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UK SUPPLY CHAIN CAPABILITIES AND REQUIREMENTS FOR OFFSHORE RENEWABLE ENERGY.

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Personal Statement.

This dissertation analyses UK offshore renewable energy (ORE) supply chain capabilities and highlights the requirements for the developing a competitive supply chain in the UK.

This dissertation serves as a continuation of work done by Supergen ORE Hub. Supergen ORE Hub is a project that leads research and connects industry, academia, and policy makers to promote innovation and maximise the positive impact of ORE [1]. This topic was developed by my supervisor, Henry Jeffrey.

In this dissertation I have provided background into the UK ORE sector to provide context for this work in the literature review. This included introducing the different offshore renewable energy technologies including, the key market players, devices, and subsystems. As part of the background, I also analysed the market in which the UK ORE sector sits, the current UK and global deployment targets, the expected grid system benefits of ORE and the expected economic benefits based on the work by Supergen ORE Hub and other academic literature.

As part of my results and discussion section I narrowed down my focus to tidal stream energy and floating offshore wind energy as these technologies are more developed than wave energy. In this section I analysed the current supply chain capabilities of floating offshore wind energy and tidal stream energy. This included highlighting the local content (percentage of project cost delivered locally) and material requirements.

In the second part of my results and discussion section, I narrowed down my focus further to the tidal stream energy sector, where I conducted are more in-depth analysis of what was required for the development a competitive tidal stream energy sector. To do this I developed three case studies that I used to evaluate the performance of the tidal stream energy, identifying strengths and key areas for improvement.

When developing this work, I received support from my supervisor, who provided guidance and feedback on my work.

This dissertation is submitted in fulfilment of mechanical engineering (MEng) degree requirements at the University of Edinburgh.

I declare that this thesis is my original work except where stated.

Signed: ………………………………
Date: 18/05/2024

Summary.

Project title: UK Supply Chain Capabilities and Requirements for Offshore Renewable Energy.
Author: Josephine Kaluba.
Date: 18/05/2024.
Word count: 9626 words.

This dissertation will explore UK supply chain capabilities and requirements in in offshore renewable energy (ORE). Focus will be placed on understanding developments in this sector, the market for ORE, workforce skills requirements, understanding UK competitors and characterising the ORE supply chains capabilities and requirements.

The main ORE technologies covered in this dissertation are floating offshore wind (FOW) energy, tidal stream energy (TSE), and wave energy. These technologies have an important role in reducing carbon emissions. They all have various levels of development with FOW energy and TSE being the most advanced.

Based on studies by ORE Supergen Hub, the UK needs to deploy 6GW of wave energy, 6GW of TSE and 45GW of FOW energy by 2050 to support net zero [2]. The UK is expected to have high economic benefits if efforts are made to develop competitive supply chains.

To understand the UK supply chain capabilities, this dissertation identifies supply chain segments and analyses what fractions of local content (percentage of project cost delivered locally) have been achieved across supply chain segments. Material requirements were considered as well. These were used to highlight strengths, weaknesses and opportunities of UK supply chains. An in-depth analysis of the requirements for a competitive TSE sector was conducted using 3 case studies.

Even though TSE has achieved high fractions of local content, there has been inconsistent government support of the sector which could negatively affect UK competitiveness TSE [3], [4]. The same applies for wave energy. However, FOW is receiving government support with the government committing to 1-5GW of deployment by 2050, this will help ensure UK supply chain competitiveness in FOW [5].

Acknowledgements.

I would like to extend my deepest appreciation to Henry Jeffrey, my project supervisor, for his support and guidance which has helped inform my work in this dissertation. I also want to express profound gratitude to Danai, Justine, my family, and friends for supporting me throughout this process.

Table of Contents.

Word Count by Chapters.

Chapter	Word count.
Introduction	414 words
Literature Review	4275 words
Methodology	213 words
Results and Discussion Part 1: Analysis of Supply Chain Capabilities	2126 words
Results and Discussion Part 2: Analysing Requirements for a Competitive UK Tidal Stream Energy Sector using 3 Case Studies.	1529 words
Conclusions and Recommendations for Further Work	1070 words
Total Word Count:	**9626 words**

List of Abbreviations.

CAPEX	Capital Expenditure
CFD	Contracts for Difference
FOW	Floating Offshore Wind
GVA	Gross Value Added
LCOE	Levelized Cost of Energy
OPEX	Operational Expenditure
ORE	Offshore Renewable Energy
PCP	Pre-Commercial Procurement
R&D	Research and Development
SET	Strategic Energy Technology Implementation Plans
TSE	Tidal Stream Energy
TRL	Technology Readiness Level
WES	Wave Energy Scotland.

1 Introduction.

As the world is being affected by climate change, it is imperative for nations across the world to reduce carbon emissions [6]. As a low carbon intensive resource, offshore renewable energy (ORE) has an important role in achieving net zero. Net zero is a global target that is set to limit average rise in global temperatures to 1.5 °C by reducing carbon emissions to minimise the negative impacts of climate change [6]. All countries across the world have a role to play in achieving net zero. Diversifying the UK's renewable energy sources by including ORE sources will also be important to the UK as it seeks to reduce its carbon emissions and maintain a reliable and secure supply of energy during its energy transition [7].

Offshore renewable being studied include floating offshore wind (FOW) energy, tidal stream, and wave. As tidal stream energy (TSE) and wave energy technologies are relatively new compared to other energy sources, they have not yet evolved strong supply chain capabilities to significantly support the UK's net zero targets [8]. FOW energy also requires significant supply chain development. This dissertation will highlight the supply chain capabilities and requirements for developing a competitive supply chain for the deployment of ORE to reach high ambition retention assumptions specified in the gross value added (GVA) report by Supergen ORE Hub [2].

GVA measures the total contribution of individuals, industries, or sectors contribution towards the economy by evaluating value of goods/services produced minus cost of inputs directly linked to that production [9]. High ambition retention assumptions are a scenarios described in the GVA report in which high local content in the supply chains are achieved compared to low ambition scenario. In a high ambition scenario, the UK is a market leader and achieves higher GVA benefits compared to a low ambition scenario [2]. Local content refers to the proportion of project cost that is delivered within the geographic region of the project, i.e. within the UK [10].

Figure 1 summarises the key areas covered in this dissertation.

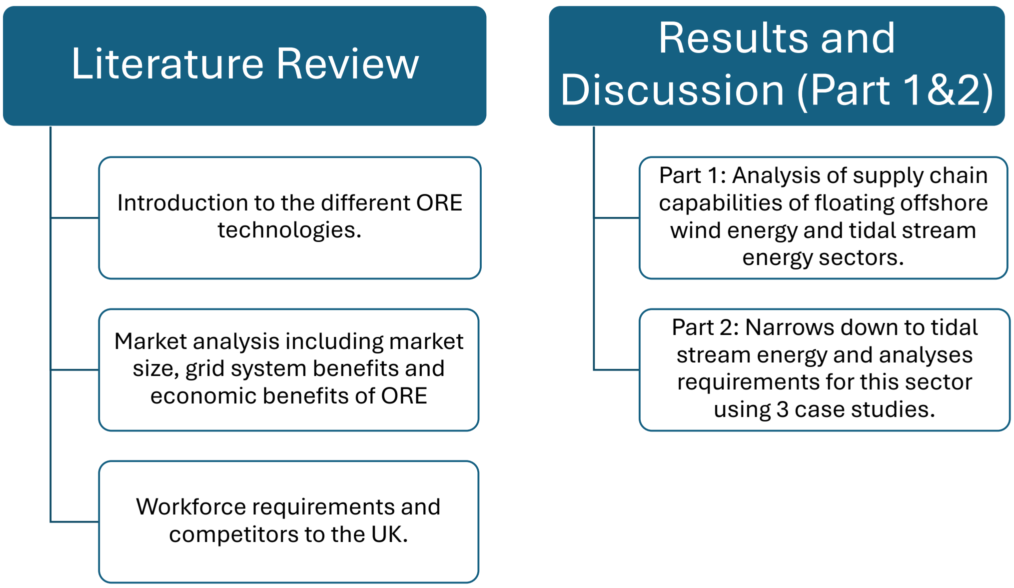

Figure 1- Summary of Project Aims and Objectives.

2 Literature Review.

To understand the context and background for this work, this literature review will introduce the different offshore renewable energy technologies, identify their levels of maturity, identify key market players, and describe the ORE devices. It will also analyse the current market for ORE by considering the current market capacity and deployment targets for the UK and globally by 2050. The grid system benefits, and economic benefits of ORE will be considered. This chapter will conclude by considering workforce requirements for 2050 and the key competitors for the UK.

2.1 Technology Status, Key market players and Devices of ORE in the UK.

The key areas of ORE being studied in this dissertation are floating offshore wind, tidal stream, and wave energy. This section will introduce offshore renewable energy, highlight the levels of technology development for the different ORE sectors and describe the key devices/subsystems.

2.1.1 Floating Offshore Wind Energy.

Floating offshore wind turbines have a floating foundation with a mooring system that hold the wind turbine in place as shown in Figure 2 [11]. These are different from traditional offshore wind turbines which have fixed foundation structures that penetrate the seabed. Floating offshore wind makes it possible to harness wind energy in locations where winds are strong, but waters are too deep for installation of fixed foundation turbines to be practical. With 80% of global wind energy resources in deep waters (greater than 60m depths), floating offshore wind presents has potential to expand offshore wind energy generation [12].

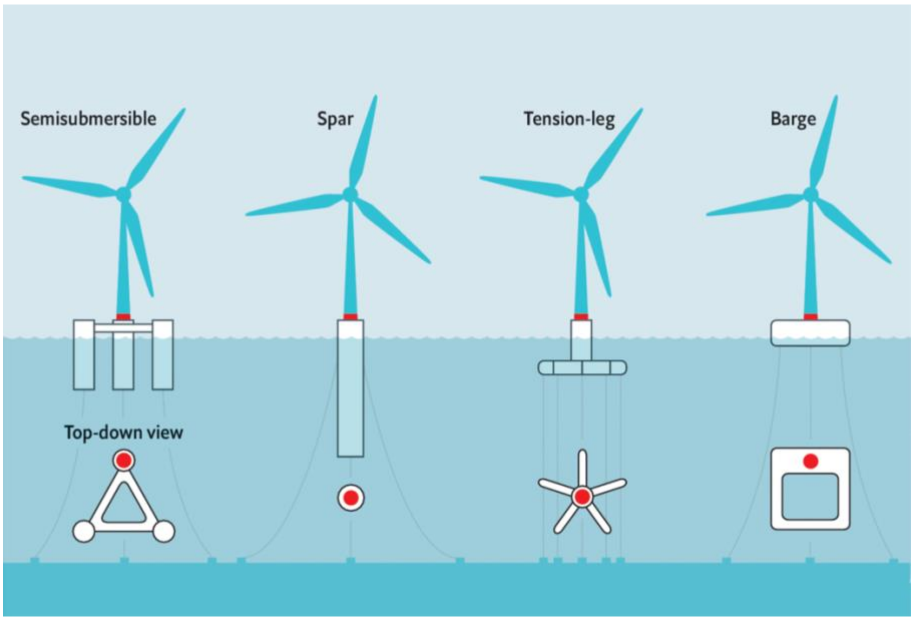

Figure 2- Floating offshore wind turbine designs.

Floating offshore wind has now entered its pre-commercial phase with expectations for it to enter the commercial phase in 2026 with 1GW in annual installations expected across the globe [12]. The first full-scale deployments of floating offshore wind where at the UK Hywind and Kincardine sites marking the UK as a market leader [2].

The of the key subsystems of FOWT include blades, nacelle, and hub, floating platform and tower, mooring system, anchoring system, gearbox, pitch and yaw systems, generators, and controllers. Key floating platform designs include the semisubmersible, barge, spar, and Tension leg foundations shown in Figure 2. They each have different anchoring and mooring configurations. These platform designs borrow floating support structure concepts used in the oil and gas industry.

The most notable projects in floating offshore wind in the UK are the Hywind Scotland pilot park by Equinor and the Kincardine offshore wind farm by Principle Power with installed capacity of 30 MW and 47.5 MW respectively [13], [14]. These projects make the UK a market leader in floating offshore wind. Principle Power's FOWT has 3-comlum semi-submersible platform that is made of steel [13]. Equinor's FOWT has a spar floating platform and uses a three-line mooring system [14].

2.1.2 Tidal Stream Energy.

Tidal stream energy generation involves extracting energy from tidal currents using tidal stream turbines[15]. Most tidal stream turbines operate and look like wind turbines except tidal turbines are used underwater[16]. Because water has higher density than air, tidal stream turbines can generate more energy than a wind turbine. They also have smaller blades and rotate more slowly than wind turbines. Dominant designs in the market are the horizontal axis turbines (includes bottom fixed and floating turbines) [17]. In horizontal axis turbines, rotors rotate in the horizontal axis when tidal streams flow through the turbine[8].

2.1.2.1 Background.

The UK tidal stream sector is approaching commercial maturity with projects approaching technology readiness levels (TRL) 8-9 [8], [17]. The most notable projects have been deployed at Meygen by SAE Renewables and at the Bluemull Sound sites by Nova Innovation since 2016 [17], [18].

TRL is a measure of the level of maturity of a technology [19], [20]. At TRL8 an actual system is completed, undergoes tests and is qualified. TRL 9 signifies the highest level in which the actual system been proven and has been successfully deployed/commissioned in operational environment. Please refer to Appendix 1: Technology Readiness Levels.

Key players in tidal stream sector in the UK are Sae Renewables, Orbital Marine Power, Magallanes and Hydrowing tidal projects which have secured 50 MW, 14.4 MW, 10.1 MW and 10 MW of projects respectively, in the last two contracts for difference (CFD) allocation rounds [21], [22], [23]. All four projects use horizontal axis tidal stream turbines. This section describes devices and subsystems of the top 2 developers.

Contracts for difference is a UK government run programme that supports low carbon emission energy generation by investing in renewable energy project developers [24]. Even though CFD is aimed at supporting deployment of renewable energy, it has not been as effective in supporting ORE technology. In the first CFD rounds, no tidal stream projects were supported as they had to compete with mature renewable energy sources [10]. The last two CFD rounds (round 4 and round 5) saw some contracts awarded to tidal stream developers, this has mainly been because of significant cost reductions that have been achieved and a result of high-profile tidal stream turbine demonstrations [10]. As it stands no contracts for difference have been awarded to wave energy projects [22], [23], [25], [26], [27].

2.1.2.2 Devices.

SAE Renewables has a lease for 398 MW of tidal stream energy to be installed at MeyGen [21]. This will be delivered in phases. Phase 1 involved deploying 6 MW of tidal energy, which is now operational. Two types of devices where deployed in this phase, the AR1500 and Andritz Hydro Hammerfest AH1000 shown in Figure 3 at the Meygen site [21], [28]. Phase 2 and phase 3 involve deploying 28 MW and 22 MW respectively. Funding for both phase 2 and 3 has been secured via contracts for difference. The AR1500 has a height of 24m and rotor blade diameter of 18m and is rated 1.5MW [28]. AH1000 has a 1MW capacity [29].

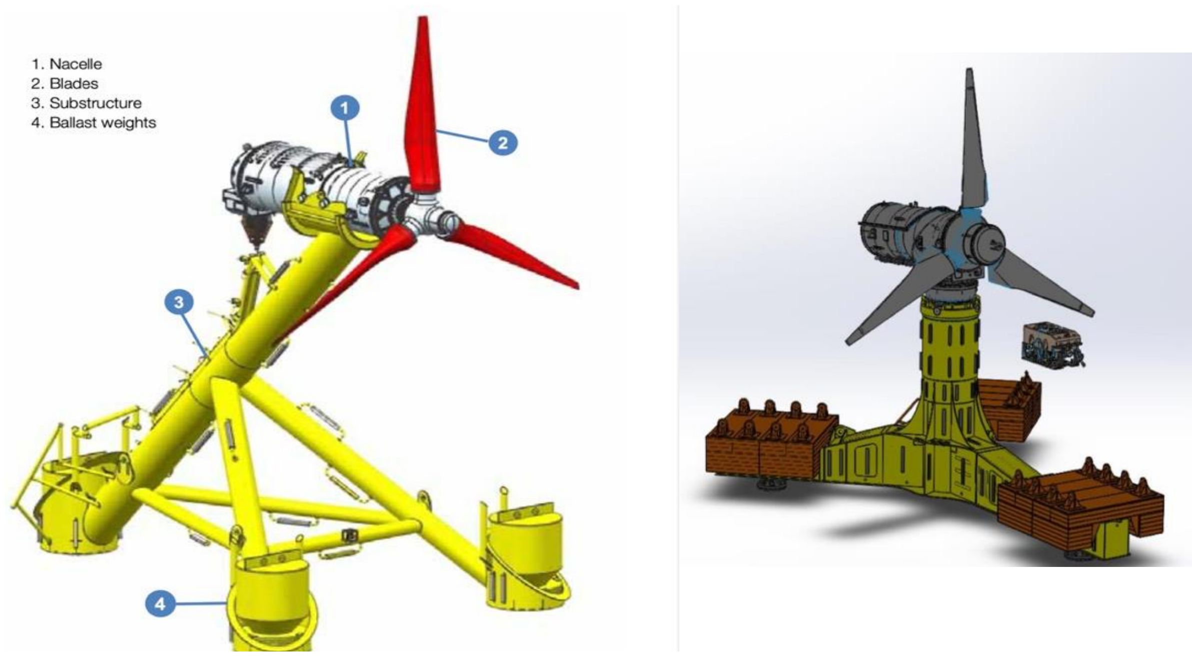

Figure 3- Andritz Hydro Hammerfest AH1000 (left) and AR1500 (right)[29], [30].

Orbital Marine Power's key device is their O2.2 tidal turbine shown in Figure 4 rated 2MW [31]. This is a cylindrical floating superstructure made of steel, housing auxiliary and power conversion systems and has nacelles mounted on two legs attached to the superstructure. Power generated is exported from the device using a dynamic cable exiting from the superstructure and connects to a static cable at seabed. The device is 80m long and the superstructure has a diameter of 3.8m. The rotor diameter at each leg is 22m.

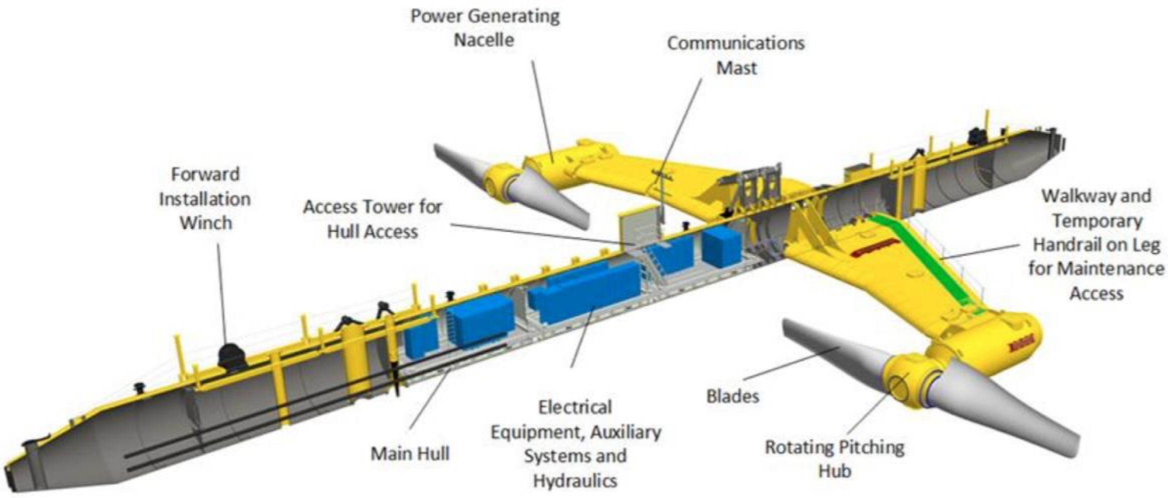

Figure 4- Orbital Marine's O2.2 [31].

Key subsystems in the UK's tidal stream energy sector across all three devices include blades, superstructures, pitch and hubs, nacelles, generators, gearboxes, control systems, cables, moorings and foundations and auxiliary systems.

2.1.3 Wave Energy.

Wave energy generation involves extracting energy from ocean waves using wave energy converters [15]. There is a lot of variations in wave energy devices with no dominant designs that are apparent [8]. Wave energy convertor designs of the top developers in the UK include [8], [32]:

- Oscillating water column design that traps air pockets which rotates a turbine.
- Point absorbers: floating structures that utilise motion of the device caused by passing waves.
- Attenuator: operates parallel to the direction of waves while riding the wave.
- Submerged pressure differential: In this device pressure differentials are generated by the rise of fall of waves.

2.1.3.1 Background.

Wave energy convertors are not yet available commercially and are still undergoing research and development. Unlike tidal energy, wave energy is less advanced with key devices ranging from at TRL 5-9 globally [8]. There are two key organisations that are driving R&D activities in wave energy in the UK, Europe Wave and Wave Energy Scotland.

Europe Waves is supporting the wave energy development through its pre-commercial procurement (PCP) programme. Here, R&D contracts are awarded to wave technology developers to develop their wave converters in phases [33]. Europe wave is a partnership between wave energy Scotland, the bask energy agency and Ocean Energy Europe, supported by the EU's horizon 2020 program [33]. It has €20 million funding secured from the UK and EU [34].

The programme consisted of 3 phases including:

- Phase 1: Concept development.

- Phase 2: Design, and modelling
- Phase 3: Sea deployment and testing.

The program is now in its 3rd and final phase where three projects have been selected to fabricate and test their wave energy convertors in real sea conditions in 2025[33], [35]. They will be sharing a budget of €13.4 million. The finalists are:

- CETO Wave Energy ACHIEVE.
- IDOM Consulting with their MARMOK Atlantic device
- Mocean Energy's Blue Horizon 250 (a 250kW device).

Wave Energy Scotland (WES) is also driving R&D activities in wave energy with £ 50 million funding from the Scottish government to support R&D activities [36]. Like the PCP programme, WES operated a 3-phase program with two companies, AWS Ocean Energy and Mocean successfully concluding testing of their devices at sea in 2021-2022. Mocean Energy's device was a 10-kW Blue X Wave Energy Machine which generated 475kW in the 5-month long sea test [36]. Archimedes Waveswing (AWS) energy converter is a device that has a 16kW capacity that outputted an average of 10kW and peaks of 80kW in moderate wave conditions.

The Scottish government released a draft energy strategy in 2023 which included plans to continue supporting WES R&D activities and plans to deploy up to four 250kW wave energy converters by 2027 [37].

2.1.3.2 Devices.

CETO 6 design is a point absorber that is submerged a few meters below the ocean surface and moves in response to ocean waves [38]. The oscillating motion of waves drives CETO device's power take off system that generates electricity. Figure 5 shows the CETO device.

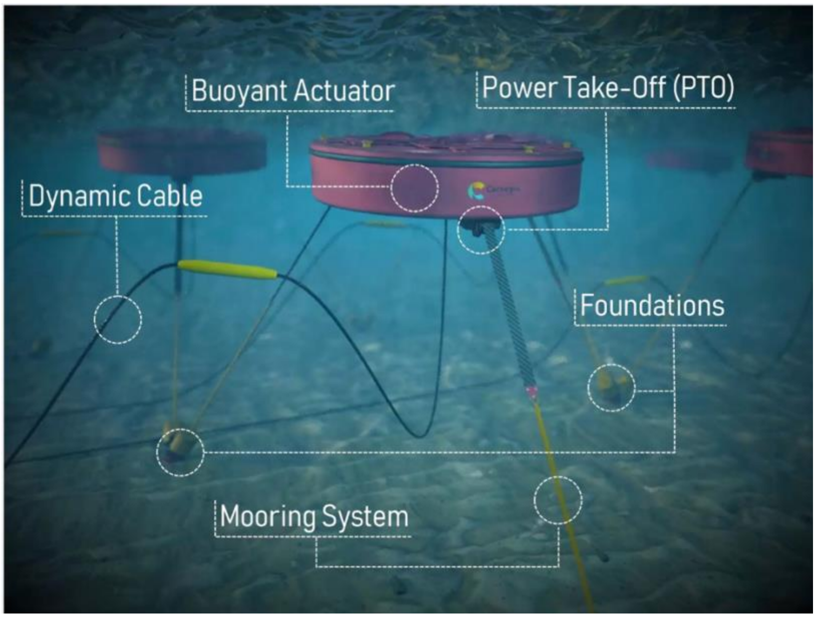

Figure 5- CETO 6 device[38].

The MARMOK device uses oscillating water column technology and has two 15kW turbines in the device [39]. The MARMOK converter is 42m long (6m freeboard, above the sea surface and 42m draft), and has a 5m diameter. The device can withstand up to 14m waves.

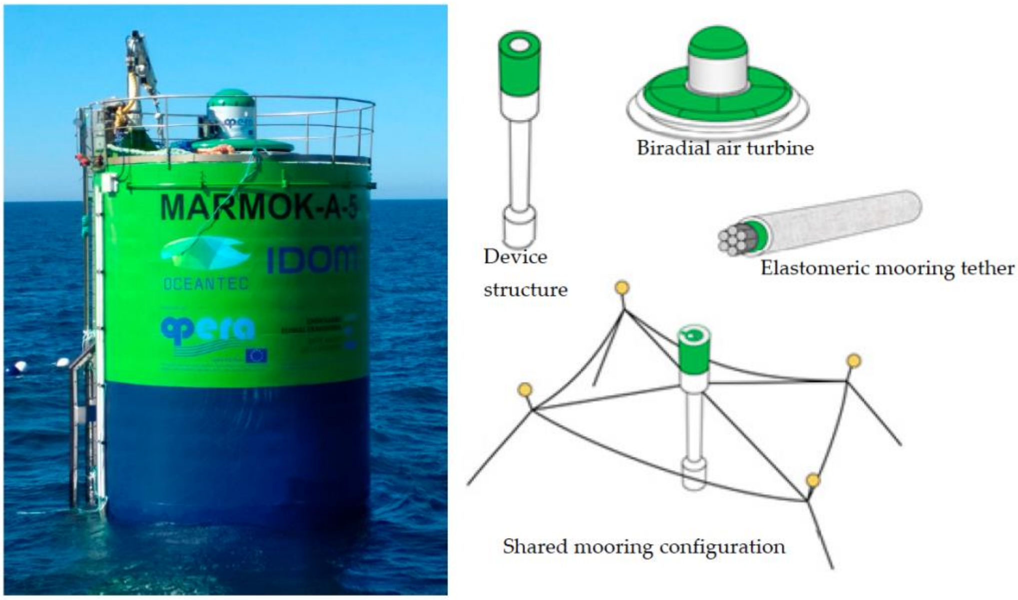

Figure 6- MARMOK-A-5 Device (left) and the device's key components (right)[40].

The blue horizon 250 is a hinged raft attenuator [32], [41], [42]. This device operates parallel to the direction of waves while riding the wave[32]. The two arms of the device make it possible to capture energy due to their relative motion. The device comprises a power take off nacelle, two hulls and power control subsystems [42]. Figure 7 shows the Blue X wave energy convertor, a 10kW version of the Blue Horizon 250.

Figure 7-Blue X Wave Energy convertor [43].

The AWS wave energy convertor is a submerged pressure differential technology [44]. It uses subsea pressure changes caused by passing waves to generate electricity. A single unit can be configured to generate between 15-500 kW. Figure 8 shows an image of the AWS wave energy convertor.

Figure 8- Archimedes Waveswing Energy Converter[45] .

2.1.3.3 Material requirements.

Due to how nascent technology is and lack of clarity on which designs will be dominant on the market. Supply chain capabilities of wave energy will be primarily described in terms of them of material requirements of the top performing devices in the UK. The table below shows the share of material usage of key wave energy devices as a percentage of total weight. This data is based upon averages taken across Europe.

Material	Steel	Other Metals	Electronics	Plastics	Concrete	Sand	Water
Attenuator	46.2	7.0	1	6.6	6.3	9	23.9
Point absorber	50.5	3.8	0.9	11.9	13.6	5.3	14
Oscillating water column	60.6	3.1	0.6	4.1	31.6	0	0
Submerged pressure differential	63.1	3.4	0.9	11.2	21.3	0.02	0.05

Figure 9- Share of material used to produce the wave energy device as a percentage of total weight [8].

2.2 Market Analysis for Offshore Renewable Energy.

This section seeks to highlight where the UK's market currently stands and required deployment rates of ORE in the UK and across the globe if net zero targets for 2050 are achieved. The section will also examine the market size, the expected economic benefit, and the grid system benefits of ORE to the UK. It will also outline the key assumptions that informed the studies by Supergen ORE when evaluating the market for offshore renewables. These assumptions will be maintained in this dissertation.

2.2.1 Assumptions.

The required deployment rates, GVA benefits and grid system benefits for the UK have been modelled by ORE Supergen and this section will highlight some key assumptions that informed these models [2].

An important assumption being made is that system and performance conditions are defined by levelized cost of energy (LCOE). LCOE is a ratio of overall lifetime costs of the energy project to its lifetime energy output [18]. Their models also assume EU Strategic Energy Technology Plans (SET Plans) for 2030 are achieved. The SET Plans includes targets to achieve significant cost reductions for ORE to be achieved by 2030 to support net zero. The target LCOEs for ORE are highlighted below [2]:

- €150/MWh for wave energy
- €100/MWh for tidal stream
- €90/MWh for floating offshore wind.

Currently, LCOE for tidal stream energy across the EU (including the UK) ranges between €110-480/MWh while wave energy LCOE ranges between LCOEs of €160-750/MWh [8]. Floating offshore wind LCOE ranges between €95-135/MWh in Europe [46].

This dissertation focuses on supply chain development when the high ambition scenario outlined by Cochrane and others (2021) is achieved. This scenario achieves high local content. Having higher local content is preferred as it allows the region to retain the project's economic benefits and allows for the creation of more jobs [10]. The high ambition scenario provides 152% more GVA than in the low ambition retention assumptions [2].

Even as having high local content delivers greater socioeconomic benefits, it is not always cost effective to have all parts of the projects delivered within the same geographic region [47]. This explains why the UK offshore wind sector has faced challenges in achieving high local content [48]. As the UK was a market follower in the wind energy sector, building out certain parts of the supply chain while competing with established developers in a saturated market was no longer cost effective. The UK having an early mover advantage in ORE will be important in enabling the UK to more cost effectively achieve higher local content.

2.2.2 Market Size.

In this section the size of ORE resources available and installed capacity in the UK will be considered. To determine the market size in the UK and globally that the UK can leverage, the necessary deployment targets to achieve net zero by 2050 will be outlined.

Wave and tidal have ability to meet 20% of UK's energy demand with tidal stream having potential to supply 11% (11.5 GW) of the UK's electricity demand [10], [49]. Floating offshore wind also presents a significant market opportunity for the UK considering 80% of wind energy resources across the globe are in deep waters [12].

The UK's current installed capacity for tidal stream energy is 10.4 MW [8]. New contracts for the deployment of up to 95.8MW of TSE between 2025-2028 have been awarded through CFD [22], [23]. This will create an almost 10-fold increase in UK's TSE capacity. The total installed capacity for floating wind is 78MW [50]. Wave energy installed capacity won't be highlighted as most technologies have not yet reached significant levels of maturity.

The required 2050 capacities for ORE in the UK based on ORE Supergen Hub modelling are shown in Figure 10 [2]. Their findings show that the UK needs to install 6GW of TSE, 6GW of wave energy, and 45GW FOW energy [2].

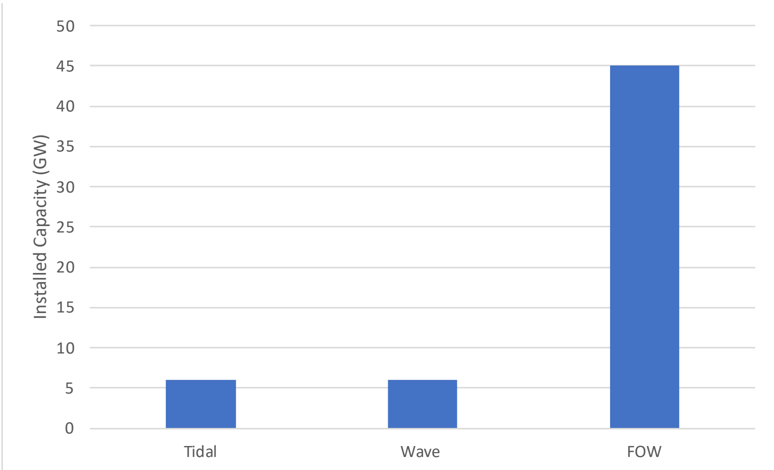

Figure 10- UK ORE deployment projections for 2050 [2].

Figure 11 shows the global deployment rates for 2050 required to achieve net zero. It is expected that 117GW of TSE, 176 GW of wave energy and 289 GW of FOW energy would be installed by 2050 in line with net zero targets [51], [52]. Figure 11 is based on models produced by DVN and ETIP Ocean. Their models assumed that net zero targets are achieved.

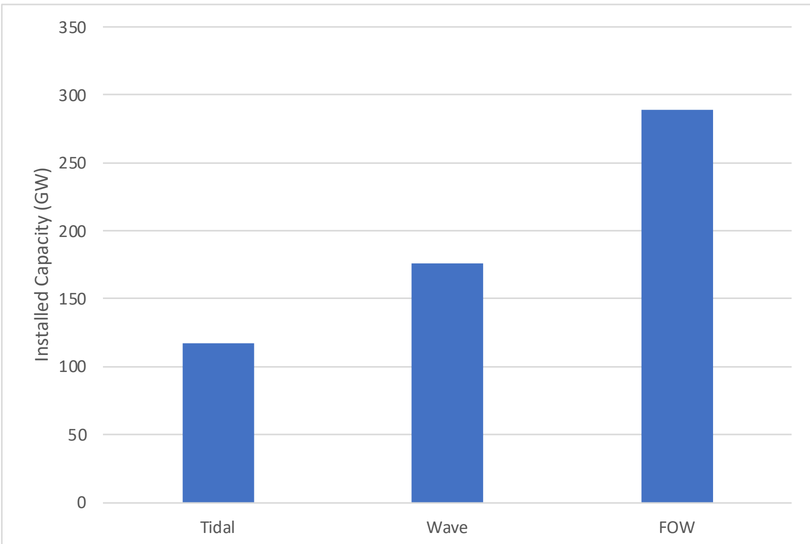

Figure 11- Global ORE deployment projections for 2050 [51], [52].

As it stands, UK government is supporting deployment of tidal and FOW through CFD and its floating offshore wind demonstration programme [3]. Wave energy development is currently not receiving support from the UK government. Even though wave energy projects can still compete for CFD funding, the structure of the scheme prevents wave projects from securing contracts as they must compete on the same level as mature renewable energy technologies [3].

The UK government had also announced targets to deliver 1GW- 5GW of floating offshore wind by 2030 [3]. However, no clear targets were announced for wave and tidal energy deployments. This could potentially undermine the delivery of 12GW of wave and tidal energy required to achieve net zero by 2050.

2.2.3 Grid system benefits of adding ORE technology.

Solar and wind energy has made significant strides in their development having demonstrated their potential to be integrated into energy grids. As these technologies have variability in their supply they require significant energy storage capabilities and interconnectors to meet demand that is also variable. Wave energy and TSE have shown promise of complimenting solar and wind by being able to generate energy during low periods for wind and solar as shown in Figure 12 and Figure 13 [7]. TSE has the benefit of being very predictable, while wave energy has the benefit of being avaliable during periods of low solar availability during periods in the winter when demand increases due to a need for more heating as shown in Figure 12 and Figure 13.

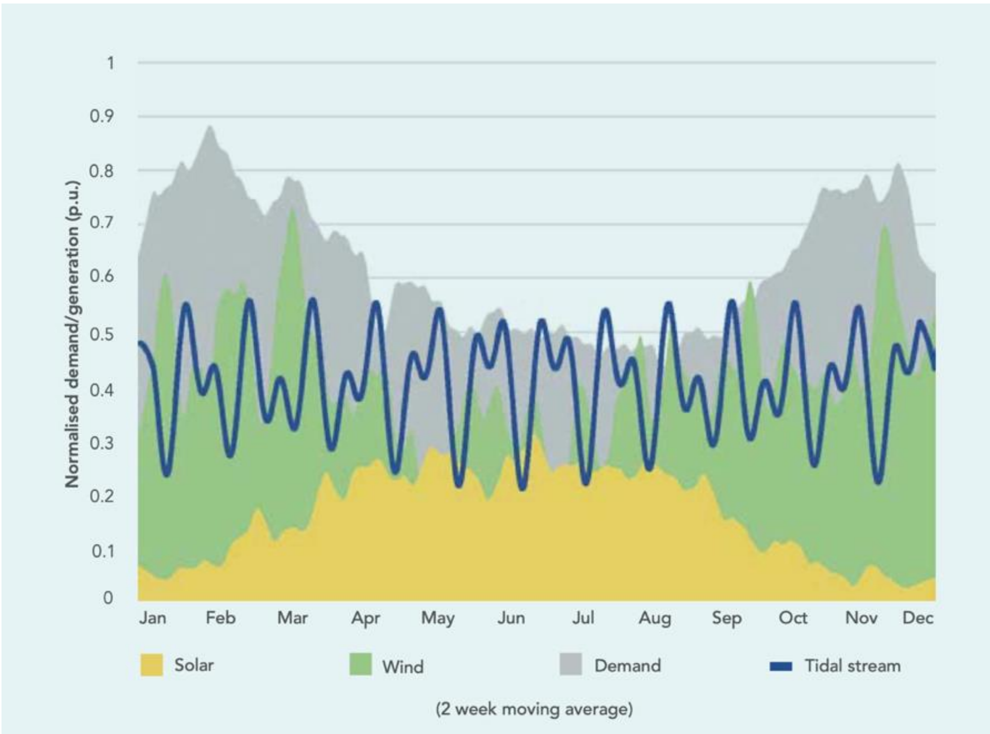

Figure 12- Normalised UK demand and variable generation of renewables in 2019 compared to tidal stream potential [7].

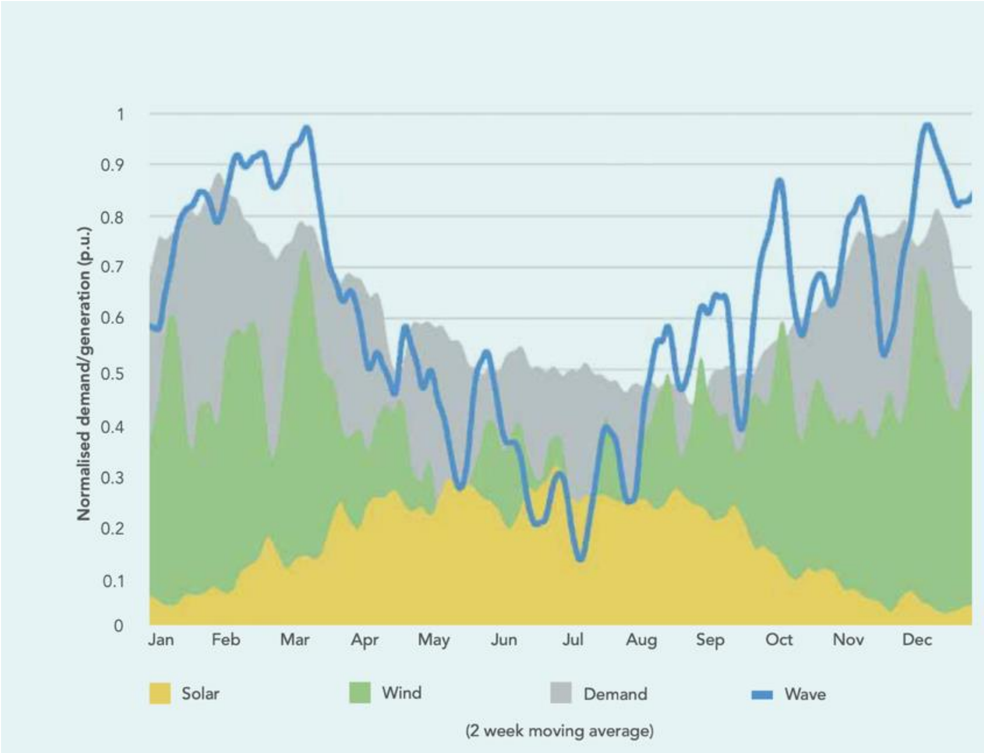

Figure 13- Normalised UK demand and variable generation of renewables in 2019 compared to wave generation potential [7].

TSE and wave energy requires 65% less (5TWh less) battery usage compared to FOW energy and 6% less (3GWh less) energy imports over interconnectors reducing the need for flexibility. High dispatch rates of tidal and wave by up to 27TWh would lower requirement for expensive peaking generation by up to 24TWh, leading to an annual reduction of £1.03 bn in dispatch costs [7]. Peaking plants are used to balance out flatulating demand and supply from other energy sources.

2.2.4 Economic benefit in terms of gross value added (GVA).

The expected economic benefits of ORE to the UK vary depending on the whether the UK follows a high ambition scenario (in which the UK works towards being a market leader and achieves high local content) or a low ambition scenario (in which the UK is a market follower and achieves low local content) [2]. In a low ambition scenario, the UK realises lower economic benefits compared to a high ambition scenario. The economic benefits of ORE technology to the UK will be discussed in terms of gross value added (GVA).

In a high ambition scenario, the expected GVA by 2050 from TSE and wave energy are of £4.47billion, £4.38billion respectively for domestic deployments [2]. FOW energy is expected to generate £32.53billion in GVA, way above the of early deployment costs of £2.2billion [53]. Floating offshore wind has a higher GVA because it has a higher deployment rate, but if you look at it from GVA per MW terms offshore wind ranks lowest as shown in Figure 14.

The maximum GVA per megawatt for floating offshore wind is £723k/MW [2]. For wave energy, it is £730k/MW and tidal £745k/MW. This estimation is depended on timescales, deployment rates, total spend per MW and as well as retention rates.

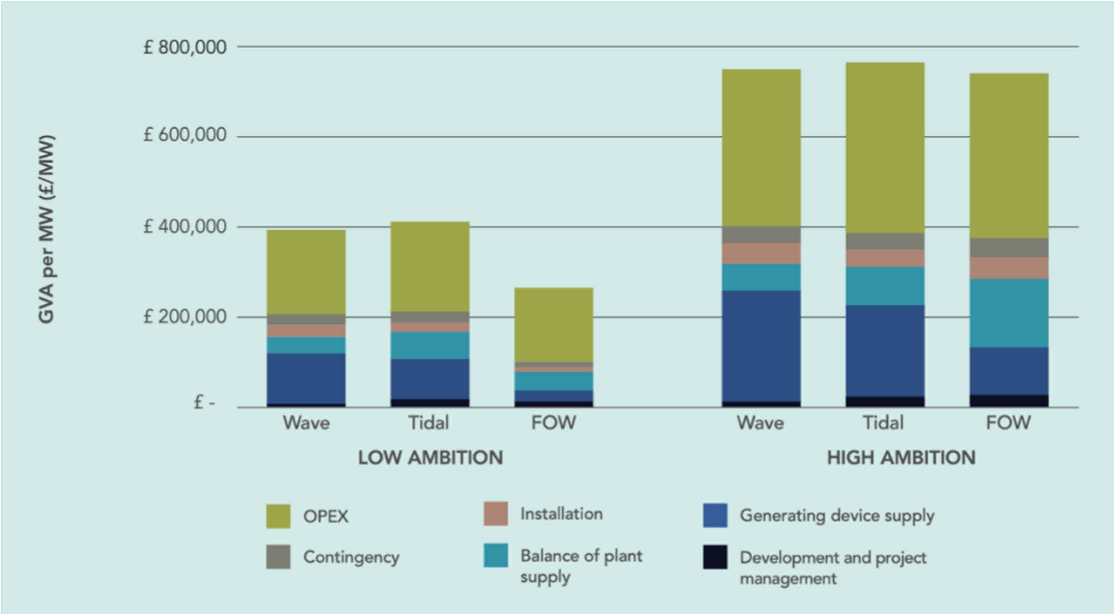

Figure 14- Expected GVA per MW for domestic deployments of ORE in 2050 [2].

As shown in Figure 14, the low ambition scenario achieves significantly lower GVA benefits compared to the high ambition scenario. The greatest GVA per MW benefits are seen in tidal energy followed by wave energy and finally floating offshore wind energy.

As the amount of local content has a significant bearing on economic benefits, this can help explain why each technology achieves different GVA per MW with FOW having the lowest values [4]. The offshore wind industry has 48% local contentment, smaller than wave and tidal [54]. While tidal stream developers have been able to achieve up 80% local content [10]. This is an important factor in why FOW has lower GVA/MW than tidal and wave energy.

2.3 Workforce Skills Requirements.

This section highlights the number of full-time equivalent jobs that will be available in ORE in the UK.

FOW is expected to support 17,000 UK jobs (ORE, Catapult, 2018)). This will include personnel who are assimilated from the oil and gas sector as the UK reduces its dependence of fossil fuels [53]. This is achievable if the UK government takes a proactive approach in deployment of ORE. In floating offshore wind, 50%, roughly 8540 of jobs will be in operations and management and related services and 17% in development and design.

In 2021, the UK's Ocean energy sector supported 928 jobs [8]. In ORE Catapult's forecasts in 2018, TSE is expected to support a total of 4, 000 jobs by 2040 and 14, 500 by 2050. ORE Catapult also forecasts wave energy will support up to 8,100 jobs by 2050 [4].

2.4 UK Competitors.

While there are growing opportunities in international deployments for the UK in FOW, this also comes with competition to the UK. Current top competitors to the UK, are France, Portugal, Japan, and Norway [12]. In the next 10 years this is expected to change with Japan, South Korea, France, and Norway being the top competitors [12].

In tidal stream energy, the UK's competitors are Canada, China, France, Ireland, the Netherlands, and the USA [8]. These are the top countries with developers that have achieved TRL 6 and above. The UK is currently leading in tidal stream energy having the highest number of tidal stream technology developers with TRL 6 and above. At TRL 6, the technology is a full representational model or fully functional prototype [19].

In wave energy development, key competitors with developers achieving TRL6 and above are Denmark, the USA, Italy, Sweden, Australia, and Norway [55].

2.5 Discussion

The models that have been used in used to ascertain the required deployment for 2050, grid system benefits and GVA benefits rely on several assumptions. Some key assumptions were that SET Plans targets LCOE cost reductions that support net zero are achieved. Cost reductions significantly rely on high deployment rates and high levels of investment in ORE technology [4], [10].

As ORE cannot yet commercially compete with mature renewables, it requires high levels of public support. The level of public support also provides an incentive to private investors who often require proof of government support in the industry before investing [8]. Wave energy is currently not receiving UK government support. Support for wave energy has mainly come from the Scottish government. As the UK government is not making the investments needed to achieve required cost reductions, this will likely hinder deployment of 6GW of wave energy by 2050.

When it comes to floating offshore wind energy, the UK government is supporting their development through CFD and floating offshore wind demonstration programme [3]. This puts the UK on track for delivering deployment targets for 2050 in FOW energy.

Even though there is significant government support for TSE, with recent CFD rounds set to have a 10-fold increase UK capacity by 2027, support for TSE development has been inconsistent [3], [4], [56]. Initially TSE was supported through the Renewables Obligation scheme, but when it was replaced by CFD, TSE projects no longer received government funding in the early rounds of CFD [4]. It is only recently that the structure has been revised to enable TSE projects to secure contracts [3].

Uncertainty in the tidal stream sector could negatively impact levels of private investment and makes it challenging for developers and suppliers to plan and/or deliver on their projects. While FOW has received a formal commitment (with plans to install 1GW-5GW of tidal stream energy by 2030) the tidal sector has not had similar commitments or targets by the UK government. If the government makes a formal commitment or sets out deployment targets this will assure private investors and make it easier for developers and suppliers to make long term plans to support the delivery of 6GW of tidal stream energy by 2050. The lack of commitment has potential to hinder deployment targets.

Significant delays/failures in the UK delivering on deployment targets for 2050 for ORE will also negatively impact the number of jobs created and will reduce UK competitiveness in ORE.

3 Methodology.

The literature review introduced the different ORE technologies, analysed the market, highlighted UK competitors and workforce requirements for the successful deployment of ORE. The literature review is followed by results and discussion, and conclusions.

The results discussed in this dissertation combines qualitative and quantitative approaches to inform the research. Current supply chain capabilities and material requirements for TSE and FOW energy are considered in chapter 4. Tidal stream energy and floating offshore wind energy are chosen as there is more clarity on which designs that will inform and shape their supply chains. Wave energy currently lacks clarity on which designs will dominate the market and by extension the nature of their supply chains [57].

This dissertation narrows down further to consider tidal energy supply chain requirements and competitiveness in chapter 5. The analysis is conducted using case studies of 3 companies. These companies are Orbital Marine Power, Enercon and Ingeteam. These case studies will be used to map strengths and weaknesses of the tidal supply chain by drawing comparisons between the 3 companies and to identify mitigation measures and economic opportunities.

To address these key areas different resources including journal articles, industry reports, sustainability reports, press releases and articles by key industry players, government, academics, and ORE companies have been evaluated.

4 Results and Discussion Part 1: Analysis of Supply Chain Capabilities.

This chapter will highlight supply chain capabilities of TSE and FOW energy. It will also consider their strengths, weaknesses, and opportunities.

TSE is currently in its pre-commercial phase with a few devices reaching high TRLs [8]. Because tidal technologies are not yet commercially mature, literature on their value chains is limited. To circumvent this, the supply chain capability of one tidal stream turbine developer is explored to provide a representation of the UK TSE sector's capabilities.

4.1 Floating offshore wind.

FOW is currently sitting in an already established offshore wind market with wind turbine technology that is well developed. The key thing that makes FOW energy distinct is the floating foundation that is different from traditional fixed foundations used in offshore wind turbines. As FOW is part of the overall offshore wind market, understanding the supply chain capabilities of offshore wind is highly relevant to understanding the FOW energy supply chain.

This section will highlight how much local content has been achieved in the offshore wind sector and current targets for increasing UK content in offshore wind. It will also highlight material requirements and key opportunities in the development of FOW supply chain.

4.1.1 Supply Chain Capabilities.

Supply chain segments that are being analysed include turbines, balance of plant, installation and commissioning, operations and maintenance and decommissioning as shown in Figure 15 [54]. The turbine segment includes supply of components such as nacelles, generators, blades, gearboxes, control systems, rotors, and towers etc. Balance of plant includes cables, turbine foundation, substations, and operations base. Turbine foundations that were considered in the ORE Catapult database did not include floating foundations [54].

The ORE Catapult database only includes lists of suppliers that are established and excludes smaller unestablished ones. This will factor into possibility that the data will not provide a complete overview of the FOW sector. However, it will still provide a reasonable representation.

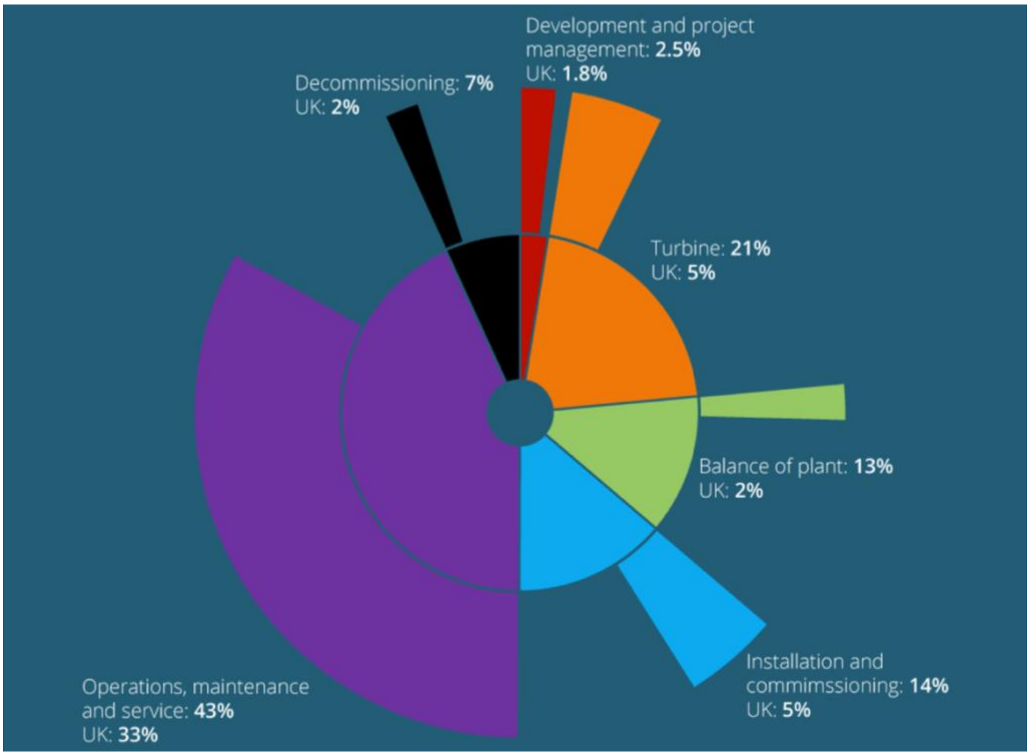

Figure 15- Current UK Offshore wind energy supply chain capabilities [54].

Figure 15 shows the fraction of total project spend for each supply segment in the inner circle and the percentage of UK content captured in each Segment in the outer circle. The UK offshore wind supply chain has achieved 48% local contentment overall [54]. Majority of this fraction is from development phase activities, operations and maintenance, installation, and blade manufacture (in the turbine segment). These are areas in which the UK has stronger capabilities.

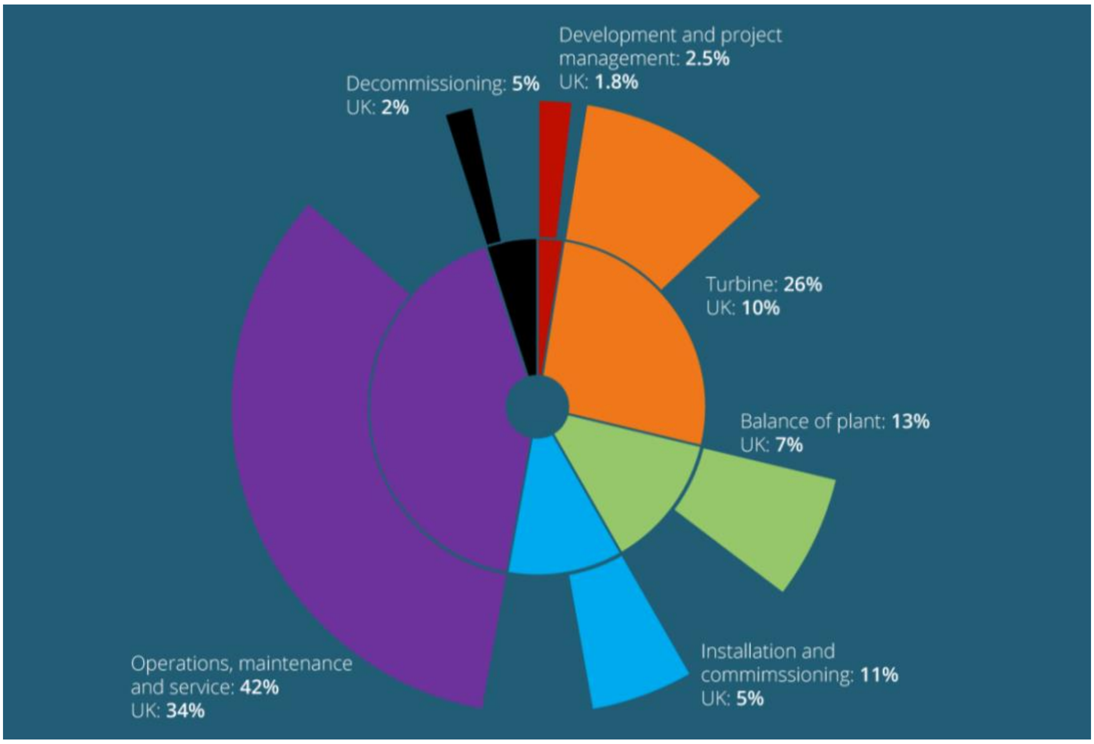

Figure 16- UK supply chain aspirations for offshore wind by 2030 [54].

Current wind energy industry targets are to have up to 60% local content by 2030 as agreed in a 2019 government and industry sector deal [5]. Figure 16 shows the amount of content that needs to be achieved in each segment to achieve the 60% target.

As the floating offshore platform designs stem from the UK oil and gas sector, the oil and gas supply chains have the potential to secure up to 57% local content of the floating offshore wind energy by 2040, while it is expected to only achieve 21% local content in fixed-bottom offshore wind [48]. Floating offshore wind energy therefore shows a greater potential to increase local content offshore wind energy overall [48]. As the UK oil and gas industry is expected to have a 50% natural decline in production with additional targets to achieve 75% reduction in production by 2035, FOW offers potential to allow career transition of workers from the oil and gas sector who will provide expertise to support FOW deployment [58].

An example of an oil and gas supplier delivering floating platforms is Oil States. As they have 30 years' experience in delivering tension leg platforms (TLP) in the oil and gas industry, they have supplied 27 out of 28 TLPs for floating offshore wind turbines installed globally [48]. Currently they can manufacture 20 units per year with potential to scale to 100 units per year.

4.1.2 Supply Chain Development Opportunities.

The UK does not have enough ports and fabrication capabilities to support deployment of FOW energy. During installation of the Hywind farm, the turbine structure was assembled in Norwegian ports as the UK did not have sufficient facilities [59]. Assembled turbines then towed out to be installed at the wind farm site instead of assembling the turbine at sea. Assembling the whole turbine structure at the quay changes the port and fabrication facilities requirements for floating offshore wind turbines.

Comparing Figure 15 and Figure 16 the greatest opportunities for increasing UK content are in turbine components manufacture, installation and commissioning, and balance of plant. All these activities will require significant investment in ports and fabrication facilities so these activities can be done locally as well [53].

A study by ORE Catapult estimates an investment of £883million is needed for port and fabrication facilities from public and private sector for floating offshore wind [53]. The share of lifetime costs for the development of UK ports is relatively low compared to the expected benefits [53]. This investment will enable the UK to secure 40% of value over projects lifetime [53].

4.1.3 Material requirements.

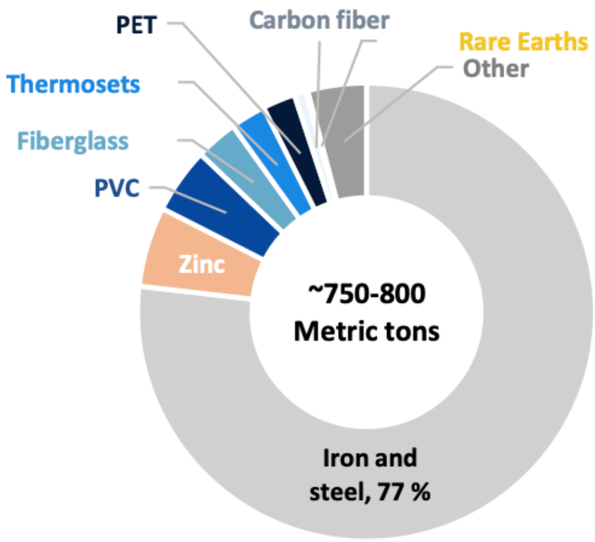

Figure 17- Material composition for an 8MW wind turbine as a percentage of total weight [60].

Figure 17 shows the average material composition of wind turbines manufactured in Europe. Large 8M-15MW turbines use a lot of steel because of their large tower heights [60]. In 15MW turbines iron and steel can take up 81% of the turbines weight. Figure 17 does not account for the material contribution from the floating platform.

4.2 Tidal Stream Energy.

TSE is currently in its development phase with a few devices reaching high TRLs. This section will highlight the amount of local content achieved by key tidal stream developers, the supply chain capabilities ORE Catapult to represent the UK tidal stream sector and provide an analysis of material requirements.

The UK TSE sector has proven it has potential to deliver higher local content than wind energy. This includes Nova Innovation that was able to achieve 80% local content on their first three turbines that were deployed in Bluemull Sound [10]. The array has a 300kW installed capacity [61].

4.2.1 Supply Chain Capabilities.

Orbital Marine Power with their O2.2 devices has achieved up to 80% UK content in its supply chain [10]. Overall, Orbital Marine Power has worked with 157 companies in the UK supply chain[62].

Work package	Total spend	Non-UK	Scotland	Wales	North England	South England	UK
Blades	9%	0%	0%	0%	0%	9%	9%
Pitch & Hub	11%	0%	0%	0%	11%	0%	11%
Nacelle	17%	17%	0%	0%	0%	0%	0%
Electrical skids, C&I, Aux Systems and Outfitting	9%	0%	2%	0%	1%	6%	9%
Leg Retraction System	5%	0%	3%	0%	2%	0%	5%
Structure	30%	0%	29%	0%	0%	0%	30%
Moorings	10%	3%	0%	4%	3%	0%	7%
Dynamic Cable	1%	0%	0%	0%	0%	1%	1%
Marine Operations & Logistics	7%	0%	7%	0%	0%	0%	7%
Ancillary	2%	0%	1%	0%	1%	0%	1%
Total	100%	20%	42%	4%	18%	16%	80%

Figure 18-O2.2 Supply Chain Analysis of O2.2 CAPEX expenditure [62].

Non-UK suppliers accounted for 17% and 3% of overall capital expenditure (CAPEX) in the nacelle assembly and mooring system respectively as shown in Figure 18. This brought the total non-UK content to 20%. Orbital Marine Power has indicated plans to increase their UK content to 95% [10].

SAE Renewables is also a key player in the UK TSE sector and ranks first having secured the largest contract through contracts for difference. It is unclear what percentage of UK content they have achieved. Based on a case study by the Scottish government, SAE Renewables has achieved 51.3% Scottish content in Phase 1A of MeyGen [63]. The case study does not mention what fraction of local content is from other parts of the UK, i.e. England, even though it is apparent that SAE Renewables also works with suppliers in parts of the UK other than Scotland [63], [64]. This means SAE Renewables' overall UK content was much higher than 51.3%.

Currently the TSE draws on supply chains from other industries. This includes subsystem suppliers, installation, operations, and maintenance drawn from industries like offshore wind or floating platforms from oil and gas industries [48], [55]. As TSE deployment scales, these supply chains will no longer be sufficient and will either need to develop new supply chains tailored to TSE or scale current supply chain capabilities.

The lack of clarity on what fraction of UK content SAE Renewables has achieved has made it a challenge clearly to ascertain what the local content is across the TSE sector. But having two TSE projects achieve high local (UK) content still shows potential to for the whole industry achieve high local content overall. This is particularly the case as Orbital Marine Power currently has the most powerful tidal stream turbine and company ranks second in TSE sector.

4.2.2 Material requirements.

Figure 19 is an extract of the average fractions of material usage in horizontal axis tidal stream turbines based on designs taken across Europe (including the UK) [8]. As these values are averages, there will be some variations on percentages across different designs. As the dominant designs in the tidal stream sector are horizontal axis turbines, this provides insight into the material requirements of UK tidal stream turbines. Based on this data, steel, and concrete account for the largest share of material in these designs at 50.2% and 32.7% respectively. These are followed by plastics and other metals which take up 6.9% and 6.4% of total weight respectively. .

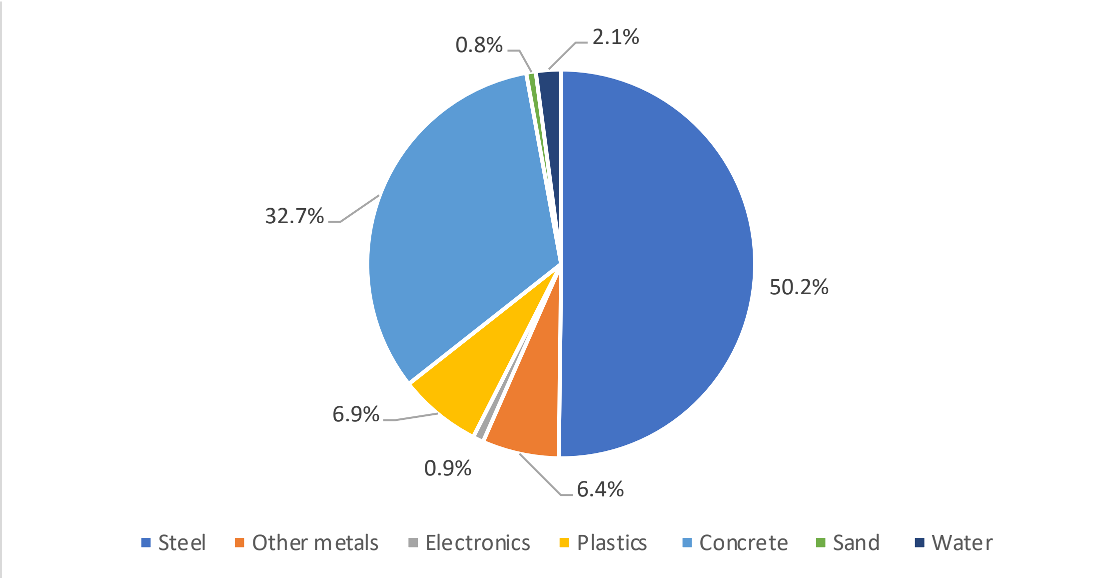

Figure 19- Share of material used in horizontal axis wind turbines as a percentage of total weight [8].

4.3 Results and Discussion.

The UK is achieving high local content in tidal stream energy which highlights that there is an opportunity for the UK to achieve higher local content in tidal stream energy and achieve better socioeconomic benefits. However, government will need to scale their investment in the tidal sector as it develops further to support development of supply chains tailored to the tidal sector. FOW shows a greater opportunity to increase UK content compared to fixed bottom offshore wind, but less than the tidal stream sector. Through the government's sector deal that includes government supporting the deployment of 30 GW offshore wind (of which 1-5GW is FOW), this can support the buildout of these supply chains and achieve the 60% UK content target by 2030.

Materials have direct implications on delivery of supply chain segments. Figure 20 and Figure 21 shows correlation of material price inflation and supply chain segments inflation.

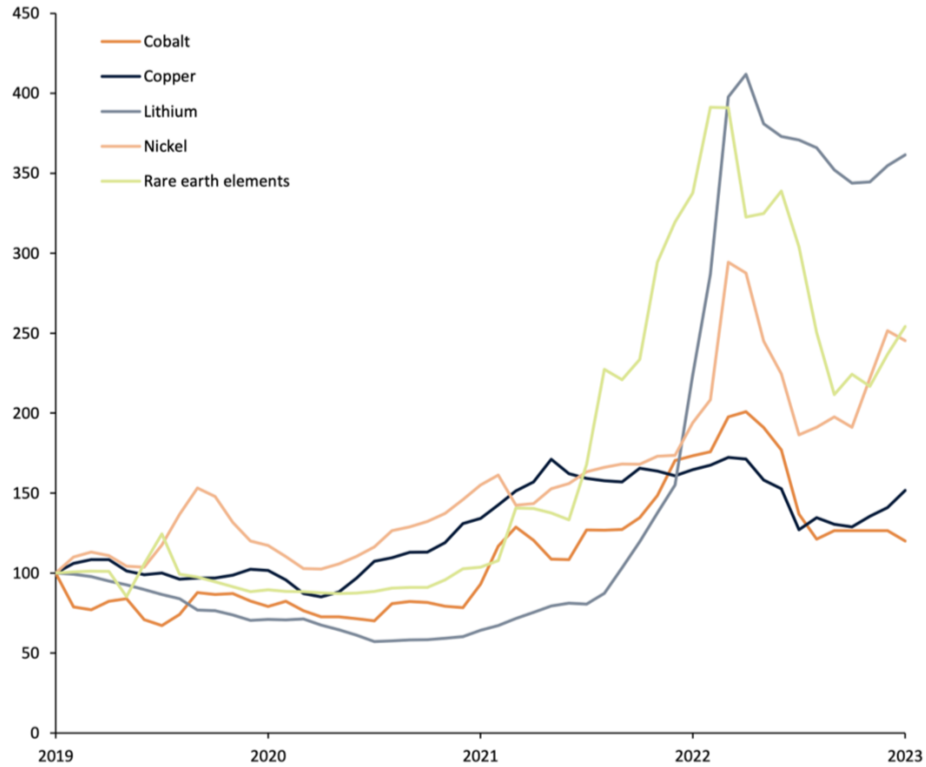

Figure 20- "Global price inflation of select materials critical in low carbon industries, indexed 2019=100" [60].

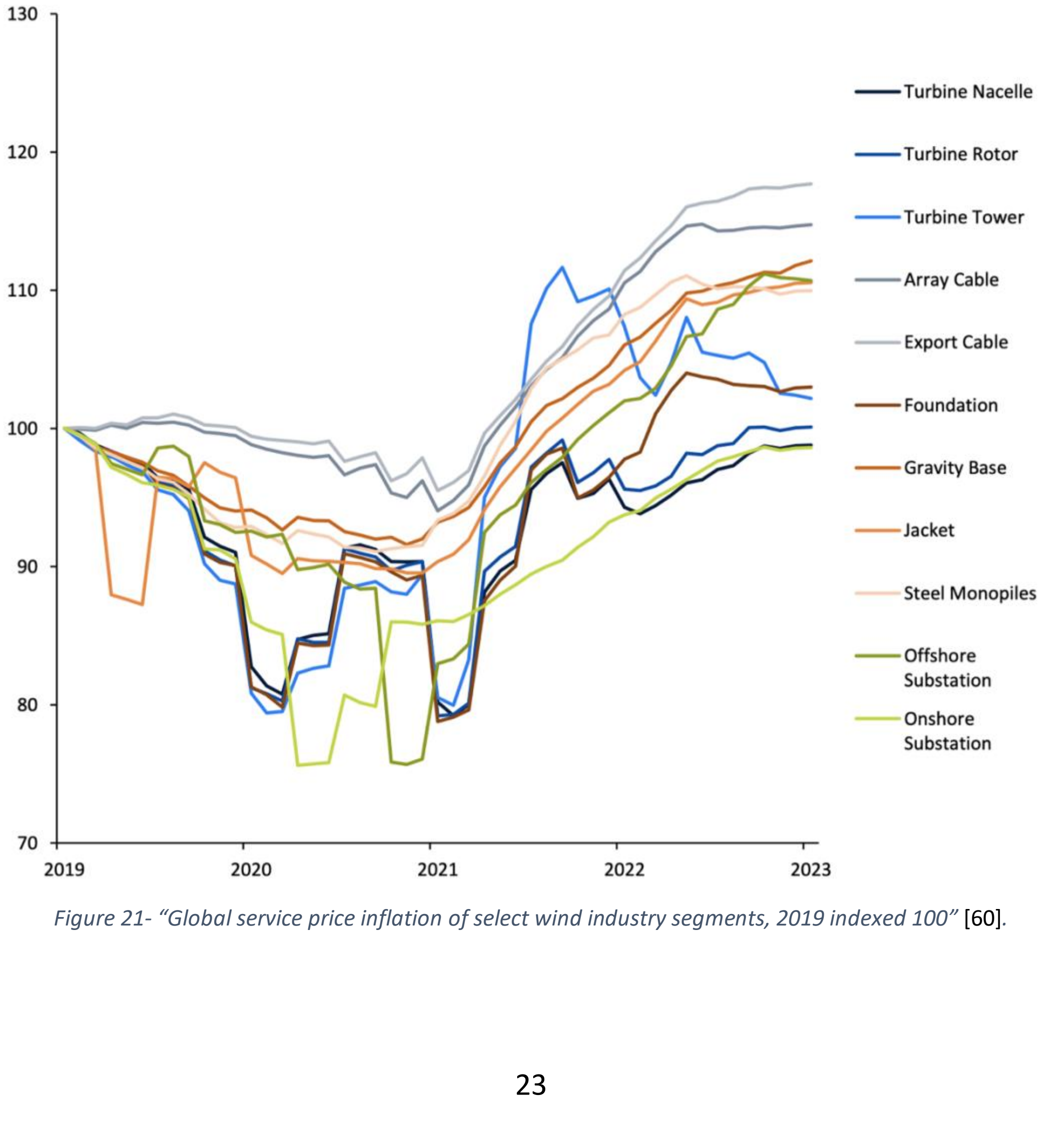

Figure 21- "Global service price inflation of select wind industry segments, 2019 indexed 100" [60].

The prices of materials and industry segments starting in 2022 were negatively affected by global inflation and energy crisis which linked to various geopolitical issues including Covid-19 and Russia's invasion of Ukraine [60]. These had negative implications on the wind industry with critical components having to be sourced at higher prices. An example of a country that was negatively impacted was Germany, which has one of the strongest supply chains. Key manufacturers went closed or bankrupt resulting in a decrease in Germany's ability to sufficiently cater for all parts of its supply chain [65]

Currently China has global dominance in the supply of critical raw materials [65]. After the covid-19 crisis passed, most countries started implementing measures to promote recovery, however when China faced another wave of the pandemic, economic restrictions were implemented, which also led to a slowdown in trade flows. However, China is also the largest consumer of materials for renewable energy, a majority of this is used locally.

These issues raised an alarm on the need for reliable supply of raw materials, as this has a direct impact the delivery renewable energy and net zero targets.

5 Results and Discussion Part 2: Analysing Requirements for a Competitive UK Tidal Stream Energy Sector using 3 Case Studies.

This chapter will analyse requirements for a competitive TSE sector in the UK drawing upon three case studies. Observing the similarity between subsystem components of wind energy and tidal stream energy, comparisons between Orbital Marine Power, Enercon and Ingeteam will be made to analyse tidal stream energy sector competitiveness. Comparisons are considered across 3 metrics: the level of public and private funding, and investment in research.

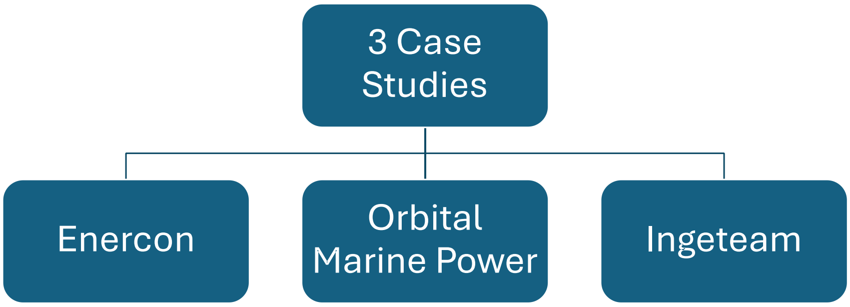

Figure 22- Case Studies.

While the 3 case studies are used to represent their industries, they won't be able to provide a complete picture of the performance of their industries. However, because they are major players and capture larger market shares in their respective industries, they can provide a representation of their industries.

5.1 Case study 1: ENERCON.

Enercon has been selected as they are a market leader in the German wind energy sector capturing 25.7% of onshore installations in Germany [66]. Enercon will be used to highlight features that characterise a competitive supply chain.

They are a market leader in onshore wind energy capturing 2.1% of global installations in 2022, having deployed 1864M of in new installations [66]. Enercon has successfully achieved a cumulative total of 60GW in wind turbine installations globally, this accounts for 32,000 turbines installed [67]. The company now employs 13,600 people globally [68].

Enercon has six production facilities with sites in Germany and across Europe that manufacture hubs, nacelles and generators [69]. They also collaborate with partners in China, India, and Turkey to supply wind turbine components [70]. Enercon works with 5700 suppliers globally with 87% of supply volume coming from Europe [66].

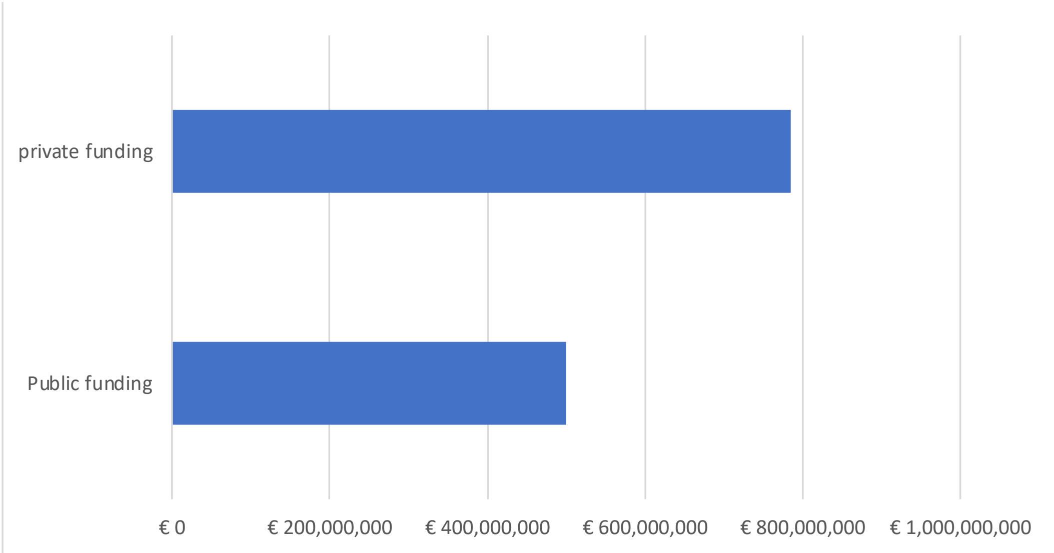

Figure 23- Funding ENERCON received [68], [71].

Enercon has raised a total of €784 million in private funding and €500 million in public funding [68], [71]. Due to the covid pandemic, several industries impacted, including some of Germany's offshore wind suppliers and developers.

5.2 Case Study 2: Orbital Marine Power.

Orbital Marine Power has been selected to represent the current capabilities of the UK tidal stream sector as it has a large market share and has the strongest tidal stream turbine [72]. They have 2MW installed capacity [73].

Orbital Marine Power had received CFD for 7.2MW of projects at a strike price of £178.54/MWh and 72.MW of projects at a strike price of £198/MWh for CFD round 4 and 5 respectively [22], [23]. CFD protect developers from price volatility and contracts run for 15 years [24]. When market prices are below the strike price, the scheme pays the developer the price difference and when market prices are above strike price, the developer pays the scheme the excess funds [24]. The nature of this scheme makes it challenging to predict exactly how much funding the developer will get from the scheme.

However, the National grid ESO provides estimates of what the actual budget of the pot will be [22], [23]. By looking at the number of projects that were awarded contracts in this pot, and estimating what share of the pot Orbital Marine gets assuming this share is proportional to the size of the project in MW and strike price, Orbital Marine Power's funding is estimated at £27.905 million. Please see Appendix 2: Calculating Orbital Marine Funding.

Orbital Marine Power raised a total of $59.21 million (£46.89 million) through grants venture capital funding and public funding (excludes CFD funding) [74]. Out of this funding €17.6 million (£15.31 million) was public funding from the EU horizon programme for R&D) [8], [55]. That means at most £31.58 was private funding. It is difficult to estimate accurately as the pitchbook data does not disclose all names of investors.

Figure 24 shows estimates of total public and private funding Orbital Marine Power has secured. Overall, Orbital Marine Power has secured £31.58 million in private funding and £43.22 million in public funding.

To support their R&D activities they have established a partnership with the University of Edinburgh [75]. The University is providing support in developing tidal turbine blades and providing access to their blade testing facility. Orbital Marine Power has a total of 15 patent families [74].

Figure 24-Funding Orbital Marine has secured [8], [22], [23], [74].

5.3 Case Study 3: Ingeteam.

Ingeteam is a Spanish organisation that develops technology for the conversion of electrical energy across a range of sectors including wind energy and hydroelectric energy [76]. Some of the technology they develop for the wind energy sector includes generators, convertors, and control electronics [76]. They are one of the most successful suppliers of components for wind turbine manufacturers having installed 22,000 generators delivering a total capacity of 40.5 GW since 1940 and 28,000 power convertors which have delivered a total capacity of 55GW [77].

Ingeteam employs approximately 4,000 people, with offices in 22 countries including manufacturing plants in the USA, Spain, Brazil, and India [67],[68]. They also have subsidiaries in 18 countries including the UK and Germany [78], [79]. It is not clear how much local content Ingeteam has achieved based on publicly available information.

R&D is an important part of Ingeteam' business. This has enabled them to stay competitive and enabled them to create different technologies across different sectors. Investment in R&D accounts for 5% of their turnover, 11% of their staff is dedicated to R&D and they have 7 laboratories and a research institutes in Spain [80]. According to JUSTIA Patents, Ingeteam had 57 patents issued between 2012 and 2023 [81].

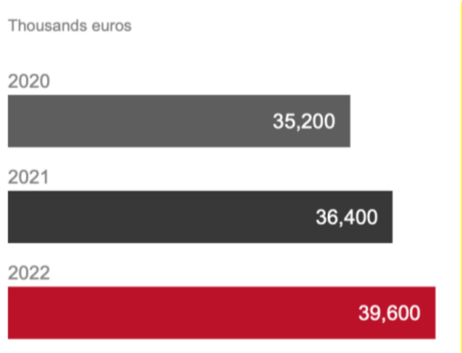

Figure 25- Ingeteam's recent R&D Investments [80].

They also created a strategic partnership with a local university to develop new products and expand the company's portfolio [82]. This helped Ingeteam adapt their offering in a wind energy market that requires specialised equipment. The university benefits from their partnership by having their research findings validated, receiving guidelines from industry on where to focus research and opportunities to develop publications.

They have been awarded 4 loans totalling €216 million from the European Investment Bank (EIB) to be invested in research, development, and innovation between 2011 and 2023 [83], [84], [85], [86]. Ingeteam has also received a total of € 10.9 million in government subsidies between 2012-2014. This brings the total public funding received to € 226.9 million.

5.4 Results and Discussion.

Having looked at the three case studies, this section will look at ENERCON and Ingeteam which highlight features of strong industries and compare them to Orbital Marine Power which highlights the current features of the UK TSE sector. By drawing comparisons, it is possible to ascertain if the UK TSE sector has the features required for a strong industry with competitive supply chains. Key metrics considered are, levels of public and private investment received, company investment in research and development.

Both Ingeteam and Orbital Marine Power have shown commitment to investment in R&D. Ingeteam commits to investing 5% of their turnover in R&D and they have also acquired loans to support their R&D activities. For Orbital Marine Power, at least 20% of the total funding they received was for R&D activities, this shows a high level of support for tidal stream R&D activities. As part of their strategies to support R&D both companies have established strong partnerships with a universities. This has meant both companies have been able to receive support from universities in developing their products through research. There are no public records on how much ENERCON has invested in research activities.

ENERCON have received significant amounts of private investment. When it comes to the amount of private investment an industry receives, this often correlates to the level of public funding. Public funding often signals to investors that the industry/sector receiving public funding has government support. For both companies, private investment made up a significant fraction of total investment received. This signals that private investment has a crucial role in the development of competitive industries. There is no publicly available data on the amount of private investment Ingeteam received.

All three companies have received significant amounts of public funding. Access to public funding has proven important to ENERCON and Ingeteam success. For Ingeteam in particular, this funding was awarded to support their R&D activities which had been important in building their competitive portfolio of products. For Orbital Marine Power, there now is significant public support, but this has been inconsistent in the past which caused uncertainty in the industry, which also diminishes the attractiveness of tidal stream energy to private investors. There will be a need for a wider commitment from the government, with government committing to deployment targets like it had done with its offshore wind sector deal.

Based on these case studies, the UK tidal stream sector is doing well in ensuring its competitiveness. To evidence this the UK has the largest installed capacity in the tidal stream energy sector across the world [87]. The level of public funding has been particularly important in deploying this capacity. However, the UK government needs to create and commit to deployment targets to ensure UK competitiveness is maintained.

6 Conclusions and Recommendations for Further Work.

This dissertation focused on the analysis of the UK supply chain capabilities and requirements for a competitive offshore renewable energy industry.

The literature review highlights various offshore renewable energy (ORE) technologies, analyses the ORE market, and highlights the workforce needs and key competitors to the UK. The results and discussion section evaluates the supply chain capabilities and requirements for tidal and FOW energy in the UK, examining strengths, weaknesses, and opportunities within these sectors.

The main ORE technologies covered in this dissertation are floating offshore wind, tidal stream, and wave energy.

FOW and tidal stream energy are about to become commercially mature, while wave energy is less developed. In FOW energy the most notable projects include Hywind Scotland developed by Equinor and Kincardine developed by Principle Power, with capacities of 30 MW and 47.5 MW respectively. Key developers in tidal stream energy in the UK include SAE Renewables, Orbital Marine Power, Magallanes, and Hydrowing. Dominant designs in wave energy are CETO, MARMOK, Blue Horizon 250 and Archimedes Waveswing.

Wave R&D activities in the UK are driven by Europe Wave and Wave Energy Scotland while tidal stream energy and FOW are being supported by contracts for difference and the floating offshore wind demonstration programme.

Based on studies by ORE Supergen Hub, the UK needs to deploy 6GW of wave energy, 6GW of tidal stream energy and 45GW of FOW energy by 2050 to support net zero. The expected economic benefit was £4.47 billion, £4.38 billion and £32.53 billion from the deployment of TSE, wave energy and FOW energy respectively. These studies assumed in a high ambition scenario were the UK had high fractions of local content. The deployment of tidal stream energy and wave energy is expected to benefit the UK energy grid by reducing reliance on battery storage and interconnectors. These studies assume the EU SET Plans for net zero, with targets for significant cost reductions are achieved.

Floating offshore wind energy is expected to support 17,000 jobs, tidal stream energy 14,500 and wave energy 8,100 jobs by 2050.

Competitors to the UK in floating offshore wind are France, Portugal, Japan, and Norway. Tidal stream energy competitors include Canada, China, France, Ireland, the Netherlands, and the USA. Wave energy competitors include Denmark, the USA, Italy, Sweden, Australia, and Norway.

The results and discussion sections of the dissertation focused on analysing the UK supply chain capabilities of FOW energy and tidal stream energy which share similar subsystems. The second part of the results and discussion narrowed down further to tidal stream energy.

Floating offshore wind has only been able to achieve 48% local content, much lower than tidal stream energy despite wind energy being more developed. The industry has targets to increase local content to 60%. FOW energy presents an opportunity to increase local content of offshore wind as floating platform designs are drawing from the oil and gas industry which has established supply chains in the UK.

One key opportunity for the UK to expand its local content in FOW is investment in ports and fabrication facilities. Estimates by ORE Catapult highlight a need for £883 million investment in these facilities. This investment has potential to secure 40% of total project cost.

The UK tidal stream sector has been able to achieve high local content with two developers being able to achieve up to 80% local content. As it stands, the UK tidal stream sector is drawing upon supply chains from other industries. There will be a need for continued support from the government to facilitate the development of tidal stream energy supply chains that are specialised to this sector and to enable supply chains to scale operations.

After investigating the material requirements for FOW turbines and tidal stream turbines, this research revealed a need for reliable material supply chains. Right now, China is the largest supplier of raw materials, and this has had serious implications on the delivery of ORE. At a time when the COVID-19 crisis passed and countries where implementing recovery measures, China was hit by another wave of the pandemic and had to implement economic restrictions. This negatively impacted the delivery of renewables particularly offshore wind energy across different parts of the world that relied on China for raw material supply. This highlighted the need for building reliable material supply chains to avoid dependence on one supplier.

The second part of the results and discussion considered case studies of ENERCON, Orbital Marine Power and Ingeteam. Comparisons were drawn to across the three to analyse the competitiveness of the tidal stream sector. The results of these case studies showed that the UK tidal stream sector was competitive. When compared to ENERCON and Ingeteam, Orbital Marine Power shared the same characteristics as the other two companies across a range of metrics.

Orbital Marine Power had received significant public funding and private funding evidencing significant public and private support towards the tidal stream industry. Based on the support received the tidal sector is on track for the delivery 6GW by 2050. However, there is still need for the UK government to show additional commitment to the deployment of tidal stream energy by setting deployment targets as they have done with FOW. This will help promote a level of consistency that is essential for the buildout of the UK tidal stream energy capacity. Without government commitment, this has potential to undermine UK competitiveness and the delivery of 6GW of TSE by 2050.

Based on UK government commitment through the offshore wind sector deal, government is on track to deliver 45GW of offshore wind. The government has committed to supporting deployment FOW with targets for 1-5GW by 2030. However, the lack of similar commitment towards deployment of wave energy will undermine UK competitiveness in wave energy.

After conducting this study, there are some key areas in which further work can be conducted. The wave energy sector supply chain analysis has not been conducted in-depth as the industry is much less mature than FOW and tidal stream energy. This is an area for further investigation as the sector matures. For tidal stream energy, the lack of availability of literature limited the scope of this project. To circumvent this, future requirements for the tidal stream sector where analysed using case studies. For future work, this study recommends revisiting the future requirements for the tidal stream sectors when the technology achieves commercial maturity and has more literature.

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Appendices.

Appendix 1: Technology Readiness Levels.

TRL is a measure of the level of maturity of a technology [19], [20]. There are 9 TRLs.

TRL9 Operations
TRL 9 signifies the highest level in which the actual system been proven and has been successfully deployed/commissioned in operational environment.

TRL8 Active Commissioning
At this level an actual system is completed, undergoes tests and is qualified.

TRL7 Inactive Commissioning
At this level a prototype is demonstrated in an operational environment.

TRL6 Large Scale
At this level, the technology is a full representational model or fully functional prototype.

TRL5 Pilot Scale
TRL 5 is a pilot phase in which key components/breadboard are tested in conditions as close to realistic environmental conditions as possible.

TRL4 Bench Scale Research
At this level multiple components are tested together.

TRL3 Proof of Concept
This level includes laboratory and analytical studies to test viability in order determine whether to proceed further in the development process.

TRL2 Invention and Research
At this level basic principles are studied. Practical applications of initial findings are considered. At this level there is usually not proven experimentally.

TRL1 Basic Principles
TRL1 represents the lowest level with basic principles being observed and reported from preliminary research.

Appendix 2: Calculating Orbital Marine Funding.

Exchange rates used.
£0.79187= $1 (based on an average rate for past 6 months).
£0.86975=€1 (based on average for 2023)

Key funds Orbital Marine has received.
Orbital marine raised a total of $59.21 million (£46.89 million) through grants venture capital funding and public funding (excludes CFD which will be estimated separately). Out of this funding €17.6 million (£15.31 million) was public funding from the EU horizon programme for R&D). That means at most £31.58 was private funding.

Estimating value of CFD contracts

CFD round 5 [22]
Calculating total funding in pot 2 based on estimates of actual monetary budget impact of pot 2 (£).

2026/27	2027/28	2028/29	2029/30
5058780	13665589	36524456	37691356

Total Estimated monetary budget impact	92940181

To evaluate what share of the total budget of pot 2 Orbital marine gets assuming that the share each project gets of pot 2 total budget is equivalent to size (MW) and strike price (£/MWhr).

Round 5 winners of pot 2.

Project Name	Technology Type	Size (MW)	Strike Price (£/MWh)	Share of pot (£/hr)
Manhay Geothermal Power Pla	Geothermal	5.00	119.00	595
Penhallow Geothermal Power P	Geothermal	5.00	119.00	595
United Downs Geothermal Pow	Geothermal	2.00	119.00	238
MeyGen AR51	Tidal Stream	11.80	198.00	2336.4
Ynni'r Lleuad	Tidal Stream	10.00	198.00	1980
MeyGen AR52	Tidal Stream	5.60	198.00	1108.8
Morlais Verdant Isles BL3	Tidal Stream	4.90	198.00	970.2
Orbital Marine Eday 4	Tidal Stream	4.80	198.00	950.4
Morlais Mor Energy Zone GO3	Tidal Stream	4.50	198.00	891
Morlais Magallanes GR3 Extensi	Tidal Stream	3.00	198.00	594
MeyGen AR53	Tidal Stream	2.94	198.00	582.12
Orbital Marine Eday 3	Tidal Stream	2.40	198.00	475.2
MeyGen AR54	Tidal Stream	1.60	198.00	316.8
EMEC Magallanes Berth 1	Tidal Stream	1.50	198.00	297
			Total (£/hr)	11929.92

Orbital marine total share (£/hr)	1425.6

Orbitals estimated total share of pot 2 funding (£)	11106153.4

CFD Round 4 [23].
Calculating total funding in pot 2 based on estimates of actual monetary budget impact of pot 2 (£).

2025/26	2026/27	2027/28	2028/29
1022096	3558482	43194943	60671110

Total Estimated monetary budget impact (£)	108446631

To evaluate what share of the total budget of pot 2 Orbital marine gets assuming that the share each project gets of pot 2 total budget is equivalent to size (MW) and strike price (£/MWhr).

Round 4 winners of pot 2.

Project Name	**Size (MW)**	**Strike Price (£/MWh)**	Share of pot (£/hr)
TwinHub Floating Offshore Win	32	87.3	2793.6
Stornoway Wind Farm	200	46.39	9278
Orkney Community Wind Farm	28.8	46.39	1336.032
Orkney Community Wind Farm	28.8	46.39	1336.032
Mossy Hill	48	46.39	2226.72
Beaw Field	72	46.39	3340.08
Viking Wind Farm	220	46.39	10205.8
Orbital MarineEday 2	4.8	178.54	856.992
Morlais Maggallanes GR3	5.62	178.54	1003.3948
Orbital Marine Eday 1	2.4	178.54	428.496
MeyGen Phase 2	28	178.54	4999.12
		Total (£/hr)	37804.2668

Orbital marine total (£/hr)	5856.112
Orbitals estimated total share of pot 2 funding (£)	16799046
Total estimated funding from CFD round 4 and 5	27905199.4

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