foundation Technologies Fund

The Scottish Innovative Foundation Technologies Fund (SIFT) supports innovation in offshore wind turbine foundations in water depths greater than 30 metres, to help drive down cost. SIFT contributes grant funding towards capital and operational costs associated with research, development and demonstration activities in eligible projects for foundations running up to 2019.

Low Carbon Infrastructure Transition Programme

The Low Carbon Infrastructure Transition Programme provides tailored support for established and start-up infrastructure projects across the private, public and community sectors. It aims to stimulate commercial interest and investment and maximise Scotland's vast potential in the low carbon sector. The £76m programme offers three forms of support to low carbon projects: catalyst support for start-up projects; development support for more advanced projects; and demonstrator support for projects already using commercially proven technology.

Green Port Growth Programme (Humber)

The Green Port Growth Programme is capitalising on Siemens' investment in the area with the aim of establishing Hull and the East Riding of Yorkshire as a world class centre for renewable energy. The programme is utilising £25.7m of Regional Growth Funding to deliver a programme of activity which will assist in securing long term sustainable economic growth and employment for the region. As well as offshore wind, there are major opportunities in bio-fuels, carbon capture and storage, waste to energy, wave and tidal power generation. The Programme includes business support and advice provision, aimed at assisting businesses in the region in their development to access opportunities within the renewables sector.

Spark Fund low carbon grants (Humber)

The Spark Fund provides a new funding opportunity for ambitious, growth oriented local SMEs seeking to grow market share, improve productivity and create new employment opportunities through the development and subsequent commercialisation of new and innovative products and services. £3m of funding is available through the Humber European Structural and Investment Funds programme, which is being delivered jointly with York, North Yorkshire, East Riding (YNYER) LEP where a further £3m is available through the YNYER ESIF Programme. The project will run from April 2017 to April 2020, with up to £50k of grant funding is available to support SMEs to become more innovative and undertake research and development projects.

Green Investment Bank

The UK Green Investment Bank (GIB), headquartered in Edinburgh, is a key component of the progression towards a green economy. Capitalised with £3 billion, its mission is to provide financial solutions to accelerate private sector investment in the green economy. The GIB is playing a vital role in supporting the financing requirements of offshore wind in the UK, having invested £1.3bn in eight projects to date with a combined capacity of 2.9GW. Offshore wind is one of the GIB's priority investment areas.

7.3 Conclusions

There is a rich eco-system of support for offshore energy in the UK for both industrial operations and research. It is clear that this connective eco-system plays a crucial role in supporting the industry and is a strong enabler of the innovations that have led to the very significant advances of the last five years.

The importance and benefits of collaboration are well understood across the SIA region. Collaboration between academia, public research bodies and industry are delivering innovative technology. Opportunities are apparent to strengthen these bonds still further and broaden the collaboration to join up with other UK regions.

Whilst this is extremely positive, it must be noted that the funding levels still fall short of those for other energy sectors. For example, EPSRC in 2015 dedicated just 5% of energy funding to wind energy (onshore and offshore combined) and 3% to wave and tidal.

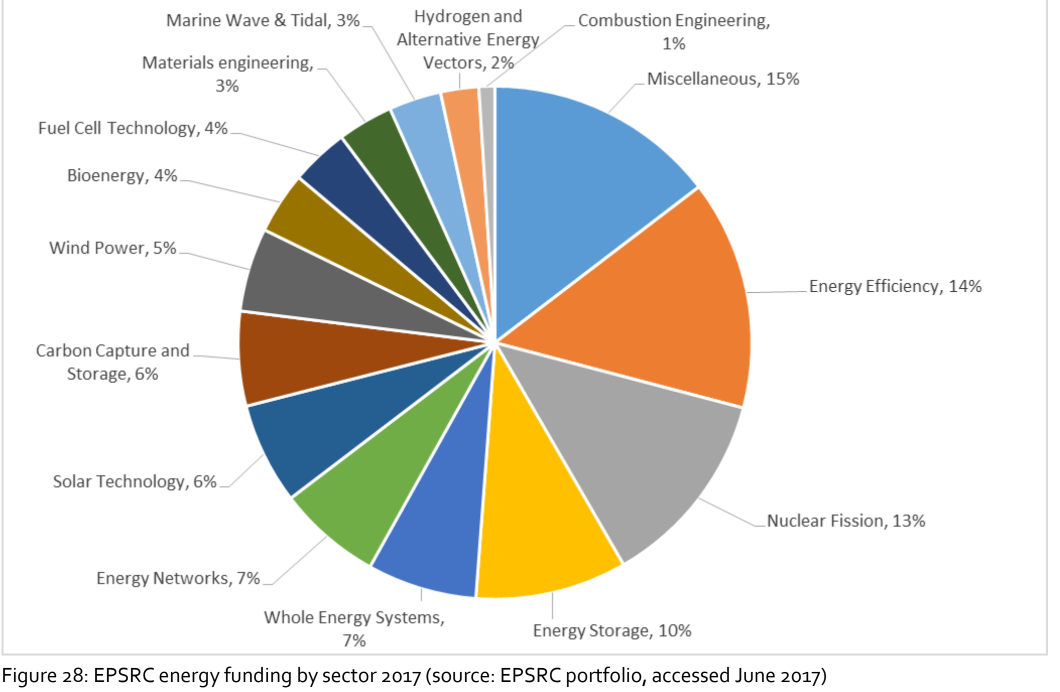

Figure 28: EPSRC energy funding by sector 2017 (source: EPSRC portfolio, accessed June 2017)

This offshore energy SIA has concentrated in the North of England and Scotland but other SIA's have also touched upon relevant activities in their respective areas.

The South West England and Wales SIA (SWW) in the first round of SIAs undertook a detailed analysis of energy activities in that geographic area. This analysis also included activities such as nuclear (that are beyond the remit of this offshore renewable energy SIA) but did focus on a number of relevant activities. As illustrated elsewhere in this report, the South West of England and Wales contain important clusters of industrial and academic activity in wave and tidal energy. For example, Plymouth University is a leading university for wave research (see Section 3.1) and also hosts impressive test facilities, whilst Exeter University manages the Falmouth Bay test facilities that enable energy devices to be tested in real-world environments.

The East England Round 2 SIA[33] also analysed relevant activities in offshore wind that are developing in that geographic area – principally as a result of deployment of offshore turbines along the East Anglian coast over the last five years.

[33] http://www.gcgp.co.uk/2017/04/businesses-help-map-science-innovation-east/

8 International Clusters and Market Directions/Opportunities

8.1 Offshore Wind

Global market growth in offshore wind has been spectacular over the last decade. Figure 29, below shows the anticipated future growth to 2045 rising to an installed capacity of over 300GW by 2045. At present, Europe is the dominant market with an installed capacity of over 11GW as compared with only 1.2GW in Asia (principally China and Japan although new projects are now being established in Taiwan). The market in the USA is further behind but new projects are emerging on the east-cost of the US. Within Europe over 50% of installed capacity lies in UK waters making the UK the largest market in the world at present.

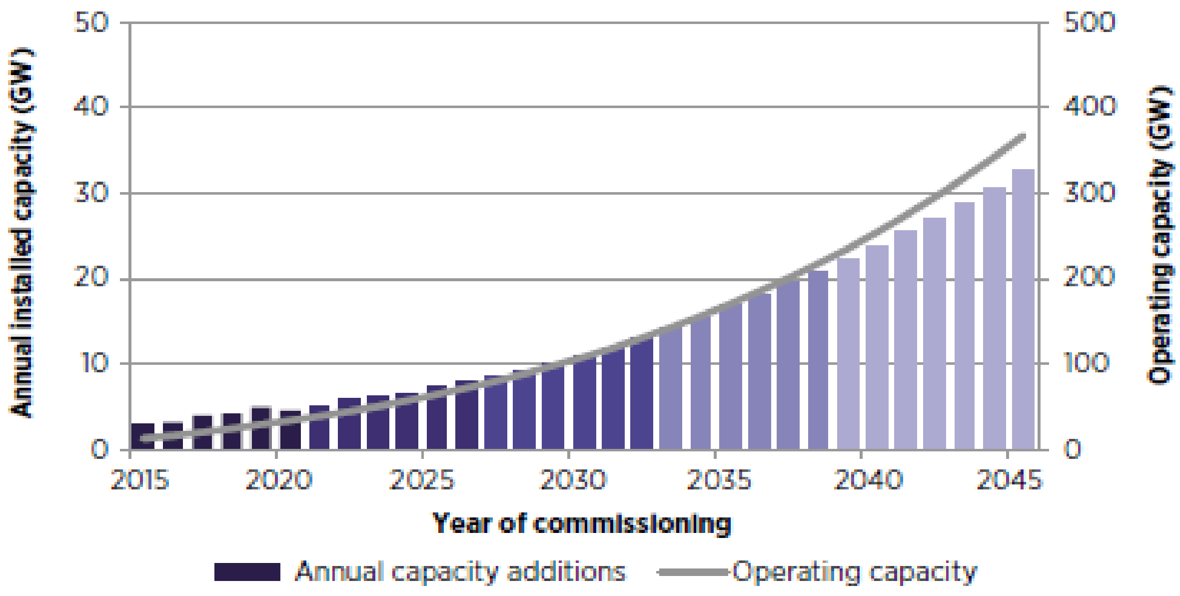

Figure 29: Forecasted global annual installed and operating capacity of offshore wind, 2016-2045 (source: © IRENA 2016).

The European market for wind turbines is dominated by Siemens whose turbines constitute around 75% of installed capacity. MHI Vestas are the next biggest player. Other manufactured components such as foundations and cables are spread more evenly over a larger number of suppliers.

Across the world, there are three industrially significant clusters of offshore wind activity:

8.1.1 Europe

The wind energy industry has a long heritage in Europe, particularly in Denmark and the adjacent districts of Northern Germany (see Figure 30). Within Denmark, there are major industrial activities at Odense, which are supported by the world-leading LORC (Lindo Offshore Renewables Centre) wind turbine test facility. MHI Vestas, which is based in Denmark has a number of active sites including, for example, manufacturing of nacelles at Lindo and blades at Nakskov. Denmark, as highlighted in the earlier research chapter also has a leading research activity at Aalborg in northern Denmark.

Siemens wind power division was acquired from the Danish firm Bonus Energy in 2004 and so has itself a long history in Denmark (e.g. at Brande and Aalborg) and across the border in northern Germany. The wider Bremerhaven district hosts Siemens, activities acquired by Siemens from Adwen and other companies. Bremerhaven benefits strongly from the Fraunhofer Institute for Wind Energy and Energy Systems Engineering (IWES), which has extensive industrial scale test facilities[34]. IWES is industrially orientated not just on testing but also production technologies, including the Blademaker project which is industrialising blade production[35]). The Bremerhaven harbour area hosts a number of companies itself, including AREVA Wind (recently acquired by GE), Repower Systems (turbines), Powerblades and WeserWind (foundations).

Figure 30: Map of Denmark and northern Germany illustrating the major industrial and research and innovation sites (source: eSpatial).

The Danish-German cluster is long-standing and includes deep links into relevant supply chain companies that have grown up to support the cluster. This whole offshore wind eco-system is very attractive for investment as evidenced by the significant investment by Siemens in a large factory to assemble nacelles at Cuxhaven. This investment is costed at over £250m and is due to open for

[34] http://www.windenergie.iwes.fraunhofer.de/en/test-centers-and-measurements.html
[35] http://www.windenergie.iwes.fraunhofer.de/en/press---media/blademaker-update.html

production in the autumn of 2017 to produce the next generation D7 turbines[36]. The Danish-German cluster is facilitated by considerable investment in transport infrastructure supported by strong inter-governmental cooperation and investment. The scale, stability and depth of activity clearly makes this cluster the world-leader and a reference point for industrial re-development following the decline of the European ship building industry.

Other significant industrial clusters exist in the UK (and the focus of much of this SIA) and in Spain, which is principally based around the activities of Iberdrola and associated supply companies. This includes manufacturing sites for both Siemens and MHI Vestas and fabrication activities at re-purposed naval yards at sites such as Cadiz. The industry is supported in Spain by a number of universities and the National Renewable Energy Centre (CENER) which is directly supported by the Spanish government. CENER has good quality test facilities including a Wind Turbine Test Laboratory (the only one of its kind in the world) and an experimental wind farm.

8.1.2 USA

Offshore wind in the US is relatively under-developed compared with Europe. The industry is beginning to get a hold on the US East Coast, particularly in Maryland. The Maryland Public Service Commission (PSC) has awarded offshore wind renewable energy credits (ORECs) to two projects to be built off the state's coast, enabling US Wind and Deepwater Wind (Skipjack Offshore Energy) to install 368MW of capacity. This is significant progress and more projects are emerging as offshore wind opportunities are being identified by a number of districts. There are a number of US districts that contain former ship building or naval fabrication yards that are hoping to become prominent locations as the US industry develops and are being actively supported by state funds.

8.1.3 Asia

Within China, the most prominent industrial cluster is at Tianjin in Northern China which hosts a number of companies (including Siemens and MHI Vestas). The cluster is supported by a well-organised industrial cluster organisation[37].

Japan is not as well-developed for offshore wind but has a considerable long-term potential around the Northern island of Hokkaido and in Tohoko Prefecture. The Japan Wind Energy Association has proposed national targets of 10GW installed by 2020 but this is not yet official government policy. The long-term prospects for offshore wind are likely to be strong though as Japan moves away from nuclear energy and towards renewable energy in general. Given the deep water close to shore, it is expected that there will be a substantial focus on floating wind development, with a number of demonstration projects already in the water. Anticipating these developments, Japanese companies such as Hitachi and Mitsubishi (including the joint venture with Vestas, MHI Vestas) have significant capability.

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[36] http://www.siemens.com/press/en/feature/2015/windpower-renewables/2015-08-cuxhaven.php
[37] http://www.twea.org.cn

8.2 Market Directions in offshore wind

The International Renewable Energy Association (IRENA) presented in 2016 a detailed analysis of how it saw the offshore wind industry developing in the future[38]. Figure 31 (reproduced from this report) is a diagrammatic representation of the relative importance of differing technology developments.

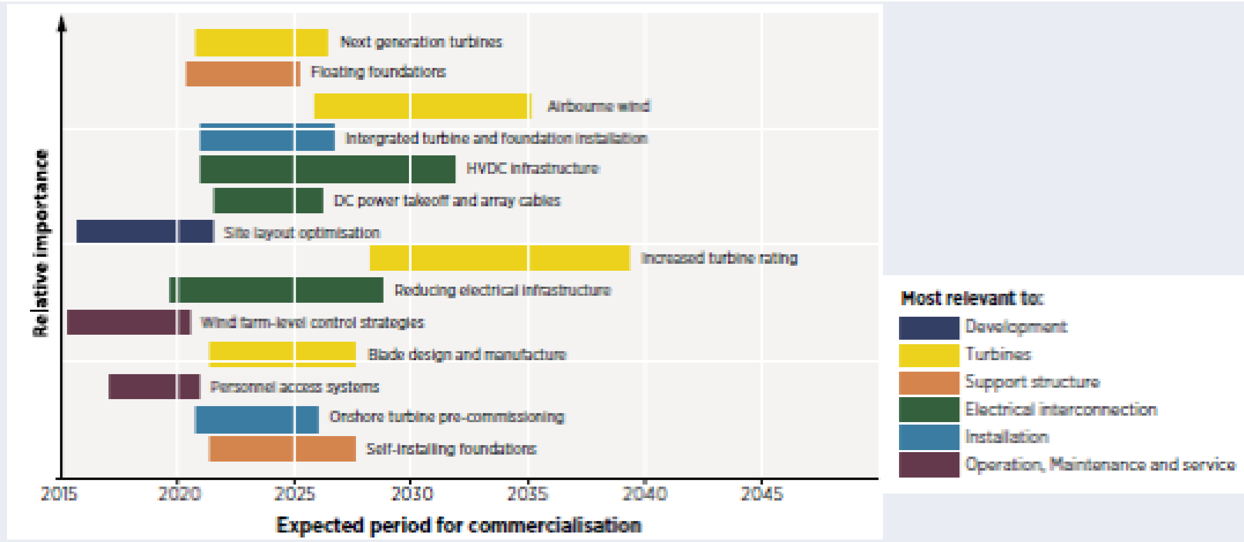


Figure 31: Anticipated timing and improvements in offshore wind 2016-2045 (source: © IRENA 2016)

The analysis of IRENA points to a focus on the development of new turbines (potentially extending the size towards a 15MW turbine) and floating foundations as being the most important developments over the next decade. This conclusion aligns strongly with the many discussions with UK based companies that have taken place during the SIA activities. The identification of floating foundations as a priority area by IRENA strengthens further the recommendations of this SIA concerning the potential opportunity for UK intellectual property and first mover advantage in floating foundation design and fabrication.

Interestingly this 2016 analysis does not pick up on the potential developments of embedded power storage in turbines that is exciting considerable industrial interest in the UK. The inclusion of 1MW of energy storage within a turbine is seen as a way to mitigate against the intermittency of wind availability and is being actively explored by industry. It is clear that linking offshore wind to energy storage is potentially very advantageous but that it is part of a broader discussion concerning the location of energy storage in the whole energy system. At an extreme level, this is might be characterised as the benefits of installing energy storage in homes, e.g. Tesla battery type technologies versus electric cars (as energy storage whilst parked/charging) versus at the point of generation (inside the wind turbine). Energy systems designers have not yet identified the preferred overall UK energy system design and these technological options will be actively debated and trialled over the next few years.

The UK is, and will continue to be, a globally significant market for offshore wind. To date, the UK supply chain has been able to able to capture only a relatively small share of contracts on UK projects, but this is set to continue to grow, with the Contract for Difference auctions requiring commitments on levels of UK content. This growth will be enabled by continued investment in supply chain innovation and further

[38] International Renewable Energy Authority, Innovation Outlook Offshore Wind 2016

linking the capabilities and activities in academic research with the needs of big industry. UK companies already have significant market share and a strong export foothold in areas such as cable supply and offshore O&M. Longer term opportunities exist throughout the value chain as well as re-powering existing arrays and offshore floating wind – platform design, subsea engineering and O&M.

8.3 Wave and Tidal Energy

When harnessed effectively, the ocean could prove to be one of the largest reserves of clean and sustainable energy. Wave and tidal energy are the two principal sources of ocean energy. The Carbon Trust (2011) suggest that in its 'high scenario' for wave and tidal energy deployment the global market could be 'worth up to circa £460bn (cumulative, undiscounted) in the period 2010-2050, with the market reaching up to circa£40bn per annum by 2050'.

This economic value would be unequally distributed globally with countries having the greatest manufacturing capabilities for exports and deployed capacity most likely to benefit. For example, given the UK's rich heritage in ocean energy the Carbon Trust estimate that 'the UK could capture circa£76bn of the global marine market, or around 22% of the accessible global market (cumulative, undiscounted to 2050 in their high scenario) between 2010 and 2050'. This would suggest a gross contribution to UK GDP of circa £15bn over the forecasted period (circa £10bn for wave, and circa £5bn for tidal, and not accounting for any displacement effects). One study estimated that this could create over 68,000 jobs in the UK from marine energy by 2050. It is important however to consider what the counterfactual would be if public and private funds necessary to develop the nascent technology were redirected to other renewables, or non-renewable energy technologies, or even outside the energy sector.

The UK has around 50% of Europe's tidal stream energy resource - potentially 30-to-50 gigawatts of installed capacity, or enough to supply around 20% of the UK's current electricity demand. The UK achieved a major milestone in 2017 when MeyGen, the world's first commercial tidal stream project, began supplying power to the grid in northern Scotland. The respective development costs of wave and tidal energy technologies remain a challenge to faster commercial deployment. Innovation is the key to reducing costs and Innovation Challenge initiatives by the ORE Catapult and funded development calls sponsored by Wave Energy Scotland are focused on sub-component, e.g. power take off, prime mover, and control systems, component integration and array optimisation. In addition, various socioeconomic, infrastructural and environmental concerns are also being addressed by Highlands & Islands Enterprise, Scottish Enterprise and the Welsh Assembly Government. These include developing supportive energy market conditions, delivering facilitative infrastructure, providing grid connection, growing supply chains and mitigating against environmental impacts. Wave and tidal have significantly different market dynamics. The wave energy sector has been struggling for some time to reduce capital costs and prove survivability and reliability, with still no sign of design consolidation towards an agreed optimised design. However, the technology and resource lends itself to support off grid and island communities and auxiliary power systems currently dependent on expensive and polluting diesel generator systems, e.g. aquaculture and offshore auxiliary power systems. Tidal energy can be broadly segmented into tidal stream and tidal range energy. Tidal stream power plants are a relatively new technology with ample scope for development. Tidal range power plants entail construction of tidal barrages, or lagoons to enable controlled water flow through mature turbine technology.

The reduction in fossil fuels and the need to create cleaner, secure energy systems and the increasing activity in the sectors suggest wave and tidal are likely to experience significant international market growth in terms of installed capacity and investments in the near future.

8.4 Conclusions

The wind energy industry has a long heritage in Europe and particularly in Denmark and the adjacent districts of Northern Germany. The Danish-German cluster is long-standing and includes deep links into relevant supply chain companies that have grown up to support the cluster. This whole offshore wind eco-system is very attractive for investment. The Danish-German cluster is facilitated by considerable investment in transport infrastructure supported by strong inter-governmental cooperation and investment. The scale, stability and depth of activity clearly makes this cluster the world-leader and a reference point for industrial re-development following the decline of the European ship building industry. Other industrial significant clusters exist in the UK and Spain. There is clear evidence in this SIA report (particularly in Chapter 4 on innovation) of emerging clusters within the SIA area. Further action, as outlined in the Recommendations section of this report, is required in order to drive further value for the SIA area and the UK as a whole through these clusters.

Wave and tidal energy technologies lag behind offshore wind in terms of maturity and cost. Their development remains in the balance due to lessening investor support. Nevertheless, the UK has around 50% of Europe's tidal stream energy resource - potentially 30-to-50 gigawatts of installed capacity, or enough to supply around 20% of the UK's current electricity demand. The Atlantis' MeyGen project, the world's first commercial tidal stream project, is now supplying power to the grid in northern Scotland. To be competitive, tidal energy will need to demonstrate that it can align itself with the cost reduction path of offshore wind, and ultimately generate power for under £100 per Megawatt-hour. Wave technology developers struggle to attract public and private sector investment and, as first movers, are burdened with the development of both enabling technologies, and components for first arrays. First commercial tidal stream arrays are now being built in the UK, with France and Canada following with prototype sites. Tidal range is a mature technology where only the upfront costs of projects and environmental concerns are holding back larger projects.

Currently, over 200 companies currently operate in the wave and tidal energy sectors. Most are extensively involved in the development of energy converter technology. Tidal markets will develop in countries with a significant resource, particularly United States, Canada, France and the UK. Markets for wave will develop where the resource can be economically harvested. Other than the UK and Ireland, the best wave resource is focused along the coasts of California, Argentina, Australia, Portugal, Sweden, Korea, Spain, Iran, and the Atlantic coast of the United States. Tidal stream international markets are now clearly emerging in France, Canada and the Asia Pacific.

Large-scale commercial array deployments of wave and tidal power plants are projected to be followed by massive cost reductions. Financial and policy support from local governments is imperative for technology developers for brisk commercialization of their energy converter devices. In the UK there are signs that industry first movers are looking for overseas projects, as the home market begins to stall due to policy and economic uncertainty.

The UK is in an enviable position with both good wave and tidal resources around its coastline and leading in both the academic understanding and technology development capability with some of the world's foremost testing assets. However, market signals indicate that other nations are quickly catching up with ambitious programmes and strong Government support.

9 Key Findings

The SIA team (drawn from the Universities of Durham, Hull, Liverpool and Newcastle, four Local Enterprise Partnerships (Humber, Liverpool City Region, North-East, Tees Valley Combined Authority), Scottish Enterprise and the Offshore Renewable Energy Catapult - see Appendix 6) undertook an extensive analysis of a wide range of activities across the broad area of offshore renewable energy. The following key findings were made.

9.1 International Competitiveness of Research and Innovation in Offshore Renewable Energy

- The academic research produced in the SIA area in offshore wind, wave and tidal is world-class in terms of both quality and volume and there are at least eleven universities in the area with centres of excellence in, or with close ties to, the field of offshore renewables.
- The existing relevant academic centres tend to cover broad areas such as sustainable practice, advanced manufacturing, environmental science and engineering and there is a potential opportunity for increased specialisation in order to address the industry's current and future needs. For example, focus on floating and other novel foundation designs, new bearing and generator designs will be essential to enable the next generation of turbines in the 13-15MW range.
- A number of mechanisms and organisations exist to coordinate academic activities in offshore renewable energy. However, the amount of funding available to offshore wind, wave and tidal is very small compared to other energy sectors, particularly nuclear.
- The SIA has a substantial supply chain active in offshore renewable energy and other offshore activities, with significant engagement in innovation projects across the value chain and strong global connections and presence. There are significant technology transfer opportunities between and across sectors and strong local eco-systems which could support open innovation.
- Innovation project funding tends to be concentrated in a small number of large grants, for example tidal or wave device development. As with academic research, there appears to be a lack of resources to focus on areas critical to enabling the next generation of large wind turbines, such as next generation installation vessels and novel foundations as well as turbine components.
- European funding, local Growth funding and Enterprise Zone and other infrastructure development activities have provided important resourcing and enabling support for this sector. As the UK's relationship with the EU changes, it is important to ensure that there is continuity and more flexibility of support from LEPs and other local partners.

9.2 Future Needs in Innovation of the Offshore Renewable Energy Sector

Based on feedback from industry in general interaction, and in response to the SIA, and the 2016 Offshore Wind technology Innovation Needs Assessment[39], a number of innovation priorities have been identified:

[39] http://www.lowcarboninnovation.co.uk/working_together/technology_focus_areas/offshore_wind/

- Turbines - development of innovative materials and components for next generation, higher reliability, turbines of up to 15MW capacity – design, materials and fabrication of longer blades, larger bearings, generators and drivetrain components
- Installation – vessels and equipment for larger, heavier turbines and installation methods for deeper waters and higher sea states
- Foundations – novel foundation designs including both fixed and floating concepts for low-cost foundations, particularly for water depths of greater than 35m and to support larger turbines and development of serial manufacturing techniques for foundations
- Operations & Maintenance – remote condition-based monitoring, control and maintenance systems, O&M access systems
- Development and FEED – improved wakes and loads models for layout optimisation, advanced resource measurement tools, and data sharing methods
- Transmission – optimised / next generation transmission systems (e.g. high-voltage direct current - HVDC) and improved, lower cost materials, cabling concepts, and installation techniques
- Windfarm clusters to enable operating efficiencies and better sharing of fixed costs
- There are a range of research and innovation opportunities available within the SIA territories through related assets of national and international standing including in digital, satellite, advanced manufacturing and energy technologies

9.3 Offshore Renewable Energy Workforce

- The SIA found clear evidence of a number of training courses and providers either specialising in, or directly related to offshore renewables. These are provided at university, further education, industrial training and apprenticeship level. However, the provision is devised on an institutional basis or organised through national policy departments with inadequate reference to local or regional industrial priorities.
- No direct skills audit was conducted as part of the SIA, but UK government forecasts highlight a net demand for engineering and manufacturing roles in Scotland and the north of England between 2014 and 2024. A shortage of skilled engineers today and a need to develop tomorrow's innovators needs to be addressed.
- Across the SIA area, with the support of business organisations, LEPs and Combined Authorities are seeking enhanced influence over skills policy to help strengthen the matching of supply and demand in the labour force and to enable strategic support for skills development. In the context of the emerging Industrial Strategy there is an opportunity to link sector and spatial skills strategies. One strategy identified in this SIA is focused on redirecting skills from Oil & Gas to address the present shortages.

10 Recommendations

Offshore wind developers, wind turbine manufacturers and other Tier 1 suppliers find the existence of four interlinked themes compelling when considering locations for new investments or expansion of existing operations:

- Research & Development & Innovation capability
- Available resource with the relevant skills
- Supply chain capability in terms of quality and capacity
- Infrastructure, including land availability, port facilities and accessibility (outside the scope of this SIA)

The SIA process has identified a number of opportunities that cut across the whole offshore renewable energy sector.

10.1 Research & Development & Innovation

- There is a clear need to do more to align key industry growth and development opportunities with the academic research base in order to maximise opportunities to develop cutting edge technologies such as composites, novel blades (smart design, aeroelastic modelling), autonomous vessels, digitalisation in design and control systems – for offshore wind, wave and tidal.

- The SIA, through the linkage to the Industrial Digitalisation review, has identified that there is a clear opportunity in the development of digital technologies for offshore wind – particularly in operations and maintenance of deployed assets and in the design phase of elements such as foundations. This could be driven forward through the Industrial Strategy Challenge Fund.

- Initiatives such as the Offshore Wind Innovation Hub, Academic Research Hubs and the Supergen programme should be given an even stronger mandate to set the industry-academia agenda in order to ensure best value for money for public and private research and innovation funding.

- Funding for innovation initiatives such as those outlined, above, should be made available at levels in line with the UK's ambition in offshore renewable energy. Some calibration is necessary between the amounts spent on offshore renewables compared to other energy sources, such as nuclear.

- The testing at scale of offshore energy technology is a crucial under-pinning factor in innovation and this must continue to be supported. This will drive maximum value from existing word-class testing assets as well as driving further investment in new assets.

- Two-way dialogue is needed between innovators and funders on the appropriate mix between capital and revenue funding, including a clear pathway for funding as the UK's relationship with the EU changes, as well as clearly defined milestones and targets for achieving technology and commercial readiness.

- The establishment of a new initiative to support subsea engineering which is a key enabler of offshore renewables. This should involve support for a small number of existing regional clusters of excellence to enable expensive capital testing facilities to be utilised and supported efficiently.

10.2 Resources and Skills

- With the UK's installed offshore wind capacity set to double to 10GW in the next three to four years and reach 20-30GW by 2030, a systematic audit across the offshore renewables sector is required, leading to a demand-led, evidence-based roadmap of skills requirements. This could be coordinated between government, relevant industry bodies and LEP's/combined authorities, leading to identification of skills gaps addressing both current and future needs.

- LEP's and Combined Authorities should be empowered to enter structured and formal consultations with industry in order to develop local skills strategies as well as structured and formal consultations with academic institutions in order to implement these strategies most effectively.

10.3 Supply Chain Capability

- Opportunities exist in tier 2 and tier 3 supply chain companies in blade design, infrastructure, robotics and artificial intelligence (AI), support to operations & maintenance, and specialist vessel design. These are industry needs not currently being addressed. Targeting research and innovation funding at these areas will mobilise a proven active innovative supply chain together with trusted academic partners towards fulfilling industry needs.

- A proactive government programme, led by the Department for International Trade (DIT), to build stronger links between engineering and design companies in the UK and overseas original equipment manufacturers (OEM's) could unlock further potential for innovative companies with no direct route to market.

- The existing momentum in development of wave and tidal solutions should be encouraged through providing a route to market in the UK via appropriate support schemes and by creating links at government level with overseas governments in order to share the cost of technology development. This will also create a natural base for building export capability and unlocking the full potential of wave and tidal energy to add significantly to UK GVA.

Appendix 1 Patent Methodology

The data on patents was collected from PATSTAT. PATSTAT is the most comprehensive patent database in the world. It contains over 70 million records of patent applications (as well as utility models and design rights) filed in 170 IP offices around the word as far back as 1844. It comprises detailed information on those applications including application year, characteristics of applicants and inventors (geography, type of organisation), application authority, technological area, status (granted, pending), among other indicators.

The patent data was classified using 'International Patent Classification' (IPC) system. The IPC provides for a hierarchical system of language independent symbols for the classification of patents and utility models according to the different areas of technology to which they pertain (WIPO, 2013). Patent applications are classified under eight top classes (e.g. Human Necessities, Mechanical Engineering) and further classified into 600 or so subclasses.

The definition of 'Wind Energy" for patent analysis has been taken from the IPC Green Inventory (http://www.wipo.int/classifications/ipc/en/est/). The "IPC Green Inventory" was developed by the IPC Committee of Experts in order to facilitate searches for patent information relating to so-called Environmentally Sound Technologies (ESTs), as listed by the United Nations Framework Convention on Climate Change (UNFCCC).

This definition includes:

- Wind motors
- Structural association of electric generator with mechanical driving motor
- Structural aspects of wind turbines
- Propulsion of vehicles using wind power
- Propulsion of marine vessels by wind-powered motors

The sub-sections below present the definitions behind for each of those five categories:
Wind motors
IPC code: F03D
Note(s)

- This subclass covers wind motors, i.e. mechanisms for converting the energy of wind into useful mechanical power, and the transmission of such power to its point of use.
- This subclass does not cover electrical power generation or distribution aspects of wind-power plants, which are covered by section H, e.g. H02J or H02P.
- In this subclass, the following terms or expressions are used with the meanings indicated:
- "rotor" means the wind-engaging parts of the wind motor and the rotary member carrying them;
- "rotation axis" means the axis of rotation of the rotor.

Including:

- F03D 1/00: Wind motors with rotation axis substantially parallel to the air flow entering the rotor (controlling thereof F03D 7/02)
- F03D 3/00: Wind motors with rotation axis substantially perpendicular to the air flow entering the rotor (controlling thereof F03D 7/06)
- F03D 5/00: Other wind motors (controlling thereof F03D 7/00)

- F03D 7/00: Controlling wind motors (supplying or distributing electrical power H02J, e.g. arrangements for adjusting, eliminating or compensating reactive power in networks H02J 3/18; controlling electric generators H02P, e.g. arrangements for controlling electric generators for the purpose of obtaining a desired output H02P 9/00)
- F03D 9/00: Adaptations of wind motors for special use; Combinations of wind motors with apparatus driven thereby; Wind motors specially adapted for installation in particular locations (hybrid wind-photovoltaic energy systems for the generation of electric power H02S 10/12)
- F03D 13/00: Assembly, mounting or commissioning of wind motors; Arrangements specially adapted for transporting wind motor components
- F03D 15/00: Transmission of mechanical power
- F03D 17/00: Monitoring or testing of wind motors, e.g. diagnostics (testing during commissioning of wind motors F03D 13/30)
- F03D 80/00: Details, components or accessories not provided for in groups F03D 1/00-F03D 17/00

In addition, the following IPC codes were also utilized:

- Structural association of electric generator with mechanical driving motor
- IPC code: H02K 7/18 Structural association of electric generators with mechanical driving motors, e.g.with turbines
- Structural aspects of wind turbines
- IPC code: B63B 35/00: Vessels or like floating structures adapted for special purposes
- IPC code: E04H 12/00 Towers; Masts or poles; Chimney stacks; Water-towers; Methods of erecting such structures
- Propulsion of vehicles using wind power
- IPC code: B60K 16/00: Arrangements in connection with power supply of propulsion units in vehicles from force of nature, e.g. sun or wind
- Propulsion of marine vessels by wind-powered motors
- IPC code: B63H 13/00: Effecting propulsion by wind motors driving water-engaging propulsive elements

The definition of patent applicants for 'Tidal and wave energy' is contained in ICP E02B 9/08 "Tide or wave power plants".

In terms of patent activity in the SIA area, PATSTAT does not offer a complete solution for exploring the data at regional level since the geographical (regional) location of applicants and inventors is incomplete (with less than 1% of patents containing this information). Based on information available to Technopolis - via the OECD and REGPAT database- it was possible to calculate the number of patents that included at least one inventor from the SIA area, for the period 2004-2012. The SIA area was broken down by NUTS 3 regions (Table 5). Since a patent can be submitted by applicants/inventors from different countries, Technopolis has applied fractional counting.

NUTS 3 Codes	Place name
UKC11	Hartlepool and Stockton on Tees
UKC12	South Teesside (Middlesborough and Redcar and Cleveland)
UKC13	Darlington

UKC14	Durham
UKC21	Northumberland
UKC22	Tyneside (Newcastle upon Tyne, Gateshead, South Tyneside, North Tyneside)
UKC23	Sunderland
UKD71	East Merseyside (Knowlsey, St Helens and Halton)
UKD72	Liverpool
UKD73	Sefton
UKD74	Wirral
UKE11	Kingston upon Hull
UKE12	East Riding of Yorkshire
UKE13	North and North East Lincolnshire
UKM22	Clackmannanshire and Fife
UKM50	Aberdeen and Aberdeenshire

Table 5: NUTS 3 Regions of the SIA Geography (source: www.ons.gov.uk)

Additional Information, Tables and Figures

Rank	Name	Country	Sector	Total
1	GEN ELECTRIC	US	Company	3500
2	SIEMENS AG	DE	Company	2809
3	VESTAS WIND SYS AS	DK	Company	2643
4	MITSUBISHI HEAVY IND LTD	JP	Company	2035
5	WOBBEN ALOYS	DE	Company	2027
6	WOBBEN PROPERTIES GMBH	DE	Company	1026
7	NORDEX ENERGY GMBH	DE	Company	561
8	SAMSUNG HEAVY IND	KR	Company	558
9	GAMESA INNOVATION & TECH SL	ES	Company	515
10	REPOWER SYSTEMS AG	DE	Company	502
11	LM GLASFIBER AS	DK	Company	418
12	BOSCH GMBH ROBERT	DE	Company	329
13	HITACHI LTD	JP	Company	326
14	STATE GRID CORP CHINA	CN	Company	312
15	DAEWOO SHIPBUILDING & MARINE	KR	Company	295
16	GUODIAN UNITED POWER TECH CO	CN	Company	261
17	SINOVEL WIND GROUP CO LTD	CN	Company	255
18	REPOWER SYSTEMS SE	DE	Company	248
19	NTN TOYO BEARING CO LTD	JP	Company	225
20	GRABAU PETER	DK	Company	217

Rank	Name	Country	Sector	Total
21	SKF AB	SE	Company	216
22	HONDA MOTOR CO LTD	JP	Company	201
23	ENVISION ENERGY DENMARK APS	DK	Company	196
24	ALSTOM WIND SLU	ES	Company	177
25	LM WP PATENT HOLDING AS	DK	Company	173
26	GARCIA JORGE MARTINEZ	DK	Company	169
27	WILIC SARL	LU	Company	162
28	FUJI HEAVY IND LTD	JP	Company	158
29	HANSEN TRANSMISSIONS INT	BE	Company	153
30	FLODESIGN WIND TURBINE CORP	US	Company	153

Table 6: Top 30 International applicants/ inventors (company and universities) in wind energy (source: Technopolis, 2017)

Source: Technopolis, based on PATSTAT, Latest release: Autumn (2016). * Location is not provided in PATSTAT database and added via Google search

Rank	Name	Country	Sector	Total
1	BIOPOWER SYSTEMS PTY LTD	AU	Company	26
2	ATLANTIS RESOURCES CORP PTE	SG	Company	24
3	WATER CROSSING INC	SE	Company	18
4	TIDETEC AS	NO	Company	16
5	ATLANTIS RESOURCES CORP PTE	--	Company	15
6	SUBSEA ENERGY OY	FI	Company	15
7	CETO IP PTY LTD	AU	Company	14
8	OCEANLINX LTD	AU*	Company	14
9	AUSTRALIAN SUSTAINABLE ENERGY	AU*	Company	14
10	BLUE ENERGY CANADA INC	CA	Company	13
11	WELLO OY	FI	Company	11
12	JUPITER HYDRO INC	CA	Company	10
13	SAM AN CORP	KR	Company	9
14	UNIV ROBERT GORDON	GB	University	9
15	CETO IP PTY LTD	AU *	Company	9
16	OCEAN POWER TECHNOLOGIES INC	US	Company	9
17	BAYER MATERIALSCIENCE AG	DE	Company	8
18	VERDERG LTD	GB	Company	7
19	COPPE UFRJ	BR	University	7
20	VOITH PATENT GMBH	DE	Company	7
21	PROTEAN POWER PTY LTD	AU *	Company	7
22	PROTEAN ENERGY AUSTRALIA PTY LTD	AU*	Company	6
23	WAVE STAR ENERGY APS	DK*	Company	6
24	WAVE ENERGY AS	NO	Company	6
25	AW ENERGY OY	FI	Company	6
26	OCEAN HARVESTING TECHNOLOGIES AB	SE	Company	5
27	TIDAL ENERGY LTD	GB	Company	5
28	KOREA WATER RESOURCES CORP	KR	Company	5
29	AUSTRALIAN SUSTAINABLE ENERGY CORP PTY LTD	AU	Company	5

Table 7: International applicants/ inventors (companies and universities) in wave and tidal energy (source: Technopolis, 2017)

Source: Technopolis, based on PATSTAT, Latest release: Autumn (2016). * Country not provided in PATSTAT database and added via Google search

Rank	Name	Sector	Total	Location*	Notes
1	ATLANTIS RESOURCES CORP PTE*	Company	15	Edinburgh	
2	ROBERT GORDON UNIV ABERDEEN	University	9	Aberdeen	
3	VERDERG LTD	Company	7	Kingston upon Thames	
4	TIDAL ENERGY LTD	Company	5	Cardiff	in administration
5	SUSTAINABLE MARINE ENERGY LTD	Company	3	Edinburgh	
6	REH INTELLECTUAL PROPERTY LTD	Company	2	Isle of Man	
7	TIDAL GENERATION LTD	Company	2	Bristol	
8	SUSTAINABLE MARINE TECHNOLOGIES LTD	Company	2	London	dissolved
9	TIDALSTREAM LTD	Company	2	Southam	
10	INTELLIGENT ORGANICS LTD	Company	2	Edinburgh	
11	MARINE CURRENT TURBINES LTD	Company	1	Bristol	
12	DARTMOUTH WAVE ENERGY LTD	Company	1	Cornwall	
13	ENGINEERING BUSINESS LTD	Company	1	Northumberland	
14	Trident Energy Ltd.	Company	1	Cambridge/Suffolk	NR32 2TE
15	UNIV NOTTINGHAM	University	1	Nottingham	
16	C-WAVE LTD	Company	1	London	
17	ANDRITZ HYDRO HAMMERFEST UK LTD	Company	1	Glasgow	

Table 8: UK applicants/ inventors (companies and universities) in wave and tidal energy (source: Technopolis, 2017)

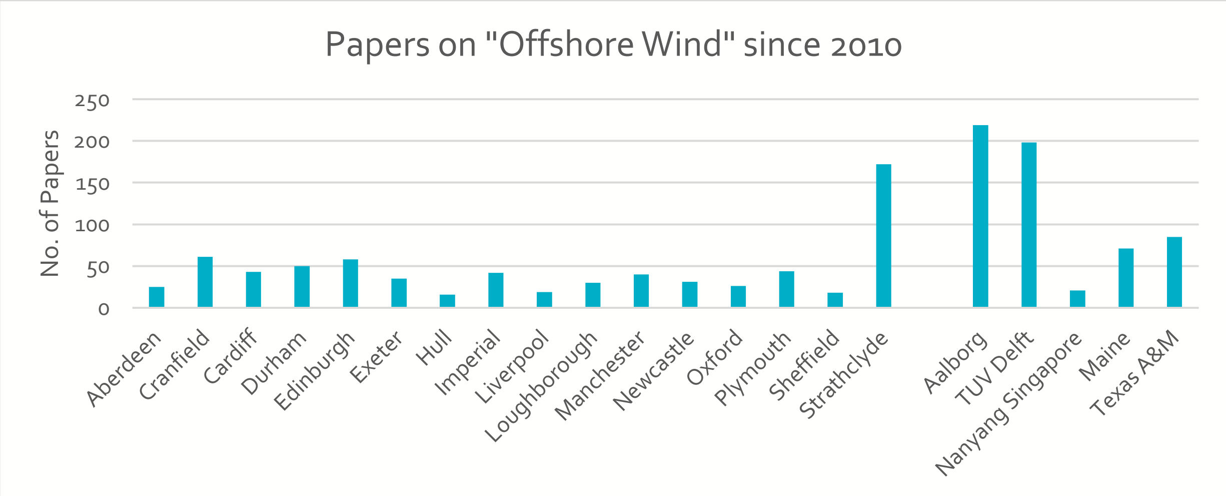
Rank	Name	Sector	Total	Location*
1	ROMAX TECHNOLOGY LTD	Company	75	Nottingham
2	BLADE DYNAMICS LTD	Company	65	Hampshire
3	ROLLS ROYCE PLC	Company	61	London
4	ARTEMIS INTELLIGENT POWER LTD	Company	30	Loanhead (Edinburgh)
5	PAPPALA VENKATA	Company	30	Not found
6	ITI SCOTLAND LTD	Company	27	Ayr (Glasgow)
7	GE ENERGY POWER CONVERSION TECHNOLOGY LTD	Company	26	Cheshire
8	MARINE CURRENT TURBINES LTD	Company	22	London
9	LIBERTINE FPE LTD	Company	21	Oxfordshire
10	QINETIQ LTD	Company	20	Hampshire
11	ORBITAL2 LTD	Company	20	Warwickshire
12	CONVERTEAM TECHNOLOGY LTD	Company	19	Warwickshire
13	CONDOR WIND ENERGY LTD	Company	19	London
14	ENGINEERING BUSINESS LTD	Company	18	Northumberland
15	INSENSYS LTD	Company	17	Hampshire
16	INTEC POWER SYSTEMS LTD	Company	17	Hampshire
17	CROSS FLOW ENERGY COMPANY LTD	Company	17	Port Talbot (Swansea)
18	FREEPOWER LTD	Company	16	Southampton
19	FREEPLAY MARKET DEV LTD	Company	16	London
20	ORBITAL 2 LTD	Company	15	Warwickshire
21	ARTER TECHNOLOGY LTD	Company	15	Guernsey
22	RICARDO UK LTD	Company	14	West Sussex
23	COCKERILL SAM	Company	14	York
24	RENEWABLE DEVICES SWIFT TURBINES LTD	Company	13	Edinburgh
25	ISIS INNOVATION	University	13	Oxford
26	IHC ENGINEERING BUSINESS LTD	Company	12	Northumberland
27	CONVERTEAM LTD	Company	12	Warwickshire
28	TTL DYNAMICS LTD	Company	12	Hampshire
29	UNIV SOUTHAMPTON	University	11	Southampton
30	EVOLVING GENERATION LTD	Company	11	Not found

Table 9: UK applicants/ inventors (companies and universities) in wave and tidal energy (source: Technopolis, 2017)

Source: Technopolis, based on PATSTAT, Latest release: Autumn (2016). * Location is not provided in PATSTAT database and added via Google search

Appendix 2 UK Research on Offshore Renewable Energy

As part of the SIA, a detailed analysis of the quantity and quality of UK research on offshore renewable energy was performed using the Scopus database. The graphs below show the quantity and quality (as measured by citations per paper) of research from the leading UK Universities in these research fields alongside leading international competitors:



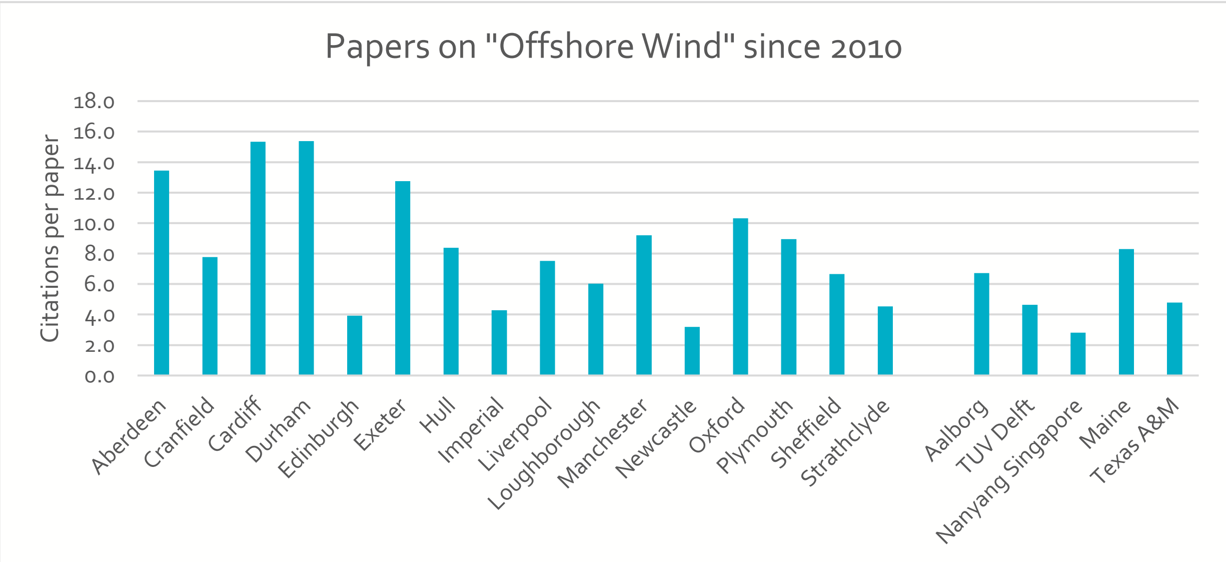
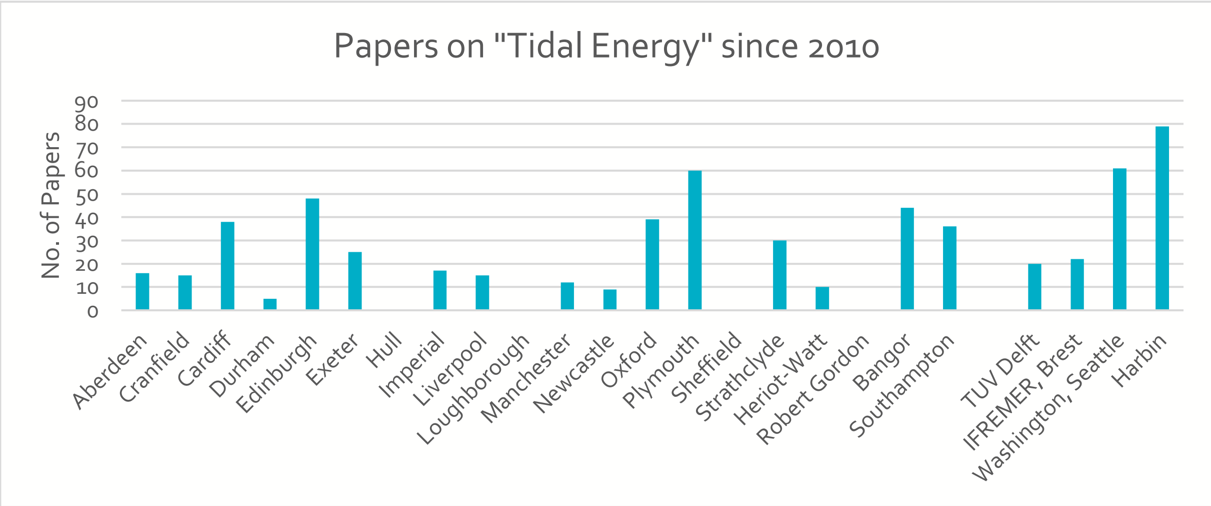


Figure 32: graphs showing a) total publications (top figure) and b) citations per paper (bottom figure) on offshore wind across leading UK and international Universities (source: SCOPUS database)



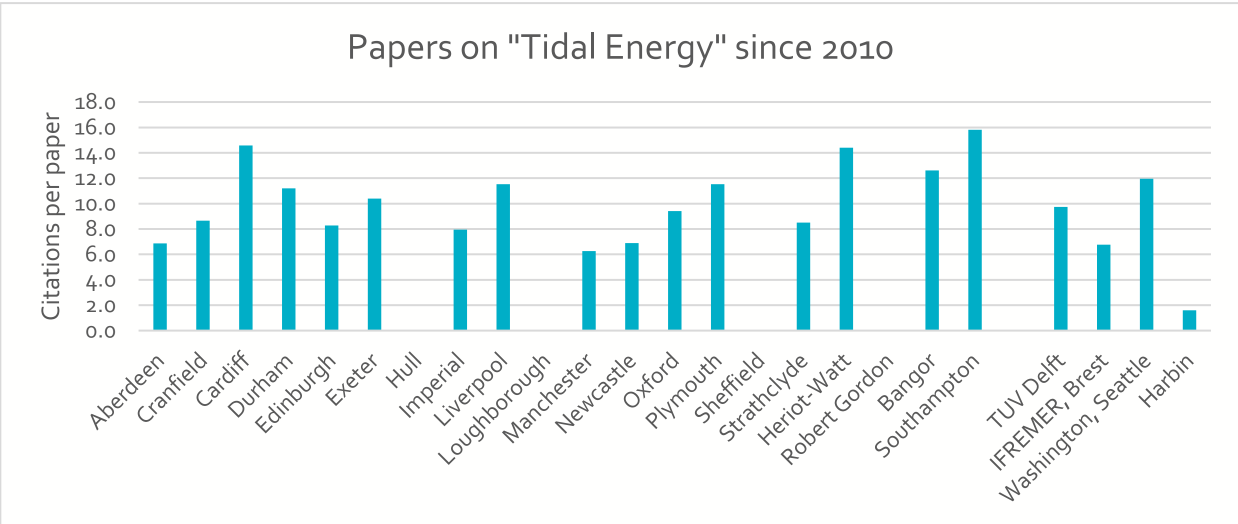
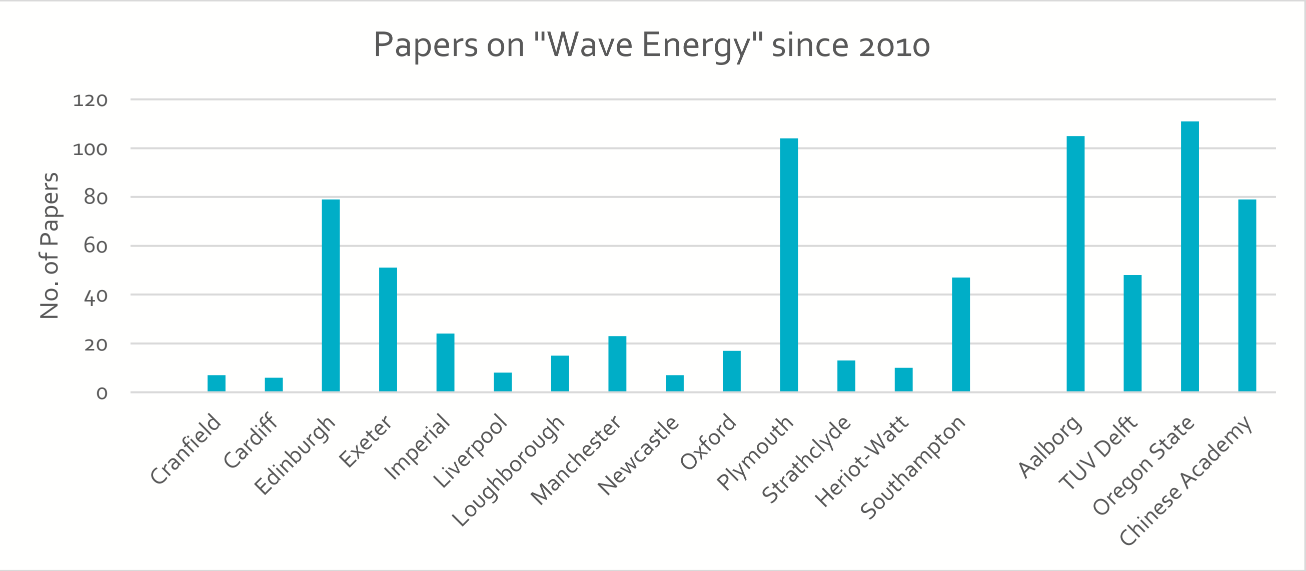


Figure 33: graphs showing a) total publications (top figure) and b) citations per paper (bottom figure) on Tidal Energy across leading UK and international Universities (source: SCOPUS database)



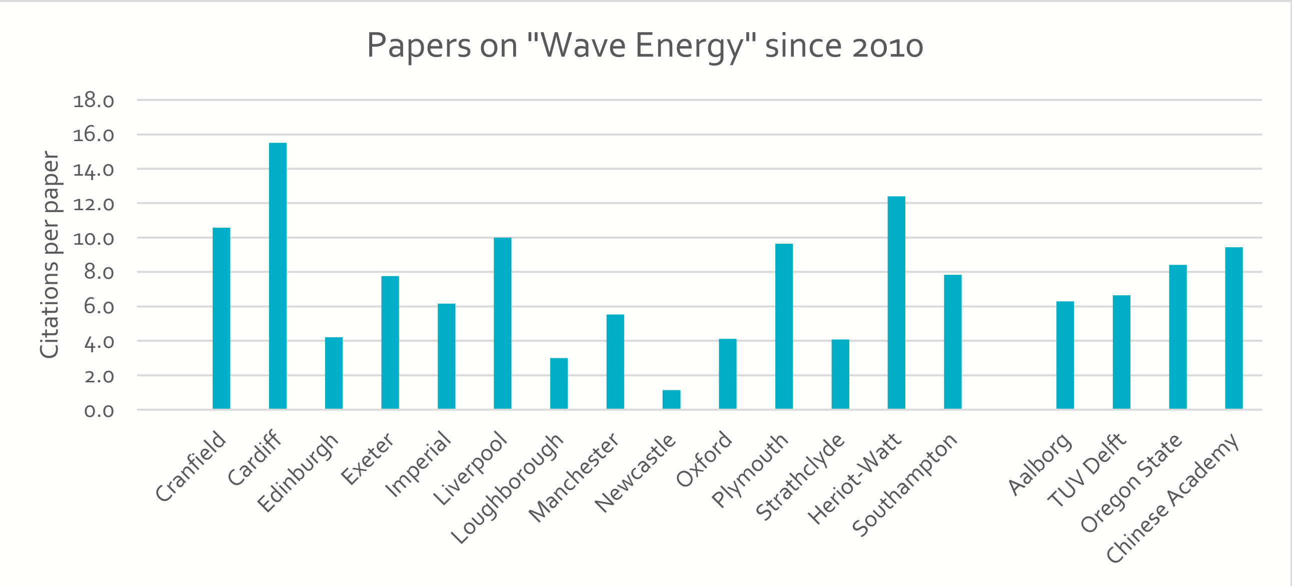


Figure 34: graphs showing a) total publications (top figure) and b) citations per paper (bottom figure) on Wave Energy across leading UK and international Universities (source: SCOPUS database)

Appendix 3 Wave and Tidal Energy Innovation Challenges and International Development

Tidal Stream

There are six principal types of tidal energy converter - horizontal axis turbines, vertical axis turbines, oscillating hydrofoils, venturi devices, Archimedes screws and tidal kites. The sector has initially consolidated on 3 bladed horizontal axis turbines, which are approaching commercial readiness. Outliers include Kepler's Transverse Horizontal Axis Water Turbine (THAWT) design, Jupiter Hydro Inc Archimedes screw design and Minesto's Deep Green tidal kite.

The tidal energy sector still faces major challenges, including:

- Determining the optimum platform design to harvest tidal energy.
- Fully understanding how to design, build and operate reliably within a hostile sub-sea environment.
- How to significantly reduce costs.

Whilst the UK leads the way with the first commercial tidal stream array at Pentland Firth, Scotland, being developed by MeyGen, markets are emerging in the UK, France, Canada and Asia-Pacific, the funding for tidal energy projects and first arrays is dependent upon public and private investor confidence in technology performance and developers' ability to demonstrate they have identified a clear path to commercialisation.

Several studies have agreed that significant tidal deployment will not occur until post-2020. To be competitive, tidal energy will need to demonstrate that it can align itself with the cost reduction glide path set for offshore wind. This is ambitious for a new technology and would be achievable only with significant innovation.

The UK's tidal power resource is estimated to be more than 10 GW, representing about 50 percent of Europe's tidal energy capacity. 25 percent of Europe's tidal energy potential resources come from Scotland.

Another important element of cost reduction is capacity roll out. So while the UK has taken the important first step towards tidal stream generation with construction work now underway on the MeyGen first array project in Pentland Firth, other market opportunities are emerging in France, Canada and across a number of countries in the Asia-Pacific.

Existing developments

Today there is almost 4.3 MW of commercial tidal stream installed capacity and until recently the largest two plants were at the Uldolmok Tidal Power Station in South Korea and MCT's SeaGen twin device installation in Strangford Lough, Northern Ireland. A further 10.5 MW of commercial capacity is under construction across four projects, all of which incorporate horizontal axis-turbines. The largest is the 6

MW MeyGen, the world's first commercial tidal stream array, located in Pentland Firth, north of Caithness in Scotland. Phase 1 of the project will incorporate three Andritz Hydro Hammerfest HS1500 turbines and one Lockheed Martin-designed Atlantis AR1500 turbine which was installed in 2016. By the early 2020s MeyGen Limited intends to deploy up to 398MW of offshore tidal stream turbines to supply clean and renewable electricity to the UK National Grid.

The second is the 4 MW Cape Sharp project in the Bay of Fundy, Canada that will incorporate two 2 MW OpenHydro turbines. The third is the Shetland Tidal Array where Nova Innovation has recently commissioned the second of three 100 kW devices targeting a community ownership model, with a view to deploy two more. The fourth scheme is a single 0.5 MW device deployed by Sabella in Brittany, France.

Numerous pre-commercial demonstration projects are also underway. One of the largest is DCNS/Open Hydro's project at Paimpol Bréhat in France incorporating two 0.5 MW ducted turbine devices, the first of which has now been deployed. The largest capacity tidal stream device developed to date has also recently been deployed at EMEC, namely ScotRenewables' 2 MW (twin turbine) SR2000 M1 full scale prototype. They have also recently won €10m via the EU development fund Horizon2020 to construct and deploy a second generation SR2000 device to be deployed in parallel to the first at EMEC over the next year. Other notable projects include Bluewater's pilot 200kW BlueTEC device in the Netherlands, as well as the numerous projects underway in both Canada (and specifically the FORCE test site) and South Korea.

Future developments

China has abundant resources of tidal power with more than 18.000 kilometres of mainland coastline and more than 14.000 kilometres of island coastline, with an estimated tidal power capacity of 3.5 GW according to the China Ocean Energy Resources Division.

Australia and New Zealand have large ocean energy resources but do not yet generate any power from them. Other territories with significant tidal power potential include North America, Argentina, Russia, France, India and South Korea.

At present planning consent has been granted for 44 MW of installed capacity with consent having been applied for a further 42 MW of capacity. Atlantis has shelved two major UK schemes including the 10 MW Anglesey Skerries array in Wales and the 8 MW Kyle Rhea array in Scotland to focus on its MeyGen project. Following the deployment of Phase 1A (4 turbines) it will look to deliver Phase 1B that will deliver a total of 86 MW installed peak capacity followed by Phase 2 will raise the total capacity to 398 MW.

The first signs of tidal markets developing are in France, Canada and Asia Pacific (South Korea, Australia, and China). The two most significant markets to rival the UK are currently France and Canada.

France

The French marine energy industry has until recently lagged behind the UK. With a series of technical challenges and limited public confidence, marine energy has for several years struggled to get established. However, the fact that France harbours up to a fifth of Europe's marine energy potential of

15GW, and strong government support over recent years means that it is a now becoming a serious player on the international renewables stage. Its two large projects are both in northern France, the Normandie Hydro project, a 5.6 MW 4 device scheme led by General Electric (2017) and the Raz Blanchard project, a 7 device 14 MW scheme led by OpenHydro (2018). Several prototypes of tidal power devices are currently being tested in France, including the D10 tidal turbine of French Sabella and OpenHydro's 1 MW turbine off the coast of Brittany.

France's multiyear programme for energy investments calls for at least 70 GW of renewables capacity by 2023. Marine energies, including floating wind and tidal power are supposed to contribute at least 100 MW.

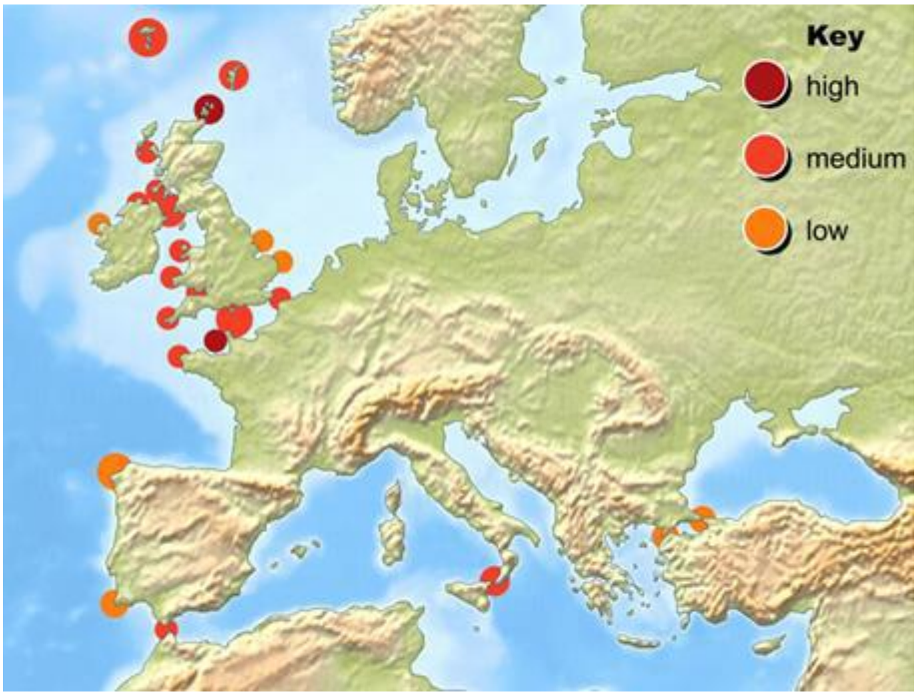


Figure 35: EUROPEAN TIDAL STREAM RESOURCE DISTRIBUTION (source: AQUARET 2012)

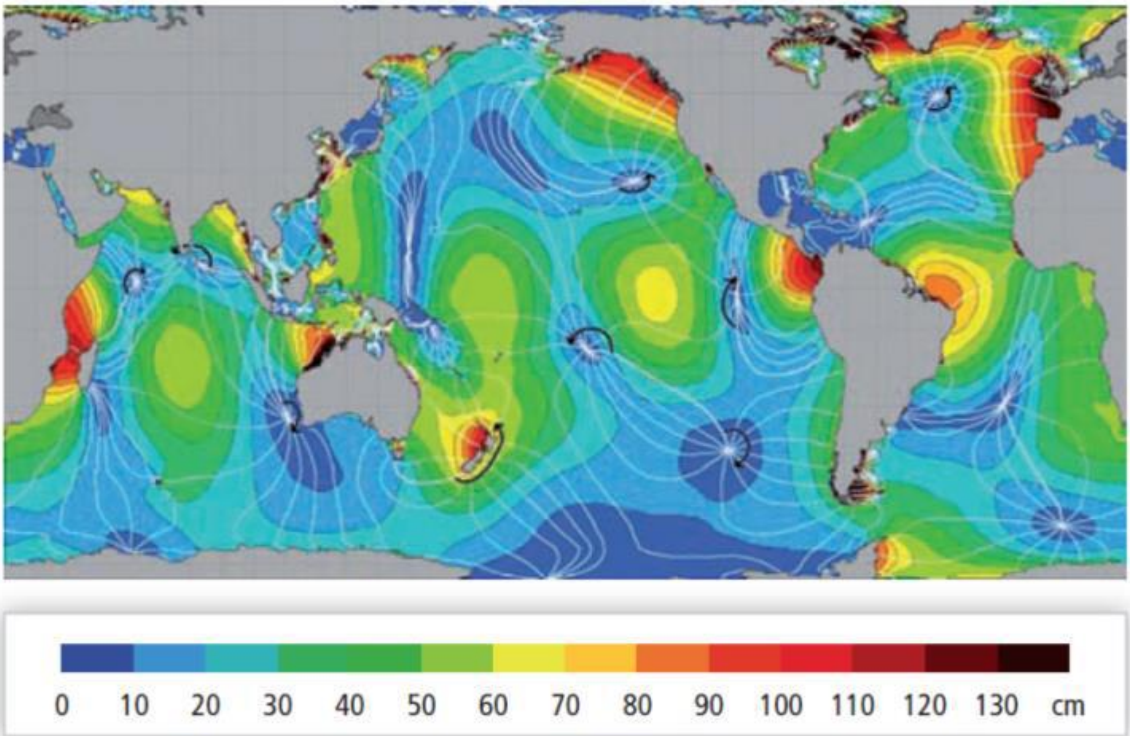


Figure 36: GLOBAL SEMIDIURNAL (M2) TIDAL AMPLITUDE (source: Cartwright, David Edgar (2000). Tides: A Scientific History. Cambridge University Press. p. 243. ISBN 978-0-521-79746-7)

Canada

Tidal stream activities in Canada are focused through the Fundy Ocean Research Centre for Energy (FORCE), incorporated in 2009 as a not for profit corporation with two roles. The first was to operate a tidal turbine demonstration facility; and the second was to enable public and private research into tidal energy extraction and its effects.

FORCE has installed four cables laid along the sea floor of the Minas Passage allowing the largest transmission capacity for tidal power in the world. With a combined length of 11 kilometres, the four 34.5kV cables have a total capacity of 64 megawatts, equivalent to the power needs of 20,000 homes at peak tidal flows. This subsea infrastructure will allow small turbine arrays to connect to the grid.

Four FORCE developers have received approval through the developmental feed-in tariff programme for a total of 17.5 megawatts of electricity: Minas Energy, 4 megawatts (MW); Black Rock Tidal Power, 5 MW; Atlantis Operations Canada, 4.5 MW; and Cape Sharp Tidal Venture, 4 MW. This approval allows the developers to enter into a 15-year power purchase agreement with Nova Scotia Power. Both OpenHydro and Black Rock Tidal Power have opened offices in Nova Scotia and begun hiring staff. OpenHydro has completed installation and testing of its initial device.

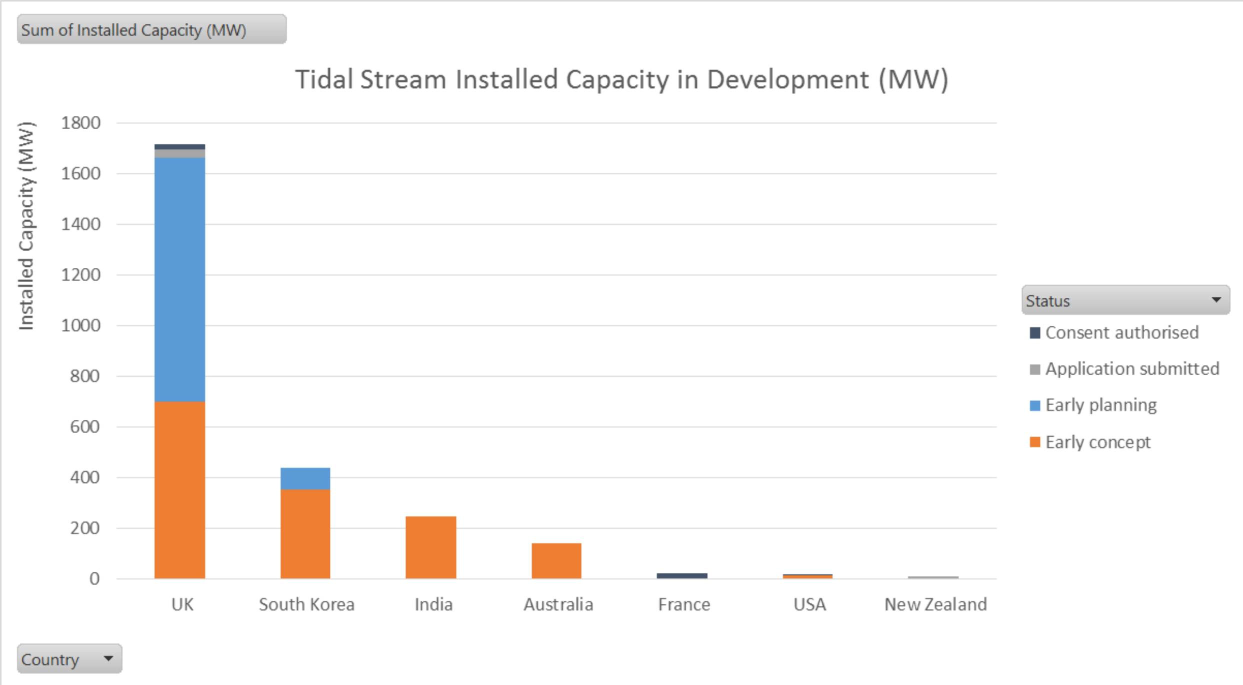


Figure 37: Tidal Stream installed capacity in development (MW) (source: © World Energy Council, World Energy Resources – Marine Energy 2016)

Tidal Range

The world's first large-scale tidal range power plant was the la Rance Tidal Power Station (240 MW) that became operational in 1966 in Brittany, France and is still operational today. Subsequent major projects included were the 20 MW Annapolis Royale plant in Canada installed in 1982 and the 254 MW Sihwa tidal plant in South Korea. An important development demonstrating confidence in the turbine technology was the upgrade of China's Jiangxia turbine capacity in the 1980s from 3.9 MW to 4.1 MW.

Existing developments

Today there is approximately 521 MW of tidal range capacity worldwide with another 1.7 GW under construction. At present there are two large tidal range projects under construction, both in the South Korean Yellow Sea: The Incheon Tidal Power Plant (1.3 GW) and Saemangeum Reclamation Project (0.4 GW). Together these projects will more than triple existing capacity.

Future developments

Over 13.7 GW of tidal range is currently planned for deployment, however only 0.7 GW of this has received consent. Major projects include the 0.42 GW Ganghwa Tidal plant consented in the East China Sea, South

Korea and the 240MW Turnagain Arm Tidal Electric Generation Project in the Kenai Peninsula, US. There is approximately 10.7GW of non-consented projects in the global pipeline with 0.32 GW under consideration for planning, with 2.8 GW at the early planning stage and over 7.6 GW at the early concept stage.

The UK leads with over 6.7 GW of non-consented planned capacity, with major tidal lagoons proposed at Swansea, Newport, Bridgewater and Cardiff. The economics of the Swansea Bay Tidal Lagoon project (320MW), and the broader rationale for tidal power in the UK was considered by the Government's Hendry Enquiry. The way forward for Swansea Bay is subject to further negotiation between the operator Tidal Lagoon Power and BEIS. These projects face a wide-range of issues and will have to overcome major political, socio-economic and environmental obstacles if they are to come to fruition. South Korea is also planning to bolster their already significant capacity with another 2 GW, with projects in both the East China and Yellow Seas, whilst Canada continues to develop its 1.1 GW Scots Bay project in the Bay of Fundy.

Tidal range's main challenge is not the power producing technologies per se, but rather how the individual aspects to build and operate the project fit together and the overall economics of upfront capital expense and long-term payback of up to fifty years. There are also consenting challenges that require innovative approaches to facilitate project development.

Wave Energy

Wave energy technology developers face a number of significant challenges in the journey towards commercialisation. The industry is still in pre-commercial development, with little evidence of design convergence, or standardisation. The wide variety of bespoke wave energy solutions that are emerging are more costly to develop, compared to those within the wind and tidal sectors where standard generic components are deployed.

By 2050, the International Energy Agency estimates that globally, up to 240GW of marine capacity could be deployed, with about 75% coming from wave energy. Energy Technologies Institute (ETI) Offshore Renewables: 2015 Insights report estimates that successful commercial development of wave and tidal energy technology could exploit a global market potential of up to £8 billion. A significant proportion – up to 10% – of predicted UK electricity demand could be fulfilled, if the technology is affordable.

Energy from wave is abundant, clean and secure. The UK and Scotland in particular, has some of the best wave resource in the world. The Crown Estate in their UK Wave and Tidal Key Resource Areas Project-Summary Report, 2012, estimated the resource at 27GW, equating to around 12% of the UKs projected electricity demand in 2050. The Low Carbon Innovation Coordination Group (now replaced by the Energy Innovation Board) has estimated the current cost for wave is of the order £250-400/MWh with little prospect for achieving commercial parity with other low carbon systems until late into the 2020s. Wave technology developers struggle, not only to attract public and private sector investment but, as first movers, are burdened with the development of both enabling technologies and components for first arrays. Wave energy converters (WECs) have progressed significantly over the last decade, from scaled testing to full-scale prototypes. Field demonstrations have shown the importance of further research and innovation focusing on subsystems and components with an increasing number of innovative concepts. Grid connected wave arrays have been operated successfully off the coast of Portugal and Australia. Single devices have operated successfully in Orkney.

A minimum of 10MW of full-scale wave energy converter prototypes should be deployed by 2020. The learnings from this phase will allow the development of whole wave energy systems through improvements of sub-systems and components. Subsequently, the most promising consolidated concepts should be demonstrated in farms for a total of a further 100MW by the late 2020's.

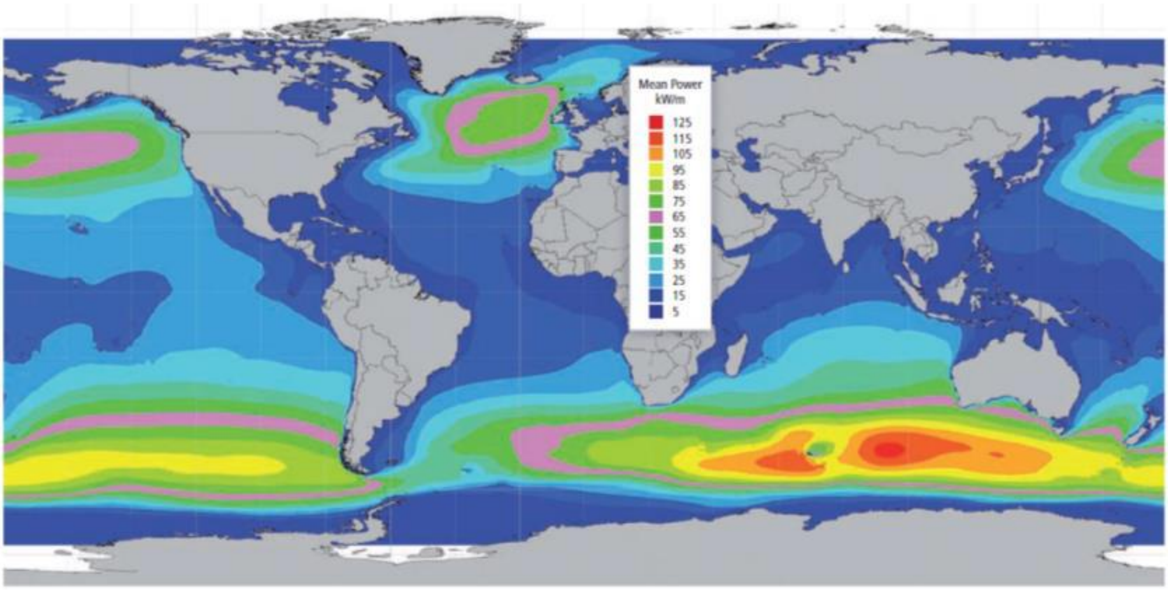


Figure 38: Global Offshore Annual Wave Power Level Distribution (source: World Energy Council World Energy Resources Marine Energy 2016)

Existing developments

Although the marine energy market, and particularly wave energy, has not progressed as quickly as some had hoped the UK has invested in infrastructure for innovation that is in demand from global technology developers such as Carnegie, Fred Olson, G-wave and Wello who are backed by overseas public programmes and private venture funds. After the loss of Pelamis and Aquamarine Power, the Scottish Government recently established Wave Energy Scotland that has a budget of £15m for the foreseeable future. Unlike previous UK wave energy RD&D funding schemes, this offers 100% funding throughout procurement, negating the needs to rely on difficult to secure match funding from the private sector. It also incorporates a strong focus on developing commercial sub-components prior to commercial device, as well as a clear 'stage-gating' approach that demands concepts meet stringent criteria before being eligible for further funding and finally, a much stronger focus on collaboration via a requirement for consortia.

ORE Catapult provides world class test rig development capability and expertise to support the testing of wave device power take offs, development and testing of sub-systems and components using a mix of laboratory facilities and sea water docks.

Sweden's Seabased has begun construction of the world's largest commercial wave energy array at Sotenas. It will incorporate 42 devices and deliver 1.05 MW of capacity. They have also recently installed a second project in Ghana consisting of 6 devices, together providing 400 kW of capacity. A host of pre-commercial demonstration projects are also underway and one of the highest profile has been in Australia where Carnegie has demonstrated 3 of its CETO 5 devices rated at 240 kW off Garden Island and is now planning to build its 1st CETO6 1MW device in the UK and deploy the device at the WaveHub test site in Cornwall. Numerous other demonstration projects are taking place across the UK, Canada, Denmark, Korea, Spain and the United States among others.

Future developments

In total, 838 MW of wave energy projects are currently at different stages of development, however only 20 MW of this has received authorised consent relating to a project at Mermaid/Bligh Bank in Belgium. In addition, there is 94 MW at the early planning and 725 MW at the early concept stage. Importantly a second phase of both Seabased's projects in Sweden and Ghana are at an early planning stage and will be contingent on the performance of the first phase. The former delivering a further 378 devices and 9.5 MW of capacity, with the second delivering a further 560 devices and 14 MW of capacity. Portugal's 5.6 MW SWELL project north of Peniche Peninsula is also at the early planning stage and will consist of sixteen 350 kW oscillating Wave Surge Converters.

At the early concept stage are Ocean Power Technologies' three major commercial projects in Australia equating to almost 100 MW, whilst AWS Ocean Energy have proposed a two phase project in the north of Scotland, the first phase would be for 4 devices (10 MW) and 67 European the second for 76 devices (190 MW).

At a pre-commercial stage, the UK is looking to take the lead once more with a number of major projects in development at the UK's WaveHub including a 10-15 MW array of Carnegie CETO 6 devices, a 10 MW array of Fortum devices and the 4 MW American GWave device.

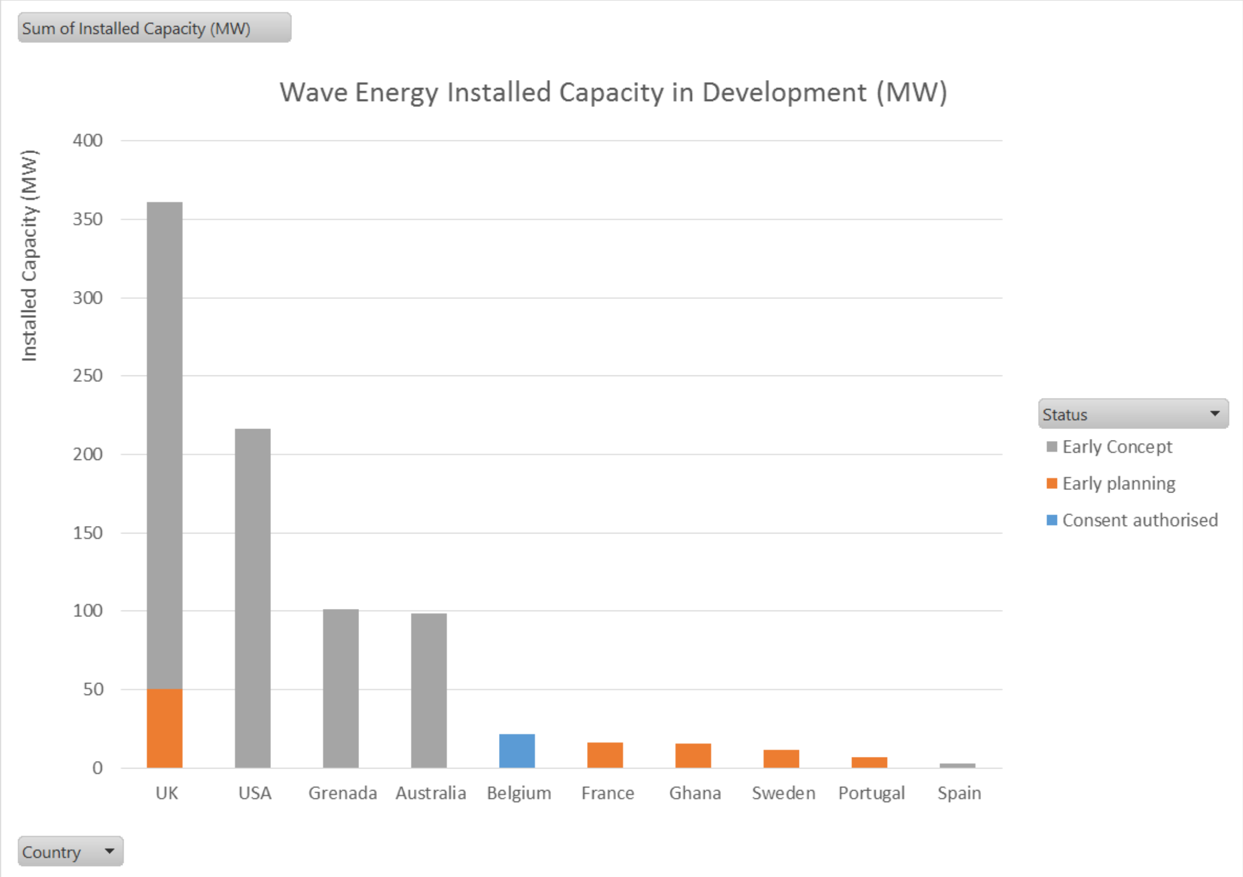


Figure 39: Wave Energy Installed Capacity (MW) (source: © World Energy Council, World Energy Resources – Marine Energy 2016)

Supply Chain

One of the major challenges facing wave and tidal energy is the under-development of its supply chain and its lacks of capacity to scale up deployment to capture the economies of scale necessary to drive down LCOE. For example, many of the current companies involved in the 'fabrication, assembly and installation of prototypes will not always have the capabilities or resource to scale-up production and deliver the value engineering required for mass deployment'. Proposed solutions involve the entry of Original Equipment Manufacturers (OEMs) who can bring the necessary expertise, finances and specialist facilities to accelerate technology development, as well as 'piggy-backing' on the closely related offshore oil, gas and wind industries that possess many of the required expertise (e.g. subsea array and export cables, support vessels etc.) but also sectors like aerospace and shipping with regards to large-scale device manufacture and survivability. Even so, each ocean energy technology presents specific supply-chain requirements making the development of a satisfactory ocean energy supply chain more complex and multifaceted. A related issue is the lack of the skills required for each of these supply chain components to function with a recent study by RenewableUK identifying that across the wind and marine energy sectors, employers reported difficulty in filling vacancies for 42% of listed jobs between 2011 and 2013.

The Northern Powerhouse is pivotal to building up the UK's supply chain capability. The North East has a strong history of subsea engineering skills. These are now transferring to wave and tidal, leveraging from the Oil & Gas market. Scottish Enterprise continues to provide attractive incentives to attract marine energy businesses to Scotland and provides business growth funding for resident organisations.

Infrastructure

While deployment of wave and tidal energy is relatively low, infrastructural constraints do not pose a huge obstacle to market development at present as test centres (e.g. Falmouth Bay test site, European Marine Energy Centre (EMEC), WaveHub, FORCE etc.) offer the necessary infrastructure for developers to test their devices. However, as deployment ramps up infrastructural capacity will be critical. The first issue is the site infrastructure required, such as a subsea electrical system, submarine cable connection, foundations, moorings etc. The second is grid infrastructure, i.e. the necessary grid connection and capacity to transfer the generated electricity to its market. This is often an obstacle as the best resource, particularly wave is often located in remote and sparsely populated areas. The third is port infrastructure to provide necessary offshore operations and maintenance services, such as ships, dry-dock facilities, lay apart areas.

The Northern Powerhouse and Scotland provide many elements of the UK's key infrastructure for marine energy, with deep water ports in Aberdeen, Hull, Liverpool and Newcastle all of which have been subject to significant redevelopment particularly driven by emerging offshore wind requirements. These facilities are equally suitable for tidal stream and wave energy.

Appendix 4 Selected Regional Supply Chain Mapping

Scottish Enterprise has provided a heat map of companies engaged either as core or peripharal business in offshore renewable energy activity in Scotland.

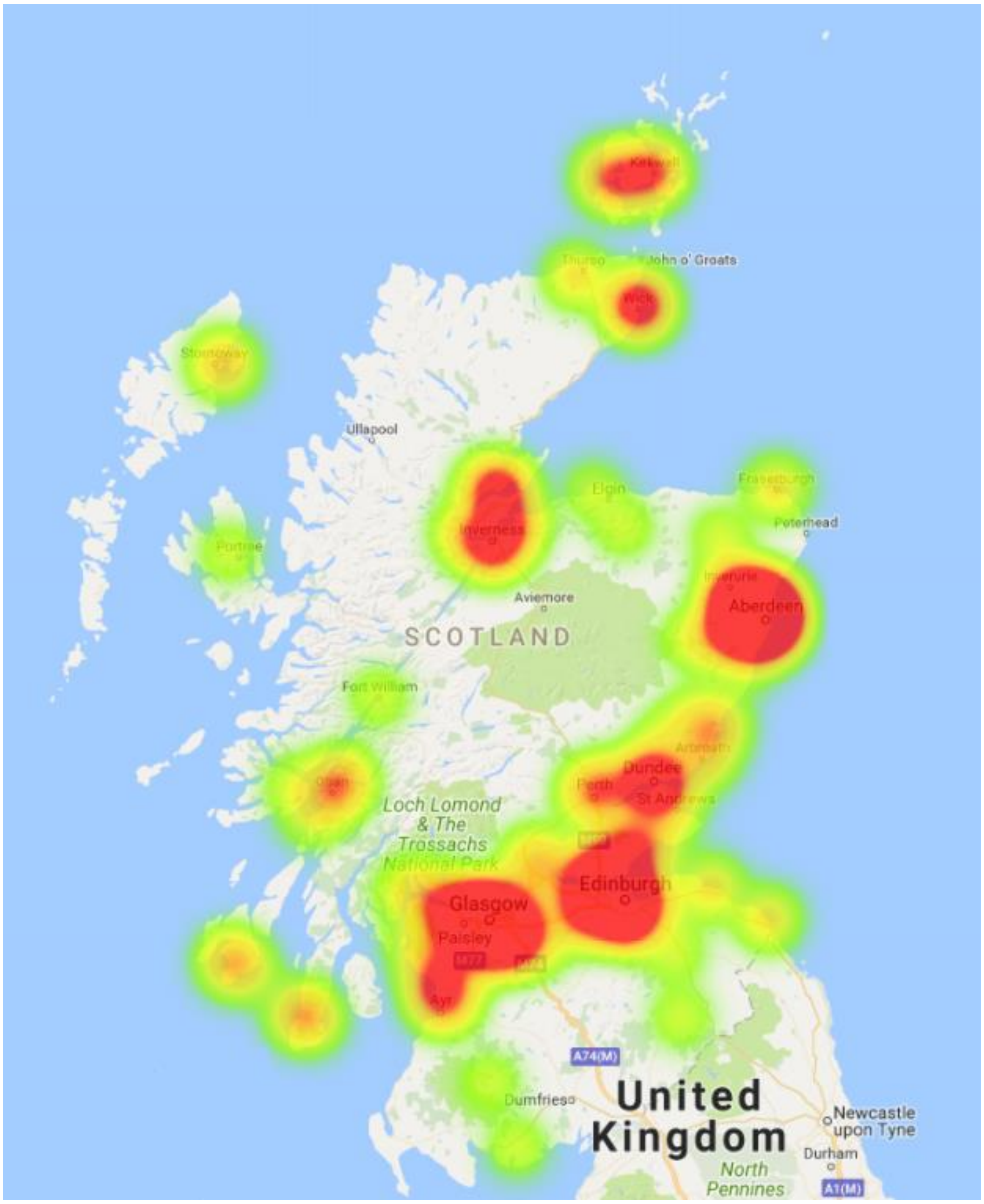


Figure 40: Scotland supply chain heat map (source: Scottish Enterprise, 2017)

The North East LEP has provided further granularity on the spatial landscapoe relevant to offshore renewable energy in the region.

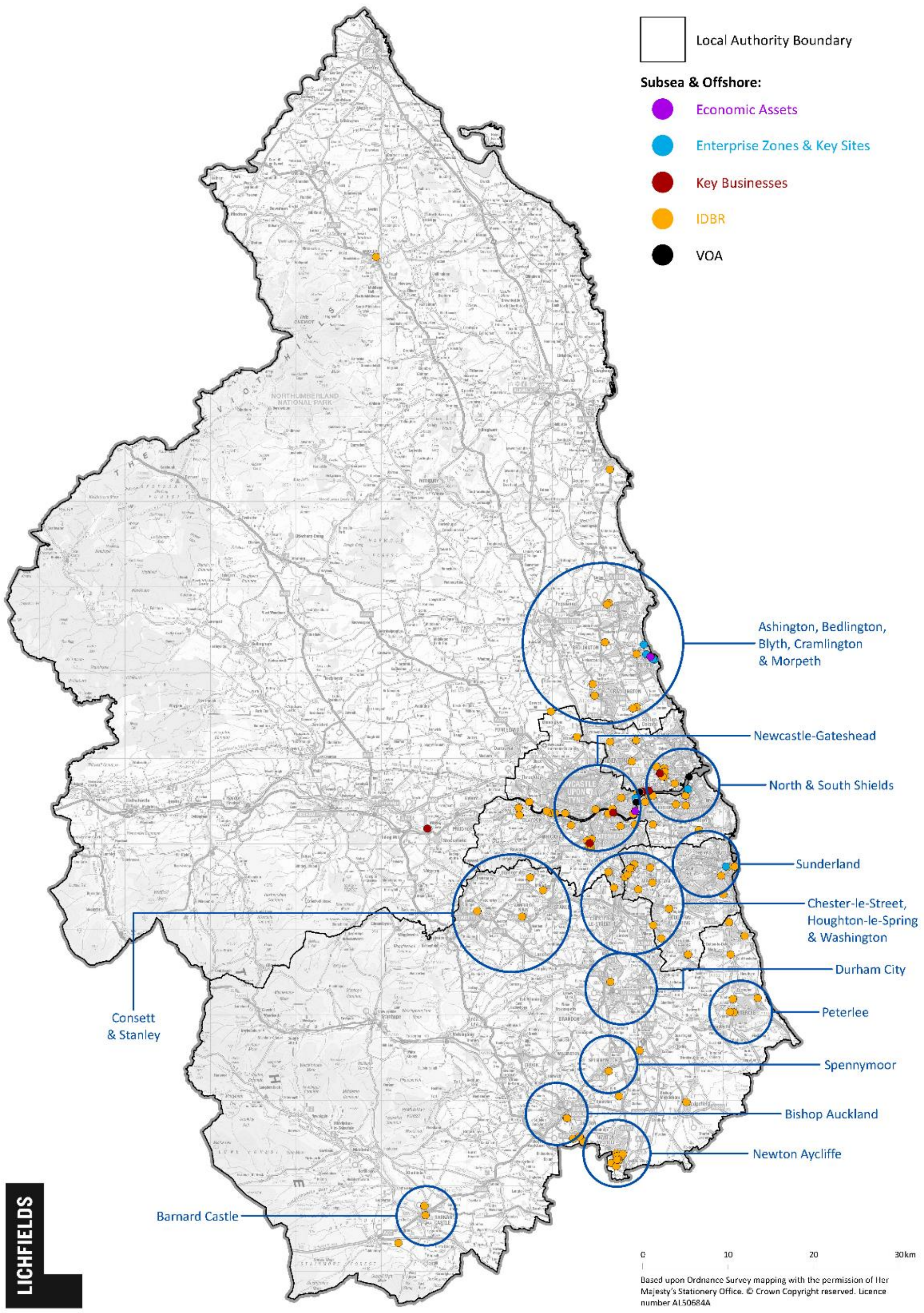


Figure 41: North East LEP offshore renewable energy landscape (source: North East LEP)

North East LEP has also provided a spatial representation of employment in sectors relevant to offshore renewable energy.

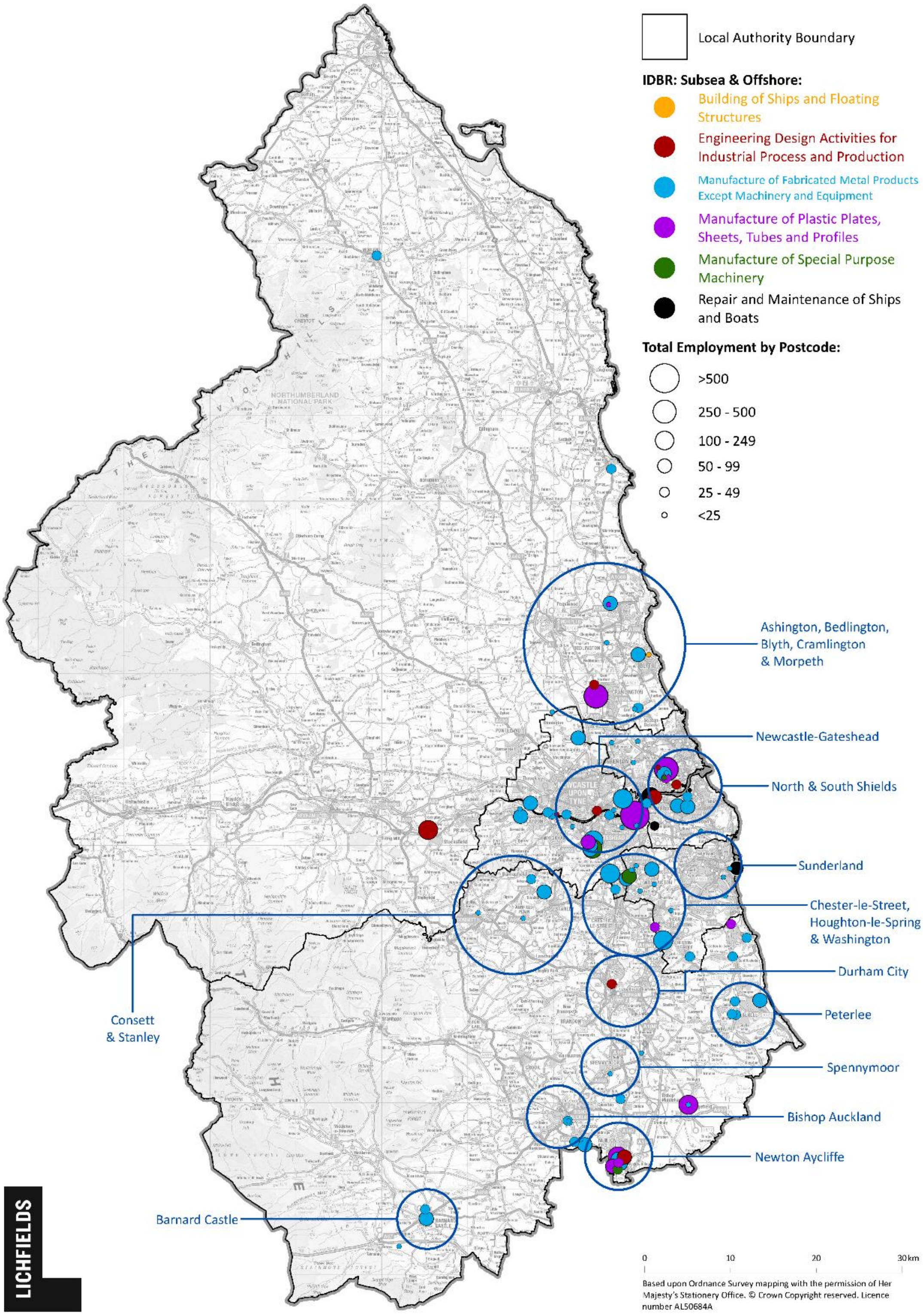


Figure 42: North East LEP sector employment (source: North East LEP)

Appendix 5 Skills Data

Key notes on data sourcing:

Data for future employment and skills needs forecasts are sourced from the UKCES Working Futures, available at https://www.gov.uk/government/publications/uk-labour-market-projections-2014-to-2024.

Geographies selected: North East, North West, Scotland, Yorkshire and Humber.

The lowest geography that the data is available for is region. Whilst all of the North East and all of Scotland is included in the SIA, it is worth noting that Liverpool City Region and Hull only account for a small proportion of their respective regions.

Industries selected: Electricity and Gas, Engineering, Mining and quarrying (includes oil) and Rest of manufacturing

The sectors included are broader than offshore.

UKCES recommends a minimum of 10,000 individuals in a cell before publishing and we have used this to help determine what charts can be drawn in broad terms.

We have applied the 10,000 rule to the underlying data rather than the change (i.e. if 12,000 were employed in 2014 and projected to be 11,000 employed in 2024 we have included – but the change shown on the chart will only be 1,000).

If there are one or two figures within a chart that are below 10,000 but the majority are above, we have included. For example, in the employment breakdown figures, there are few employees in 'caring, leisure and other service' – but we have included for completeness. Similarly, mining and quarrying (as it is concentrated in NE Scotland) has less than 10,000 employed in other regions.

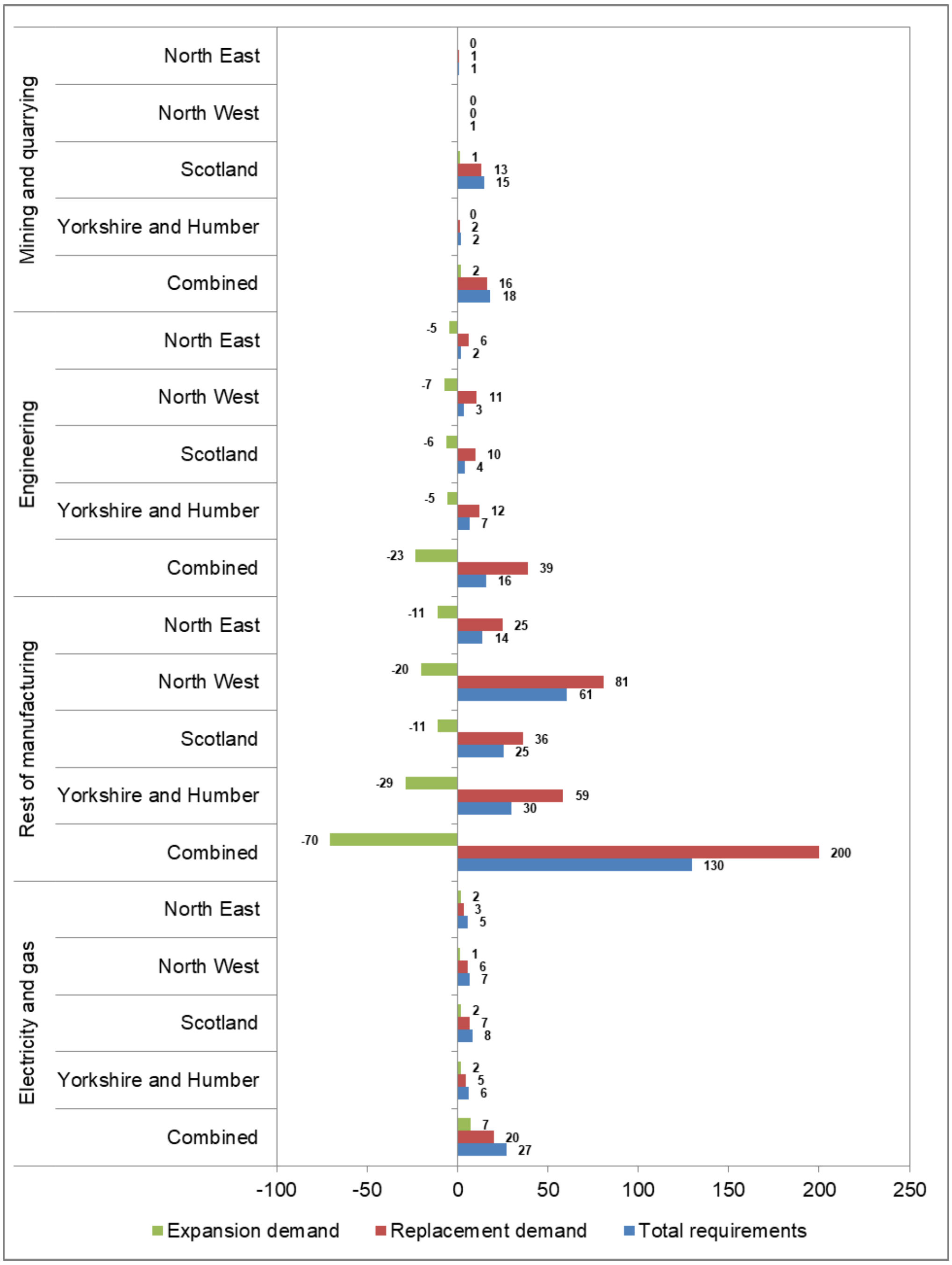


Figure 43: Job openings in offshore-related sectors, various regions, 2014-2024 (source: UKCES Working Futures 2014 – 2024)

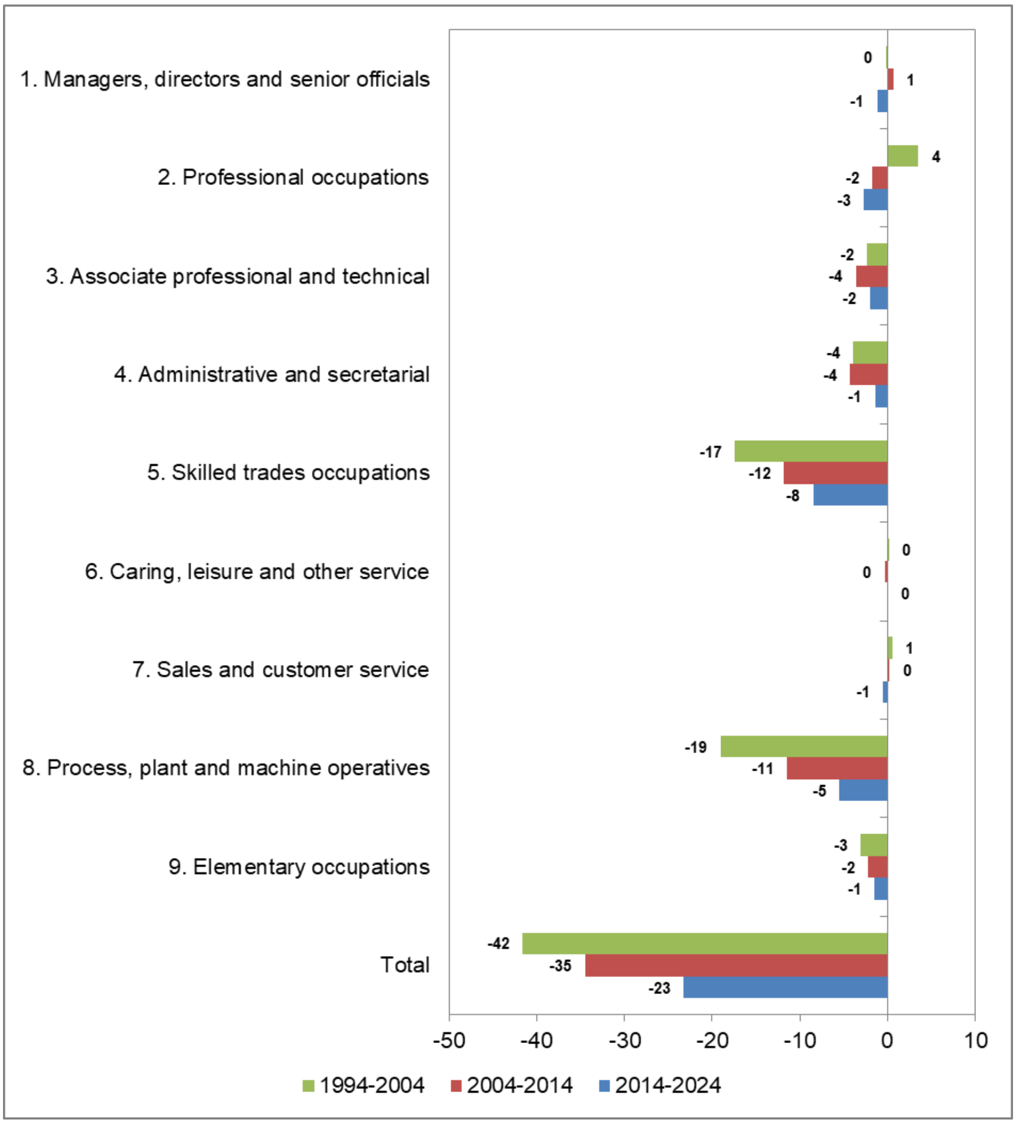


Figure 44: Change in engineering employment (000s), North East, North West, Scotland and Yorkshire and Humber combined, 1994-2024 (source: UKCES Working Futures 2014 – 2024)

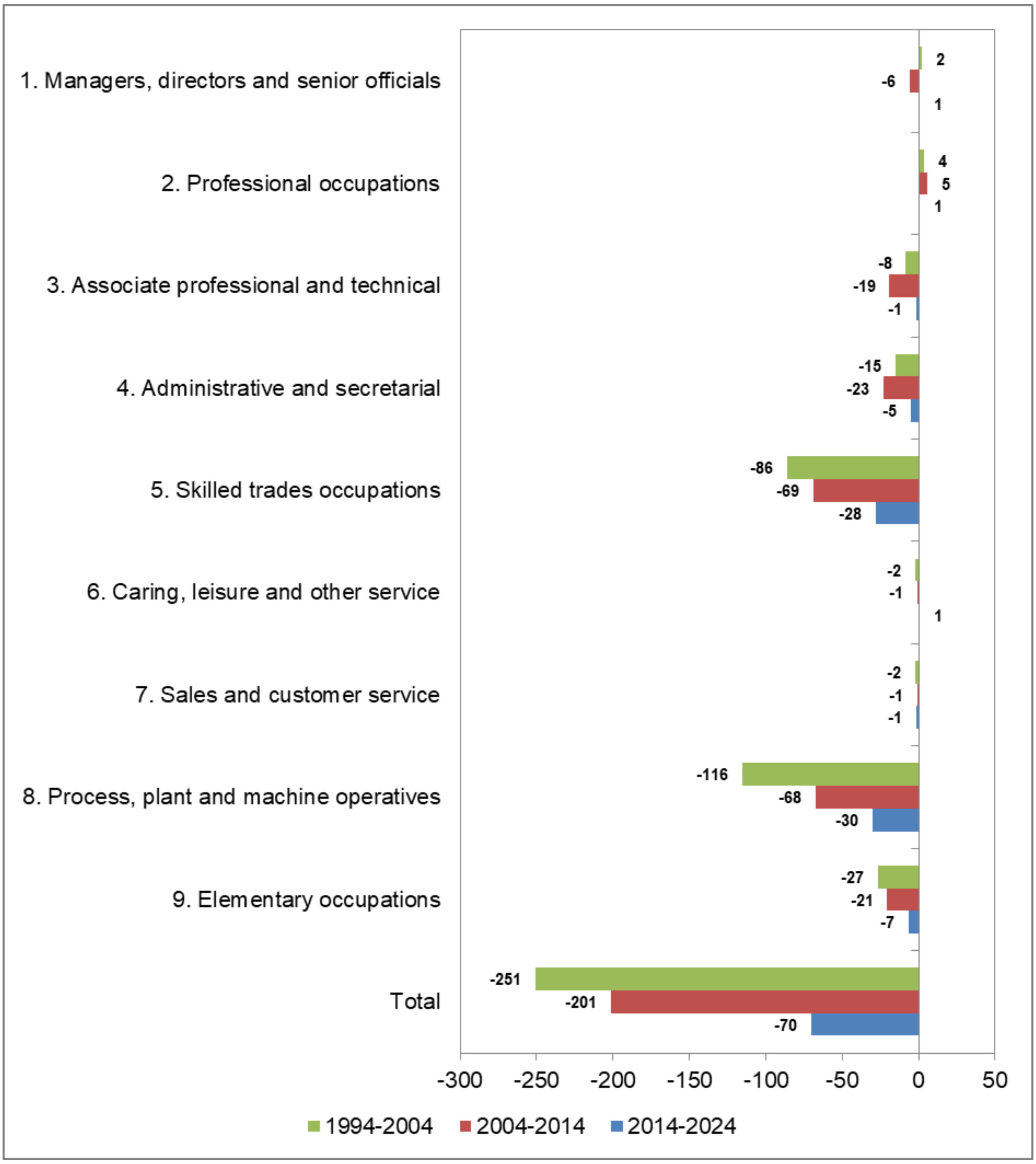


Figure 45: Change in rest of manufacturing employment (000s), North East, North West, Scotland and Yorkshire and Humber combined, 1994-2024 (source: UKCES Working Futures 2014 – 2024)

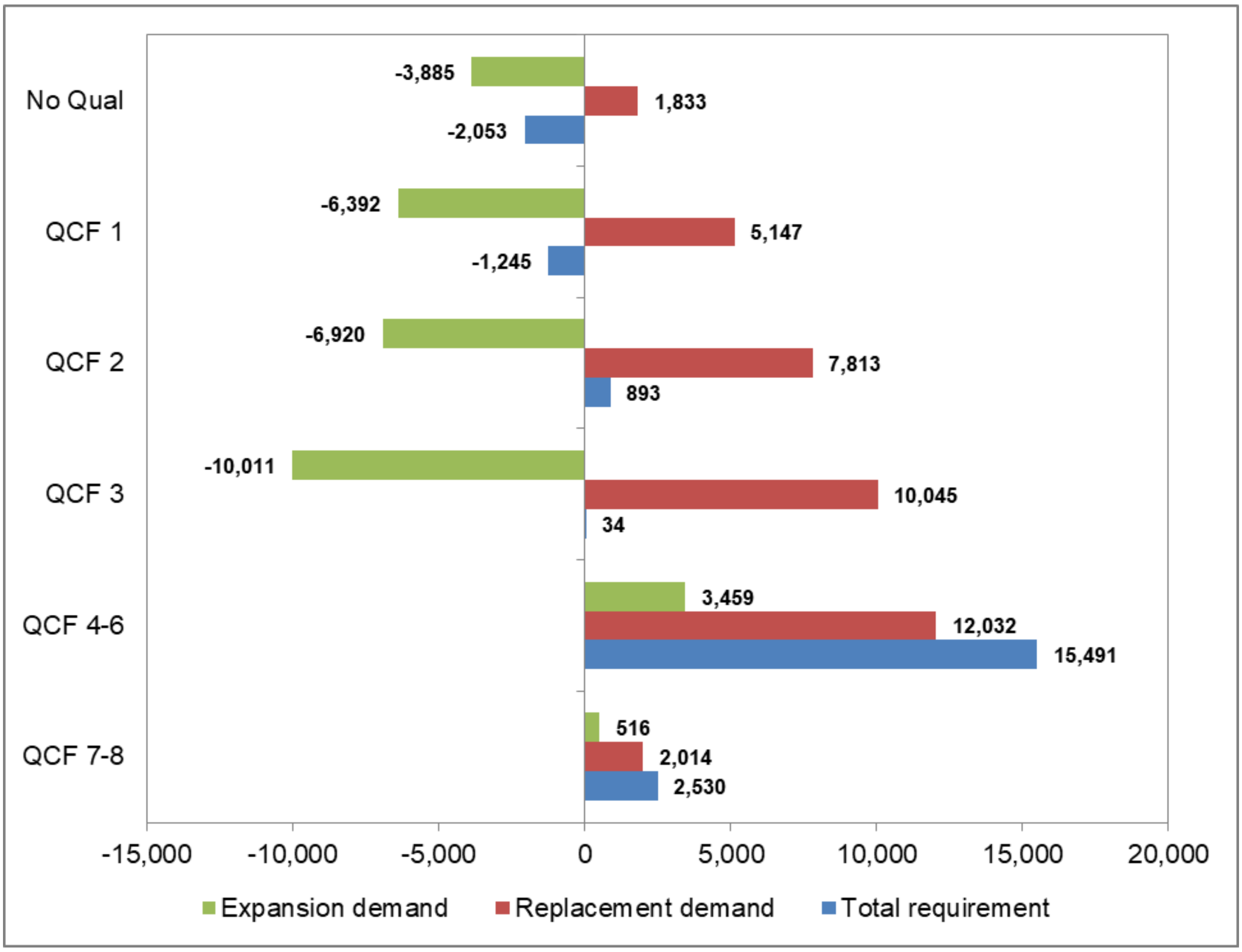


Figure 46: Implications of change in engineering employment for qualifications required, North East, North West, Scotland and Yorkshire and Humber combined, 2014-2024 (source: UKCES Working Futures 2014 – 2024)

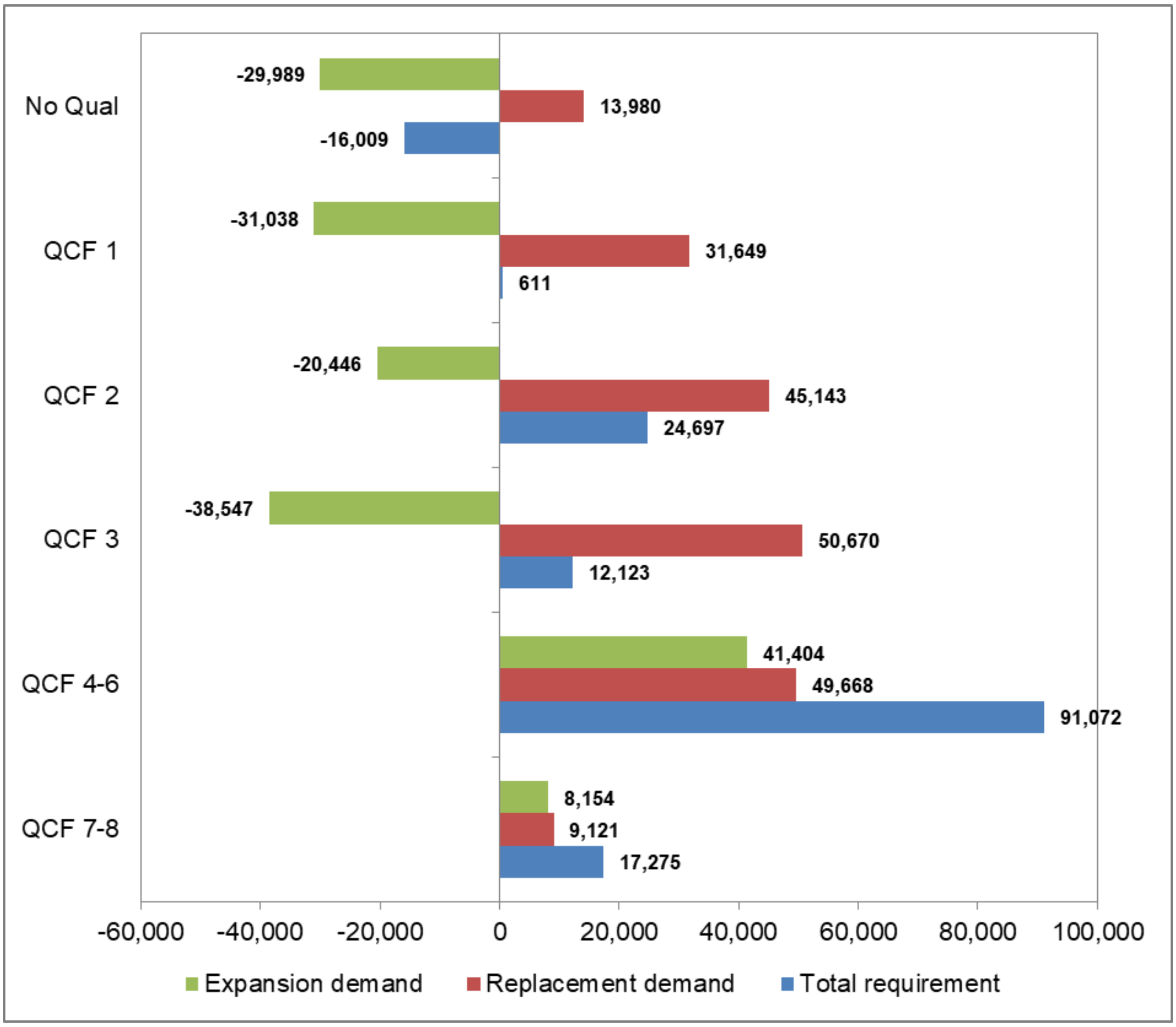


Figure 47: Implications of change in rest of manufacturing employment for qualifications required, North East, North West, Scotland and Yorkshire and Humber combined, 2014-2024 (source: UKCES Working Futures 2014 – 2024)

Appendix 6 Consortium Members

Rob Ashworth	Liverpool LEP
Richard Baker	North-East LEP
Chris Beck	TWI
Chris Bryceland	Scottish Enterprise
Simon Cheeseman	ORE Catapult
James Davies	North-East LEP
Giles Davidson	Hull University
Ben Fisher	Newcastle University
Jon Gluyas	Durham University
Lin Jiang	Liverpool University
Mark Knowles	Liverpool LEP
Ian McDonald	Scottish Enterprise
Gavin Smart	ORE Catapult
Angeliki Spyroudi	ORE Catapult
Sarah Tennison	Tees Valley Unlimited
Emma Toulson	Tees Valley Unlimited
Bill Walker	Hull University
Nick Wright	Newcastle University
Steve Wyatt	ORE Catapult