TIGER TIDAL STREAM INDUSTRY ENERGISER

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TIGER Site Development Report: Ramsey Sound T3.2.1

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Acronyms

Acronym	Description
AR4	Allocation Round 4
COSW	Cambrian Offshore South West Ltd.
ERDF	European Regional Development Fund
FCE	France (Channel Manche) England
JS	Joint Secretariat
JV	Joint venture
MEC	Marine Energy Council
MEW	Marine Energy Wales
MHWS	Mean high water springs
OREC	Offshore Renewable Energy Catapult
PSG	Project Steering Group
SAC	Special Area of Conservation
SAG	Stakeholder Steering Group
SPA	Special Protected Areas
SSSI	Site of Special Scientific Interest
TIGER	Tidal Stream Industry Energiser Project
TEL	Tidal Energy Ltd.
TSE	Tidal stream energy
WADZ	West Anglesey Demonstration Zone

Executive Summary

Ramsey Sound is a promising location for tidal stream energy (TSE) located off the coast of South West Wales between Ramsey Island and the mainland. Within the Sound there is a project lease, owned by project developer Cambrian Offshore South West Ltd (COSW). Their aim is to recover a device previously tested at the site and abandoned on the seabed and retrofit it or deploy a brand new turbine. This work is being supported by the Tidal Stream Industry Energiser (TIGER) Project, a €45.3M Interreg funded project assisting developments at six sites in the Channel region between the UK and France.

The aim of this report is to assess the potential of the Ramsey Sound site for a commercial TSE array. The report is targeted at prospective project developers, investors, investors, policymakers and suppliers who would benefit from an updated holistic and third-party evaluation. Our study consists of the following aspects:

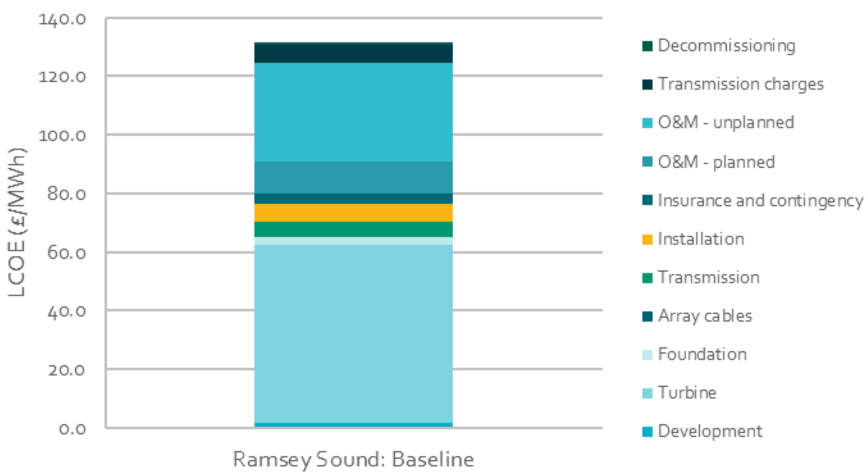
- *A Literature review*: including descriptions of the history of the site, the main stakeholders, regional support and schemes and the flow conditions.
- *A GIS analysis*: to assess the size of the commercial farm that could be built, identify potential impacts on other sea users and show the potential barriers and geographical aspects that must be considered.
- *A techno-economic analysis*: to estimate the levelized cost of energy (LCOE) that a representative farm at the site could achieve and the CfD strike price that would be required to encourage project development and private investment. We considered optimistic and pessimistic industry cases and applied learning rates to gain insight into the trajectory of LCOE and appropriate CfD strike price over time.

From our analysis we provide the following insights into the site:

- Ramsey Sound is a remote location with low barriers to development. There do not appear to be any significant conflicts with other sea users as the sound and surrounding area have little to no significant fishing or commercial shipping activity. The exception to this could be environmental designations, as the whole coastline lies withing a Special Area of Conservation (SAC) and Ramsey Island a Site of Special Scientific Interest (SSSI). This would need to be explored further for a larger 10MW+ array.
- The flow speeds are decent, tidal flow modelling using the coastal flow solver THETIS indicating maximum spring tidal currents exceeding 5m/s. The area is known for its uneven bathymetry, resulting in a turbulent, uneven flow which may make the site less desirable for some types of technology.
- Outside of the Ramsey Sound itself there are locations that could be suitable for both fixed and floating devices of both small and utility scale. These warrant further investigation as next generation sites, with emphasis on devices designed for lower flow conditions.
- The GIS analysis indicated a 0.6km2 area within the COSW lease area suitable for a small-scale technology. Analysis by the University of Plymouth using THETIS suggested that a 40 device farm of 0.5MW devices (15m rotor diameter) would have a gross capacity factor of 36%. We used this representative case as the basis for the techno-economic assessment.

- By 2030 our model indicates that a 20MW farm (40x0.5MW turbines) could be deployed at an LCOE of £85-£195/MWh with a central estimate of £131/MWh (as shown below). At this central estimate we believe that £191/MWh would be a sufficient level for a CfD. This would ensure a 7.5% project IRR (unlevered, assuming 100% equity) and hence offer a reasonable prospect for private funding streams.
- Our study considers one hypothetical farm example. There are numerous project options that could unlock greater levels of cost reduction, bringing the LCOE down to the lower £85/MWh estimate. These could include greater economies of scale from larger farms, techno-economic optimisation of rotor diameter and turbine rated power and improved O&M strategy, among other things.

To summarise, our analysis shows that Ramsey Sound is a site with decent potential for an early commercial array and could provide meaningful amounts of predictable power into the Pembrokeshire grid. The success of the site could depend on the cost trajectory of small, sub 1MW turbines. The commercial prospects of this site will improve once we see TSE deployed on a larger scale, and it will likely be a site of interest by 2030 as other commercial locations are developed and lessons are learnt.



LCOE breakdown for the Baseline scenario. Note that this is quoted in 2012 terms to be consistent with the base year for strike prices

The Welsh mainland from the Ramsey Sound [1].

1 Introduction

Tidal stream energy (TSE) is gaining traction with policymakers. While historically political support has been mixed, in the UK the industry was awarded a £20M per annum ringfence in Contract for Difference (CfD) Allocation Round 4 (AR4) in late 2021. In France there are several projects under development, with arrays in the La Raz Blanchard negotiating Power Purchase Agreements (PPA) with the regulator.

TSE technology has unique advantages that make it well suited for a role in our future energy system. These include extremely high predictability of the resource, a skilled domestic supply chain with high local content on early projects and anticipated high energy density of farms. In light of recent geopolitical events (Russia-Ukraine conflict) and current high energy prices, TSE offers a dependable and regular cyclical production profile that can strengthen energy security.

Ramsey Sound is a stretch of water between the Ramsey Island and the Welsh mainland. There has been longstanding interest in the area as a place for a TSE demonstrator project, with potential scope for an early commercial array.

The site has many advantages that make it an ideal candidate for such a project. It is well sheltered and has close proximity to the electricity grid and Pembroke Dock. Moreover, previous development of the site by Tidal Energy Limited (TEL) means that there is good understanding of the site, with permits already in place for a turbine of up to1.2MW farm. This lease includes an offtake agreement at a level of five ROCs, a generous subsidy, which would give a source of income to a developer of the scheme.

Cambrian Offshore are the owners of the site. Within the activities of the TIGER project they plan to recover an existing device deployed at the site in 2015 (the TEL Deltastream) and deploy new technology. Outside of the 1.4MW lease, there is the potential for further TSE in the wider region. St David’s head to the north is regarded as a promising area, but has not been researched to the same extent as the Ramsey Sound.

This site report describes the wider Pembrokeshire region, encompassing both the Ramsey Sound and St David’s Head, and assesses the future TSE capacity that could be deployed.

1.1 Cambrian Offshore South West Ltd.

Cambrian Offshore South West Ltd (COSW) was founded in 2018. COSW acquired the Ramsey Sound assets of TEL in 2019. The initial aim of the company is to repurpose the

Ramsey Sound site via the Ramsey Sound Regeneration project, using as much of the existing infrastructure as is possible, taking on the role of project developer.

The COSW team have over 30 years of experience in marine energy and have held director level positions in a number of high-profile companies. Managers of COSW also lead the UK Marine Energy Council (MEC). This is an organisation made up of representatives from the leading UK-based wave and TSE companies, which aims to commercialise the industry and encourage industry-wide collaboration.

1.2 TIGER activities

Unlike some of the other sites being developed in TIGER, the Ramsey Sound already has a marine license for 1.4MW of capacity. The aim of TIGER is to assist the license holder, Cambrian Offshore South West Ltd. (COSW) in deploying technology at this site.

The first activity is to recover the TEL Deltastream from the seabed. This will be forensically examined, providing valuable insight on the impact of the marine environment on the structure.

COSW will then deploy a new device at the site. This would mean either repurposing the current Deltastream with new rotors or procuring a new turbine from an established TSE technology supplier (for example, Proteus Marine Renewables, Orbital Marine Power, Verdant Power or Sabella).

The TIGER project is a broad base of partners, including academia, research and industry. It is led by the Offshore Renewable Energy Catapult (OREC). By linking COSW with other partners, particularly the academic institutions, the project will allow faster and more cost effective development of the Ramsey Sound site.

A key ambition of TIGER is also to bolster relationships between UK and French organisations. COSW's influential role within the MEC means that they are well suited to lead this effort, expanding the knowledge and experience of the UK members to accelerate the French industry.

2 Site history

2.1 Ramsey Sound

As interest into TSE increased in the 2000s, Ramsey Sound was identified by a number of early studies as a promising location (for example [2]).

Historically, the majority of investment in the site was done by TEL. TEL was founded in 2001. They commissioned a study from ABPmer, prior to 2008, that indicated several promising TSE sites across the UK [3]. Ultimately Ramsey Sound was chosen due to a number of advantages including its sheltered location and close proximity to grid and port facilities. The location of the project within the Sound is shown in Figure 2.

Around this time, E.ON also announced a collaboration with Lunar Energy to develop a TSE project in the Ramsey Sound [4]. This would have a been a six turbine, 8MW project, made up of Rotech's ducted tidal turbines [5], however the project never went ahead and Lunar Energy was eventually dissolved.

In 2011 TEL obtained consent to test a prototype of their DeltaStream within the Ramsey Sound, at coordinates 51^{o} 52' 40" N and 05^{o} 19' 34" W.

The DeltaStream device is shown in Figure 3. The concept consisted of three 400kW, 15m diameter rotors mounted to a triangular frame and fixed to the seabed. The installed prototype featured a single 12m diameter rotor on a smaller triangular frame, in order to firstly demonstrate the turbine technology and keep costs down ahead of upscaling.

The device was deployed in December 2015. Electricity was successfully created and transferred to the grid but, after about a month of operation, the device developed a fault in its sonar system for detecting marine wildlife and hence could not be operated within its marine license [6]. A further mechanical problem occurred, before the company went into administration in October 2016. The device is still on the seabed, with recovery of the device planned and funded by the TIGER project.

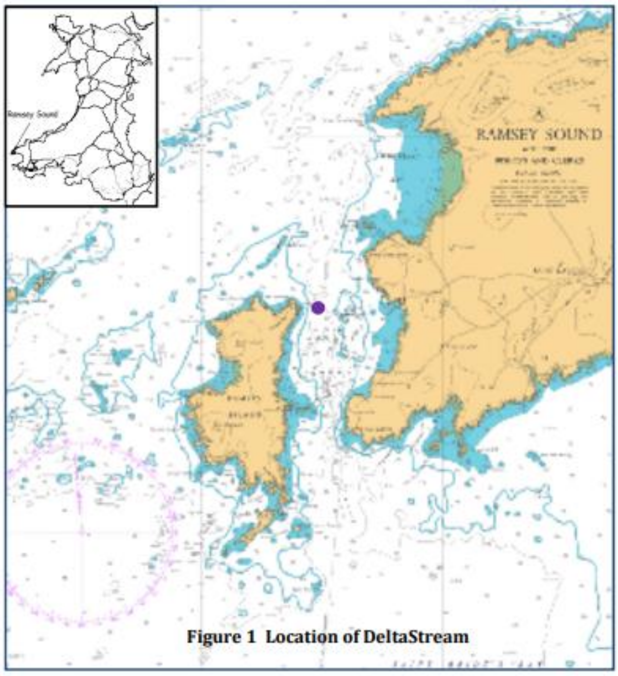


Figure 1 – Location of the DeltaStream in the Ramsey Sound. Taken from [7].

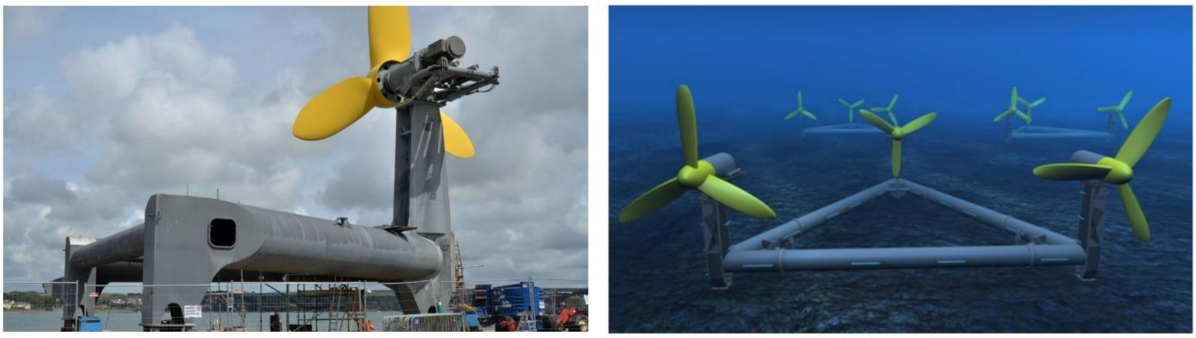


Figure 2 – The TEL DeltaStream. Left: The device that was constructed and installed at Ramsey Sound. Image is from 2014 at Pembroke Port. Right: artist's impression of an array of DeltaStream devices.

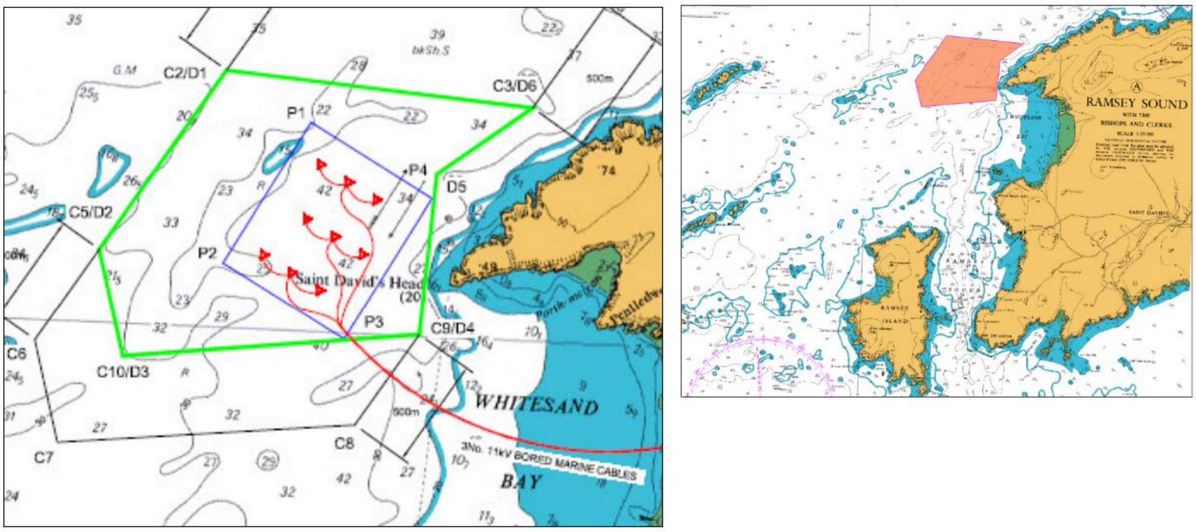


Figure 3 – TEL's proposed 10MW commercial array at St David's Head. Left: Proposed site boundary and turbine locations. Right: Location of the area of search with respect to the Ramsey Sound. Taken from [8].

2.2 St David's Head

In 2012, TEL obtained a lease agreement with the Crown Estate for up to 10MW operating for a period of 25 years. The location of this planned project is shown in Figure **4**. The lease was valid for five years, until 2017, giving TEL time to carry out the necessary surveys and get planning consent and marine licenses for a full lease.

The planned project was a commercial array of nine devices, rated at 1.2MW each [8]. This was going to be the next project phase after the Ramsey Sound demonstrator project, but was never progressed as TEL went into administration. To the author's knowledge, no other TSE developers have publicly expressed an interest in this area since TEL's demise, likely because the tidal resource is relatively low and the site is exposed to wave conditions.

3 The region

3.1 Wales

Wales has a strong industrial heritage and was regarded as the world's first industrial nation. This was largely spearheaded by the abundance of coal, which was mined in the valleys and shipped worldwide, as well as other raw materials like iron ore, copper and limestone. Indeed, Swansea was formerly known as "Copperopolis" and was the centre of global copper production in the early 1800s [9].

The Welsh coal industry suffered a decline into the 20th century, pit closures and a shrinking workforce due to several factors (namely the rise of the nuclear industry and North sea oil). This came with some significant social impacts, particularly in the valleys which saw outmigration [10]. A key focus for government has been to reduce such social impacts and provide rejuvenation to Welsh communities. Recent examples with relevance to marine renewables include:

- *The Welsh Government Coastal Communities Fund*. The aim of this was to promote sustainable economic growth and jobs for coastal communities [11].
- *The Small Scale Coastal Infrastructure Scheme*: This scheme makes grants of up to £100,000 available to ports and harbours for capitals expenditure [12].

Wales is of significant interest for marine energy. It has a coastline of about 2,700km (Including Anglesey and Holy Island), with significant TSE resource both in the North, most of this off Anglesey, and in the South in Pembrokeshire. It has been estimated that 6GW of wave energy and TSE could be deployed off the Welsh coast [13], with seabed agreements in place for 532MW [14].

The Welsh government has been very supportive of marine renewables. Examples of policy and support have included:

The Marine Renewable Energy Strategic Framework (2011).

This £1M study examined the marine energy resource in Welsh territorial waters and examined different scenarios on how it could be exploited [15]. Targeting a 4GW deployment capacity by 2025, the study found that up to 6.4GW could be possible in the high deployment scenario. The amount of capacity was very dependent on the constraints that were assumed, that in reality may or may not be acceptable. The analysis was largely GIS-based.

SMARTCymru

This scheme, run by Business Wales, supports Welsh businesses and research organisations through ERDF (European Regional Development Fund) funding [16]. Funding is allocated via Innovation Vouchers, that can be used to purchase equipment or bring in expertise. They also offer technical and commercial feasibility services.

Examples of marine energy companies who have used this service include Bombora Wave Power [17] and Marine Power Systems [18].

Welsh European Funding Office EU Structural Funds

Wales received £2bn of European Structural Funds from the EU for the period 2014-2020. Of this, £100m was allocated to marine renewable energy. This money was administered by the Welsh European Funding Office, and has been used for various projects including £14.9M to Minesto to continue development of their Holyhead Deep project [19] and £10.3M to Bombora to construct and test their 1.5MW wave energy demonstrator [14].

3.1.1 Tidal stream projects in North Wales

Ramsey Sound and St David's Head are not the only TSE sites being examined in Wales. In North Wales, particularly around Anglesey and Holy Island, there is significant interest, with commercial projects being developed.

Morlais

Morlais is a TSE project being undertaken by Menter Môn, a social enterprise in North Wales who aims to deliver projects that benefit local communities. The aim of Morlais is to develop the West Anglesey Demonstration Zone (WADZ), a stretch of water off the west coast of Anglesey that was awarded a 45 year lease by The Crown Estate in 2014. It is a 35 km^2 area with an estimated 240MW of capacity [20].

The site is designed for developers to test and deploy their devices at scale. A key aim of the project is to showcase different types of TSE devices. In the current plans, Morlais would own the electrical infrastructure, including up to nine subsea cables. Developers would pay an annual site fee.

Several technology developers have signed up to the project, including HydroQuest, Sabella, Orbital Marine Power, Magallanes Renovables and Verdant Power [21]. Other industry partners include Black & Veatch and Royal Haskoning.

A consent application was submitted in autumn 2019. During 2020 various public consultations were held, with a decision expected in 2021. Several developers have ambitions to bid for tidal projects at Morlais as part of the UK Allocation Round 4 (AR4).

Holyhead Deep

Holyhead Deep is a project being undertaken by Minesto. Minesto are a Swedish TSE developer, and TIGER partner, with a strong Welsh presence. They have a novel tidal stream kite designed for low flow applications.

In 2014 Minesto were awarded an Agreement for Lease by The Crown Estate for a 10MW project. This was followed up with a Marine License in 2017 and an installation of a 500kW device in 2018, where the device was tested. The device was connected to a Micro Grid System buoy, rather than the grid, for monitoring and dissipating the electrical output.

Minesto's vision is to deploy 80MW of capacity at the site, rolled out over time. Due to the proximity of the site to the WADZ, Minesto are collaborating with Morlais to develop grid and cable infrastructure [22]. They also cite the Welsh government commitment to marine renewables as a key reason for choosing Holyhead as a site:

"Numerous locations around the UK were considered, but Wales was selected as the preferred option due to the highly suitable environmental conditions and government commitment to marine renewable energy, which offers significant opportunities to attract support and investment into the Holyhead project." [23]

Ynys Enlli (Bardsey Sound)

This project, also in North Wales, is being developed by Nova Innovation. Nova Innovation are a Scottish technology developer who specialize in smaller scale devices. Their Shetland Array was the world's first TSE array, with three 100kW turbines installed in 2016. A fourth turbine was added in late 2020, with two more to be installed in 2021/22.

The Enrii project is to be installed in the Swnt Enlli, or Bardsey Sound. The project will be up to 1MW, with Nova currently securing the necessary consents.

Offshore wind

Wales has three operational wind farms, all in the waters to the north: North Hoyle, Rhyl Flats and Gwynt y Môr. Awel y Môr , an extension to Gwynt y Môr is also in the development stages. The properties of these are shown in Table 1. All of the wind farms are operated by RWE Renewables.

Table 1 – Welsh offshore wind farms

Name	Developer	Commissioning date	Farm size (MW)	Turbine size (MW)	Foundation type
North Hoyle	RWE npower	2003	60	2	Monopile
Rhyl Flats	RWE npower	2009	90	3.6	Monopile

Gwynt y Môr	RWE npower	2015	576	3.6	Monopile
Mona	BP & ENBW	2028 (estimated)	Approx 1500	TBC	TBC (likely monopile)
Awel y Môr	RWE Renewables	2030 (estimated)	TBC (likely 300 – 1100)	TBC	TBC

All of the windfarms make landfall near the town of Rhyl in Denbighshire. The port of Mostyn was used for the construction and is used for the O&M bases of the wind farms.

3.2 Pembrokeshire

Pembrokeshire is a county in the southwest of Wales and is where the Ramsey Sound site is located. The population is about 125,000, with larger proportions than the GB average working in accommodation and food services (2x GB average), construction (1.5x) and extractive industries (2.2x) [24]. The two largest settlements in the region are Haverfordwest (population of about 15,000) and Milford Haven (population of about 14,000) [24].

In 2020, Pembrokeshire had the joint highest unemployment rate in the whole of Wales, at 6.4% [25]. While the rate of population growth was the highest in South West Wales between 2008-2018, there has been a general trend of outmigration of young people. This has resulted in an aging population demographic [24].

A study for Pembrokeshire County Council in 2015 [24] identified renewable energy, and specifically marine energy, as a significant opportunity for the region. This included mention of the powerful synergies with the ports of Milford Haven and Pembroke. These are described in section 3.2.2.

A thriving offshore renewables sector could bring prosperity and migration to the region, helping to reverse some of the trends that have been seen.

The 2.2 GW Pembroke Power Station is operated by RWE. Historically Pembrokeshire has been a net exporter to the grid [26], and grid capacity and infrastructure is very good, especially around Pembroke.

3.2.1 Marine Energy

Marine Energy Wales and META

Marine Energy Wales (MEW) was founded in 2016, set up by the Pembrokeshire Coastal Forum, although it has its origins further back, formerly known as Marine Energy Pembrokeshire. It has a focus on advancing the marine energy sector of Wales by bringing together technology developers, the supply chain, the public sector and academia. Emphasis is on establishing a strong Welsh marine energy sector and creating export potential for Welsh companies through first mover advantage.

MEW has an important role in promoting marine energy throughout Wales, particularly through communication with government.

A key project of MEW is the Marine Energy Test Area (META). This project is establishing national marine energy test areas around the Milford Haven Waterway. Eight sites have been identified and pre-consented, offering testing capability for small scale/scale models of TSE and wave devices.

Five first phase test sites are located adjacent to Pembroke Dock, quayside, and are suitable for microscale devices and scale models. Three second phase sites secured marine licenses in January 2021 [27], and offer open water test facilities for larger scale models and small commercial scale devices (water depths about 8-30m).

META has been getting assistance from the European Marine Energy Centre (EMEC), with an agreement signed in May 2020 [28]. This built on previous collaborations between the organisations. More recently, META has been working with Bangor University to characterize the tidal resource at their test sites, with ADCP data collected [29].

Pembrokeshire Development Zone

The Pembrokeshire Development Zone (PDZ) is a 90 km^2 demonstration zone to the south of Pembrokeshire, about 13-20km offshore [30]. A site lease was initially agreed with The Crown Estate in 2017. While the initial ambition was to use the site as a wave energy commercial demonstration site, the emphasis has shifted to floating wind over the last few years.

Wave Hub have estimated that the site could support up to three, 30MW arrays, and a 90MW floating wind project. The 400 kV transmission line at Pembroke is a touted advantage of the PDZ, and is likely where connection to grid would be made.

Floating wind

Within the Celtic Sea there are a number of floating wind demonstrator projects being developed, with the aim of securing CfDs in Allocation Round 4 (AR4). The Celtic Sea Cluster was launched in 2021 and is a collaboration between the Welsh government, Cornwall & Isles of Scilly Local Enterprise Partnership, Celtic Sea Power, OREC and MEW. The aim is to drive floating wind market creation in the Celtic Sea by developing supply chains and regionmal strategy.

Early stage floating wind projects that are being developed close to Pembrokeshire include:

- The Erebus floating wind farm is being developed by Blue Gem Wind, a joint venture (JV) of TotalEnergies and Simply Blue Energy who are based at Pembroke Dock. It will be up to 96 MW, made up of 7-10 turbines fixed to Principle Power’s WindFloat floating platform. The project is expected to be commissioned by 2027.
- Valorous is a larger, 300MW floating wind project also being developed by Blue Gem Wind. This will consist of 18 to 31 turbines, depending on the turbine size chosen, and will be commissioned 2028-29.
- Floventis Energy, a JV between SBM Offsyhore and Cierco, is planning two 100 MW projects on the Welsh coast south of Pembrokeshire: Llŷr 1 and Llŷr 2. These will be used to test different floating technologies.

3.2.2 Port facilities

Milford Haven Port

Pembrokeshire is home to the Port of Milford Haven (PoMH), located in the Milford Haven Waterway. This is a natural deep water port, the waterway an example of a ria estuary (or “drowned river valley”).

The port has a rich energy industry heritage. It is the largest energy port in the UK, its depth making it suitable for large vessels with 22m drafts. Tankers deliver oil and gas, which is distributed to the rest of the UK via pipelines. It is capable of processing up to 30% of the UK's gas demand [31].

A decline in oil and gas activity means that there is increasing interest in the port as a hub for renewable energy [32]. The deep water means that it would be well suited for assembling floating foundations, and there is a 400 kVA substation at the port. A study commissioned by the port in 2011 found that the waterway supports over 4,000 jobs in Pembrokeshire (and 5,000 in Wales), with 30% of these jobs in oil refining, gas processing and power generation [33].

The PoMH also owns Pembroke port on the other side of the Cleddau Estuary. As mentioned in Section 3.1, MEW are developing some small scale wave and tidal test sites off the Pembroke Port quayside. This is part of the larger, £60M Pembroke Dock Marine programme, summarised in Figure 5. This also includes new fabrication areas, a larger slipway, assembly and maintenance buildings [34] and the setup of the Marine Energy Engineering Centre of Excellence (MEECE) by the Offshore Renewable Energy Catapult. A planning application for some of these works was submitted in December 2020 [35]. While it is likely that these facilities will be prioritised for the aforementioned floating wind projects in the Celtic Sea [36], TSE projects in the region will also benefit from these transformations.

The port is also examining the potential to serve as a hub for hydrogen research and commercial activity. The oil and gas expertise means that the port is a leading candidate for green and blue hydrogen production and injection into the UK network. Renewable energy produced off the coast of Pembrokeshire could be converted to hydrogen at the port. This is a particularly exciting application for offshore wind so that excess energy can be used rather than being curtailed.

The two-year £4.5m MK:EK (Milford Haven Energy Kingdom) project is examining this possibility [37]. A hydrogen electrolyser is being built on the quayside. The local energy system is being examined to determine the leading applications and benefits of the hydrogen. One part of the project is building two hydrogen powered cars to be used as fleet cars in the local region.

MEECE - £11m

Supporting Welsh SMEs by offering:

- Free desk based feasibility studies
- Free demonstration and validation of technologies
- Free access to university facilities and skills
- Closely aligned with META

Pembroke Dock Infrastructure - £42m

- Modernizing Pembroke Port
- Creating new laydown space
- Creating new Mega-slipway
- Focus on floating wind

Marine Energy Test Centre (META) - £2.7m

- Facilitates component, sub-assembly and device testing through pre-consented test areas
- Reduces the time, cost and risks faced and accelerate growth in the sector

Pembrokeshire Demonstration Zone - £5m

- The largest area of seabed licensed for wave energy in the world
- Enabling offshore infrastructure to catalyse the Celtic Sea floating offshore wind and wave industries.

Figure 4 – Summary of the four projects making up the £60M Pembroke Dock Marine programme.

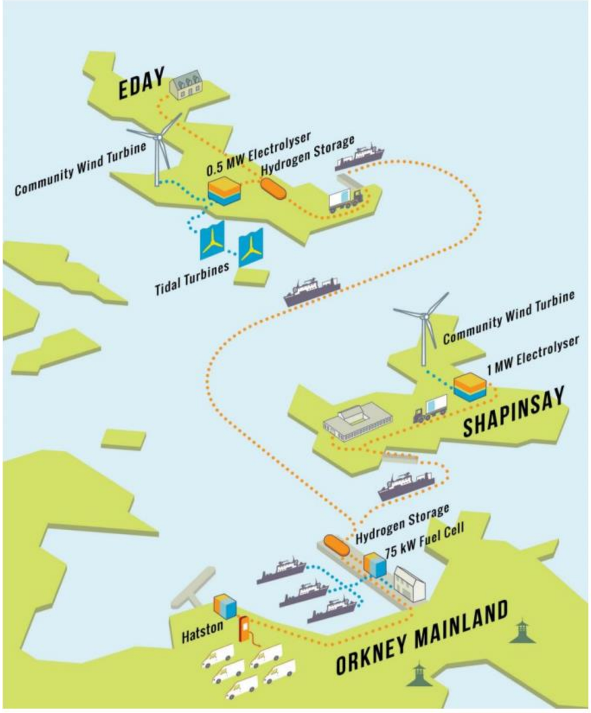


Figure 5 – The hydrogen economy in Orkney. Image created by EMEC [39].

Hydrogen production is also being implemented and examined in the wider TSE industry, offering an effective option for long term storage. A recent example of this is at EMEC, where a hydrogen plant made up of a 500kW electrolyser was installed in 2016. EMEC then produced the worlds first hydrogen using tidal energy in 2017 [38]. In 2019 there were nine hydrogen projects on Orkney, with a value of £63m [39].

A commercial TSE project in Pembrokeshire could offer similar benefits, with hydrogen generated and exported to Milford Haven for refinement.

Other ports

Fishguard Port is on the north side of Pembrokeshire, to the East of St David's Head. It is operated by Stena Line Ports Ltd, where ferry service is offered across to Rosslare in the Republic of Ireland. The port has seen a drop in demand for this, due to the combined impacts of Brexit and Covid-19 [40], which could offer an opportunity for marine renewables. While it has been identified as a port of interest for offshore wind, perhaps serving as an operations and maintenance (O&M) base [32], this is not something that Stena Line have promoted publicly. The location and status of Milford Haven as a leading energy port and hub of renewable energy activity means that it is the preferential option.

There are several small harbours nearby. These include a lifeboat launch centre at St Justinian's and Porthclais harbour that is used for recreational activities like canoeing. These

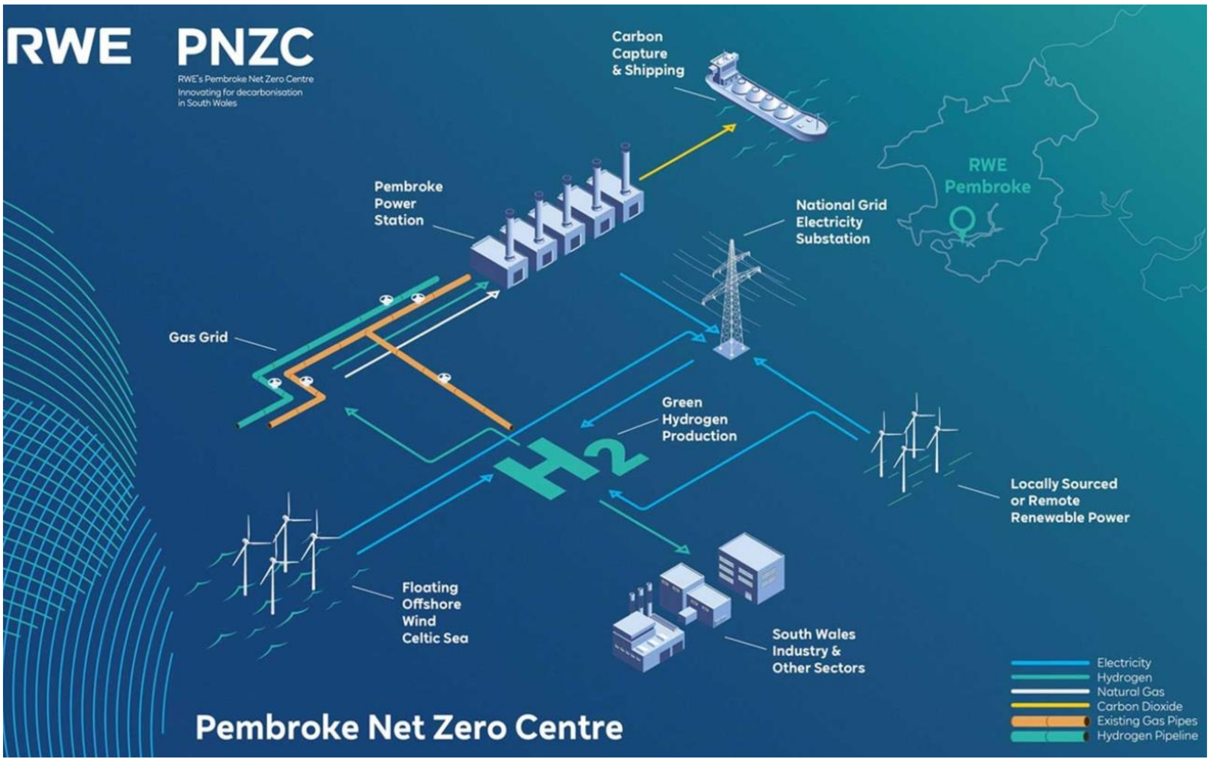


Figure 6 – The elements making up the RWE Net Zero Centre. Taken from [41].

are likely to be too small and remote to serve as O&M bases for the MW-scale TSE devices anticipated for the region.

Other projects

In May 2021 RWE announced a decarbonisation hub in Pembroke: the Net Zero Centre [41]. This would link RWE's Pembroke Power Station and floating offshore wind into the gas grid via green hydrogen production. The project will examine how hydrogen production and carbon capture and storage (CCS) can be integrated into the existing power plant.

Pembrokeshire is also the location of the proposed Greenlink interconnector. This 190 km, HVDC cable would run from Pembroke Power station to Country Wexford in the Republic of Ireland. It would have a capacity of 500MW, with commissioning planned for 2023.

4 Site characteristics

Table 2 shows the main characteristics of the two Pembrokeshire sites in the Ramsey Sound vicinity. Both of the sites, as planned, are fairly small. As mentioned, TELs ambition was to use Ramsey Sound as a demonstration site and St David's Head as their first commercial scale project.

Table 2 – The two sites that were being developed by TEL. COSW took over the Ramsey Sound site in 2019.

Site name	Ramsey Sound	St David's Head
Owner	COSW	None
Previous Owner	TEL	TEL
Planned capacity (MW)	1.2	10 [8]
Status	Consented	Lease formerly granted, expired 2017. Currently dormant
Support mechanism	5 ROCs	None
Site area (km^2)	0.5	1.6 [8]
Maximum spring tide flow velocity (m/s)	3.23 (at 23.3m above seabed) [26]	~3 [42]
Typical water depth range (m)	31-44 [43]. Mean depth 32m at turbine [26]	30-42 [8]
Potential ports	Fishguard (~35km0F[1]) Milford Haven (~45km[1])	Fishguard (~30km[1]) Milford Haven (~50km[1])
Cable landing	St Justinians (~1.2 km [44])	Whitesands Bay (~2.2km [8])

4.1 Ramsey Sound

4.1.1 Environment

Ramsey Sound

The Ramsey Sound lies between the mainland and Ramsey Island to the west. The stretch of water is approximately 3km long, with a width varying between 500 m and 1.6 km [45]. The area is about 3 km^2. The southern part of the sound has some notable bathymetric features that both influence the tidal flow and would make energy extraction more challenging for bottom-fixed devices [46]. These include:

- A deep trench exceeding 75 m in depth.
- The Horse Rock pinnacle that is sometimes visible above the water surface in low tides.
- A surface piecing reef, known as The Bitches.

[1] Estimated using GIS analysis

The north of the sound, by contrast, is fairly uniform. This was a deciding factor for TEL's choice of project location in the area.

Initial scoping studies by TEL noted that grey seals and harbour porpoises are the most common marine mammals observed in the area [7]. As their technology is underwater, they also noted that it would only be a risk to diving birds, such as gannets, razorbills and shearwaters, however these are not observed frequently (indeed only one shearwater was observed in a nine month period [7]). The Ramsey Sound was also assessed as of "low to moderate conservation value as regards fish ecology", additionally "the area does not seem to be suitable as a spawning area or nursery".

The site is outside any shipping routes [26]. It is largely inaccessible due to the high tidal flows, the main vessels being recreational craft, canoes and boat trips to Ramsey Island.

Ramsey Island

Ramsey Island has an area of 2.6 km^2 and is owned by the RSPB [47]. The island is know as Ynys Dewi or St David's Island [1].

As part of the Pembrokeshire Coast National Park, the island is a nature reserve has several protection designations. These include its status as an Site of Special Scientific Interest (SSSI), Special Protection Area (SPA) and Marine Area of Conservation (MSAC). It is home to bird species like the Manx shearwater and European storm petrels, which have seen increases in numbers over the last 20 years as a result of a coordinated rat extermination on the island [47].

The island can be visited via boat trips from St David's. It is usually occupied by two people, but is essentially uninhabited. Thus, any power generated by renewable energy projects in Ramsey Sound are better off being exported to the grid on the mainland rather than to the island.

The area is regarded as an area of exemplary natural beauty. Because of this, the area is particularly sensitive to construction activities that would negatively impact the local environment.

4.1.2 Flow regime

The maximum spring tide in the flood direction has been measured at 3.4 m/s [45]. This is not as high as some tidal sites, for example Meygen where maximum spring tides regularly exceed 4.5 m/s [48], but exceeds the 2-3 m/s typically regarded as economically viable (for example [49]).

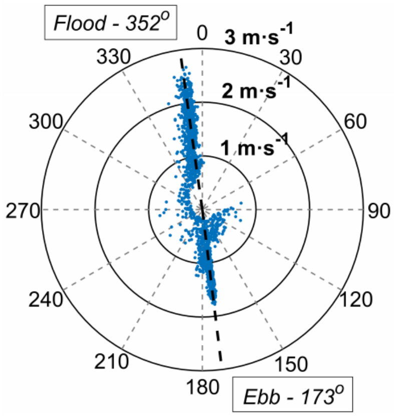


Figure 7 – Current profile at the TEL Ramsey Sound turbine location. Taken from [46].

In the south of the sound the flow is more turbulent, due to the bathymetric features mentioned above. The flood flow occurs through the sound in the northerly direction. This is stronger than the southerly ebb tide due to the constriction of the tide by the Bitches and the aforementioned trench [46]. Evidence for this was gained during an ADCP deployment by TEL at the turbine location, before turbine installation, which found a maximum flood flow of 2.7 m/s compared to 1.8 m/s in the ebb direction. This can be seen in Figure 8.

This large asymmetry in the ebb and flood tides is also noted in [50]. Taking measurements from two ADCP measurement campaigns (September 2009 and October/November 2011), the data showed very large variations in turbulent kinetic energy in the ebb direction (140% difference for two locations only 50 m apart). This proves the need for careful siting in the sound.

The reason for this is the uneven bathymetry, resulting in a fairly unsteady and turbulent flow [46]. This also has an impact on the vertical shear profile, making it inconsistent across the sound [45]. This turbulence could lead to uneven loading on turbine components, for example blades, which can shorten the fatigue life of mechanical components [50]. This must be considered in the turbine design and is why micro-siting in the sound is so important.

Both The Bitches and Horse Rock offer obstructions to the flow, resulting in velocity deficit downstream from the features [45]. Horse Rock in particular makes the flow more turbulent in its vicinity.

4.1.3 Grid connection

The site is connected to the grid, via a 1.2 km export cable. This a six core, double armoured 6.6kV (6 copper cores 6/10(12) kV, 35mm^2) cable that links the device to the mainland at the former RNLI lifeboat station [26]. COSW have indicated that the capacity at the site could be increased. This is accompanied by a 24 strand, 9/25 Micron way single mode fibre optic cable.

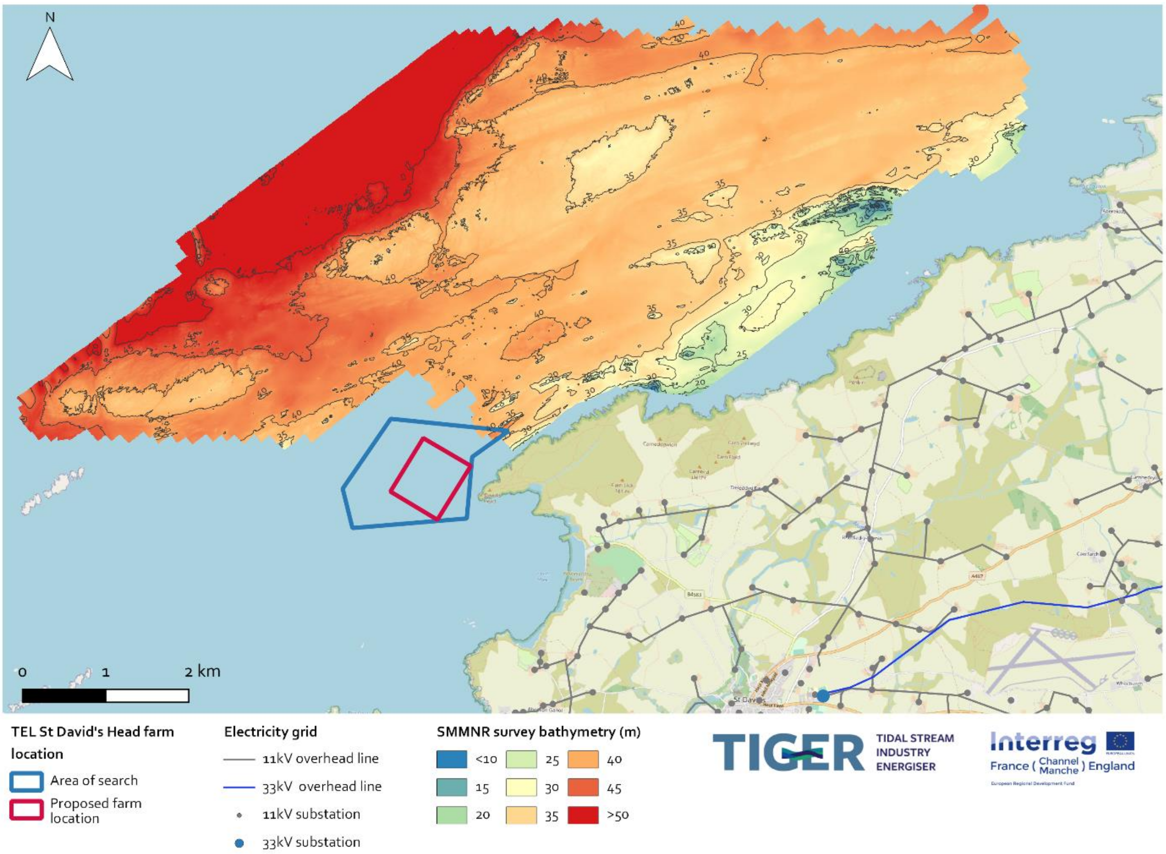


Figure 8 – Bathymetry data (collected for the SMMNR project) and electricity grid in the St David's Head region. The previously proposed TEL St David's Head tidal farm location is also shown.

Onshore the export cable is fed into a securely fenced electrical compound. This contains the high voltages transformers necessary to export to the grid at 11 kV. There is also an office and control centre in the compound where the device will be monitored and power production verified.

There are also dump resisters built into the electrical system, which allow electricity generated to be dumped if the grid connection is lost. A G59 breaker is also present, a requirement for power generation, to protect the grid.

St David's Head

4.1.4 Environment

St David's Head is located to the north of the Ramsey Sound. It is also located in the Pembrokeshire Coast National Park and is a remote location, with a reputation as an area for star gazing due to low light pollution.

Like Ramsey Island, St David's Head falls within some protected area designations including the Pembrokeshire Marine SAC. The cliffs are protected within a Pembrokeshire Cliffs SSSI. Despite these steep cliffs, cable landfall is possible in the Whitesands Bay area, as was planned by TEL [8].

In 2019, ABPmer carried out multibeam bathymetry surveys in the St David's Head region, on behalf of the Welsh Government. This was for the second work package of the Sustainable Management of Marine Natural Resources (SMMNR) project, aimed at collecting data and knowledge to support sustainable planning of aquaculture, wave and TSE projects in Welsh waters. These data, free to download, are shown in Figure 9.

The data, obtained at a 5 m resolution over a 35 km^2 area , indicate that the bathymetry is generally uniform, with little in the way of extreme bathymetric features as for the Ramsey Sound. There is a large area of seabed in the centre of the region between approximately 30 and 40 m, with depth increasing from shore as could be expected.

The surveys revealed a range of ground conditions including sand, mixed sediment and rocky reef [51]. ABPmer also did video surveys for selected areas, which showed some very rocky sea bed either site of the central 30-40 m band. Biogenic reefs were found to the north west, and marine mammals and birds were recorded during the surveys. Other sources note that grey seals, harbour porpoises and Atlantic puffins (among other species) can be found in these waters [8] [52].

4.1.5 Flow regime

There have not been as many studies of St David's Head compared to Ramsey Sound. This is because the project was in an earlier stage of development and has not been advanced since TEL were liquidated.

The tidal range at the site has been quoted as 5 m, with peak spring velocity of about 3 m/s [42]. ADCPs have been deployed at the site, for example as mentioned in [53].

4.1.6 Grid connection

TEL's plan was to land an export cable in Whitesands Bay, with a cable length of approximately 2 km [8]. While there is a 11 kV line in the vicinity of the bay, as shown in Figure 9, this would be insufficient for the 10MW project that was planned.

In [8], TEL noted that a 20 m x 12 m compound would be built to house the substation and transformers. This would be connected to the 33 kV network at St David's via an underground cable, installed by Western Power Distribution (WPD). The straight-line distance from Whitesands Bay to the 33kV substation at St David's is 3km.

5 Technology options

Table 3 shows the properties of the TEL device that was deployed in the Ramsey Sound. Initially one 400 kW rotor was mounted to the DeltaStream, which was going to be followed with a full scale design with three rotors mounted.

The turbine contained a hydraulic yaw system. A particularly novel aspect of the design was a rotor capable of overspeeding at rated power as a way to regulate power and loading. This differs from other turbine concepts that use pitch control.

Table 3 – The TEL DeltaStream that was planned for the Ramsey Sound.

Property	Value
Turbine model	DeltaStream
Description	Horizontal axis bottom fixed turbine
Rated power (MW)	0.4 (further 0.8 was planned)
Rotor diameter (m)	12 x 1 (2 further were planned))
Dry weight (tonnes)	250
Rated flow speed (m/s)	2.7 (2.25 for 15m design [42])
Pitch control	Fixed pitch
Foundation type	Gravity base

The Ramsey Sound site is well sheltered from waves, making is suitable for floating devices. The uneven bathymetry means that siting devices using gravity base foundations could be challenging. The DeltaStream was a single device, so this was less of an issue, but the number of devices using this foundation could be limited, particularly when considering wake effects too.

Something to note about both Ramsey Sound and St David's Head is how shallow they are. With water depths generally in the range 30-45 m, this will limit the size of the rotors that can be deployed. While not an issue for current devices, future generations of devices are anticipated to have rotors exceeding 30 m for the largest devices. Increasing rotor size is a primary cost reduction driver for the tidal industry, as has been seen in offshore wind [54], which these regions might not fully be able to exploit.

Lastly, the electricity grid will ultimately limit the sizes of farms that can be deployed. This is less of a concern for Ramsey Sound, which is a demonstration scale site. The grid upgrades for a multi-MW farm at St David's Head would be costly, as the 11 kV in the locality is not sufficient for a commercial array.

6 Viable farm locations

For this analysis, we used GIS datasets and analysis methods to quantify the area available at the TIGER site for a future commercial farm. Our analysis also indicates areas in the wider region that would be suitable for future projects. The motivation is to give context beyond TIGER, when future sites are being examined for next generation technology.

6.1 Methodology

6.1.1 Area selection

For the GIS study we chose an analysis area encompassing both the Ramsey Sound and St David's Head sites. This is shown in Figure 10. The area was selected based on the underlying tidal model being used, expanding beyond the two known tidal sites to include the areas to the west and south of Ramsey Island. The western extent includes the Bishops and Clerks islands, as it was thought that these could channel some tidal flows.

As the domain gets larger, for a given resolution, the tidal flow speed simulation becomes more computationally complex and hence takes a longer time to execute. The chosen area took about a week to run. This was deemed an acceptable and practical length of time in the context of the study.

6.1.2 Tidal flow speed data

Tidal flow timeseries data were provided by the University of Plymouth, a TIGER project partner. Flow speeds were simulated using the coastal flow solver Thetis

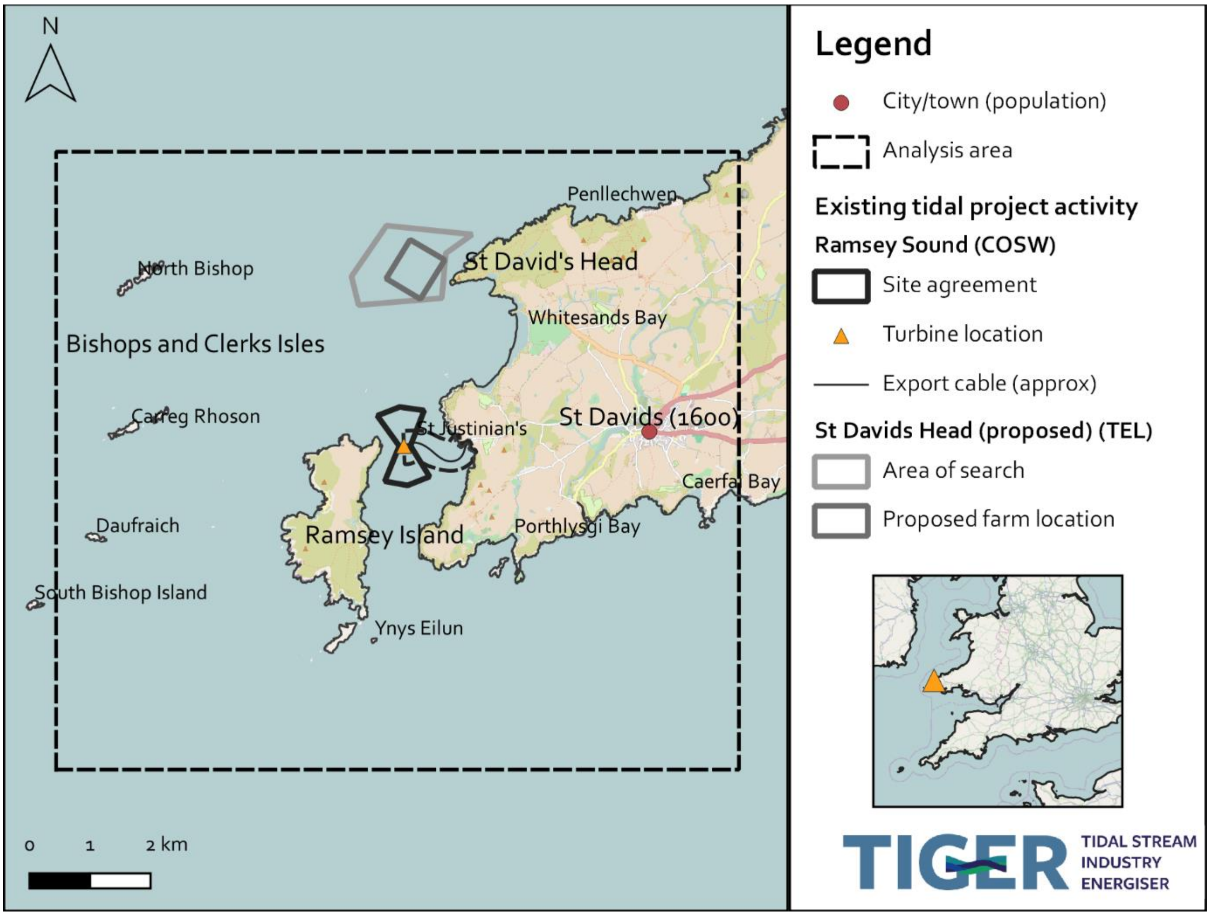


Figure 9 – The analysis area that was examined. The Ramsey Sound and St David's Head lease areas are also shown.

(http://thetisproject.org/) [55] and finite element partial differential equation solver Firedrake [56] to solve the non-conservative form of the shallow water equations.

The domain, which encompasses a large section of the Irish sea, is discretised using an unstructured mesh domain generated with qmesh [57]. Bathymetry is interpolated by combining 2m resolution measurements in the vicinity of Ramsey Sound [58] and coarser measurements elsewhere [59].

The model was validated against gauge data, as well as bed mounted and vessel mounted ADCP datasets. Further information on the model can be found in [60]. The model was run over a spring tide on 27th April 2017, to achieve close alignment with the peak of the 18.6 year lunar nodal cycle. Depth averaged flow speeds were extracted from the model at a 100 m resolution over the desired area.

6.1.3 Data from technology developers

Several technology developers were contacted, to understand the deployment constraints that affect their specific devices. They were asked about their current generation of technology as well as the trends that they anticipated for future device generations. This covered the following aspects:

Device properties

- Device rating
- Rotor diameter (nominal and minimum/maximum envisioned)
- Rated flow speed
- Cut-in and cut-out flow speeds
- Clearance above and below device
- Design water depth range (min and max)

Farm properties

- Farm size (at given date)
- Design turbine spacing
- Approximate farm energy density
- Foundation properties:
- Preferred foundation type
- Corresponding design conditions (seabed gradient, seabed type, installation vessel required)

Transmission system properties

- Maximum distance to shore (to prevent high transmission losses)
- Devices per subsea hub
- Grid requirement (based on farm size, kVA)

Devices included small (<500kW) and utility scale (2MW+) fixed devices and utility scale floating devices.

From this information we were able to determine the types of areas that would be more suitable for these classes of technologies. We modelled four generic devices: three of the most popular designs being developed today and a next generation utility scale turbine (rated at 3MW). The properties of these are shown in Table 4.

Table 4 – The four device classes that were considered for the analysis.

Technology	Generic small scale fixed	Generic utility scale fixed	Generic utility scale floating	Generic next generation utility fixed
Configuration	Horizontal axis turbine	Horizontal axis turbine	Horizontal axis turbine	Horizontal axis turbine
Foundation type	Gravity base/pile	Gravity base/pile	Gravity/drag/pile anchor Catenary mooring	Gravity base/pile
Nominal rated power (MW)	0.5	2	2	3
Nominal rotor diameter (m)	15	20	20	25
Required maximum spring current speed (m/s)	>3.5	>3.5	>3.5	>3.5
Required water depth range	25-40	35-50	30-80	40-55

The flow speed constraint was chosen to exclude any lower flow areas that would be less economically viable, leaving only the most promising locations. The water depth constraint considers minimum depth to allow sufficient clearance above and below the rotor and an economically viable maximum depth, as in reality developers will target more economically viable areas first.

6.1.4 Environmental constraints

As well as the device specific constraints outlined above, we also ruled out other areas where there would be interactions with marine hazards or other sea users. These hard constraints included:

- Areas close to shipwrecks (<250m)
- Areas close to ports (as devices could be navigational hazard) (<500m)
- Oil and gas platforms, boreholes and exploration zones
- Offshore wind farms and other marine renewables (operational and in development)
- Dredge spoil dumping sites
- Site agreements for mineral/aggregate extraction

- Dumped munitions

We also mapped soft constraints. Development in these areas could be possible, so we did not remove them, but would require more detailed site assessment and evaluation. These included:

- Vessel traffic
- Fishing activity
- Marine protected areas: Site of Special of Scientific Interest (SSSI), Special Protected Areas (SPA), Special Areas of Conservation (SAC)
- Seabed sediment type
- Distance to shore
- Distance to grid
- Seabed gradient

Some of these, for example the distance to shore and grid were derived using GIS software. Main data sources included:

- Admiralty data portal (bathymetry data)
- Crown Estate data portal (wind farm areas)
- EMODnet data portal (human activities, e.g. dredge spoil dumping, dumped munitions)
- Western Power Distribution (transmission and distribution grid lines)

Full information about the constraints considered and data sources used can be found in Appendix A.

6.1.5 Approach

Our main aim was to visualise viable deployment areas for the four devices classes across the region.

We downloaded the necessary datasets and loaded them into GIS software (QGIS). First we visualized the datasets, to gain appreciation of their prominence in the area selected. We derived distance to coast and distance to 33kV grid using algorithms within the software.

For each of the four device classes we determined the viable area where it could be deployed. To do this we applied the flow speed and bathymetry conditions as shown in Table 4 and converted the raster datasets into vectors, effectively grouping together viable locations into polygon layers. We combined the viable flow speed and bathymetry areas into one layer and subtracted the other hard constraints, resulting in polygons showing the potential areas for deployments.

6.2 Maps: soft constraints

6.2.1 Vessel traffic

Figure 10 (top) shows the vessel traffic in the oceans surrounding Pembrokeshire, with units of average hours per month. We chose the 2019 dataset, as the more recent 2020 dataset had anomalous traffic, noticeably lower than previous years due to the coronavirus pandemic.

There is significant vessel activity around Milford Haven port, as expected, as this is a large port. Within the Ramsey Sound region there is notable traffic within the sound, particularly to the south of the island. This is due to boat tours, which the company Voyages of Discovery currently run eight times per day [61]. This is unlikely to be a barrier for a tidal farm, especially a fixed-bottom device, as evidenced by the fact that TEL were able to deploy their turbine. Moreover, a tidal farm would be of interest to the public and could boost interest in such boat trips and tourism more generally.

There is a higher area of vessel traffic to the south of the analysis area and to the North of Milford Haven, in St Brides Bay. This areas is used for mooring tankers [62] that are working at Milford Haven.

6.2.2 Environmental protection areas

Figure 10 (bottom) shows the designated environmental protection zones in the waters surrounding Pembrokeshire. The whole analysis area lies within an SAC, with some areas also designated SSSI. Ramsey Island itself is a protected nature reserve. Because both Ramsey Sound and St David’s Head areas obtained seabed leases, these constraints are not considered barriers to tidal farm developments. A previous study by Haverson et al. concluded that a 10MW array at St David’s Head would likely have a low impact, however tidal farms could have a notable effect on the benthic environment through localised sediment accumulation [42]. This is something that could be investigated if larger farms were to be considered, as it could influence factors such as device specification and array layout.

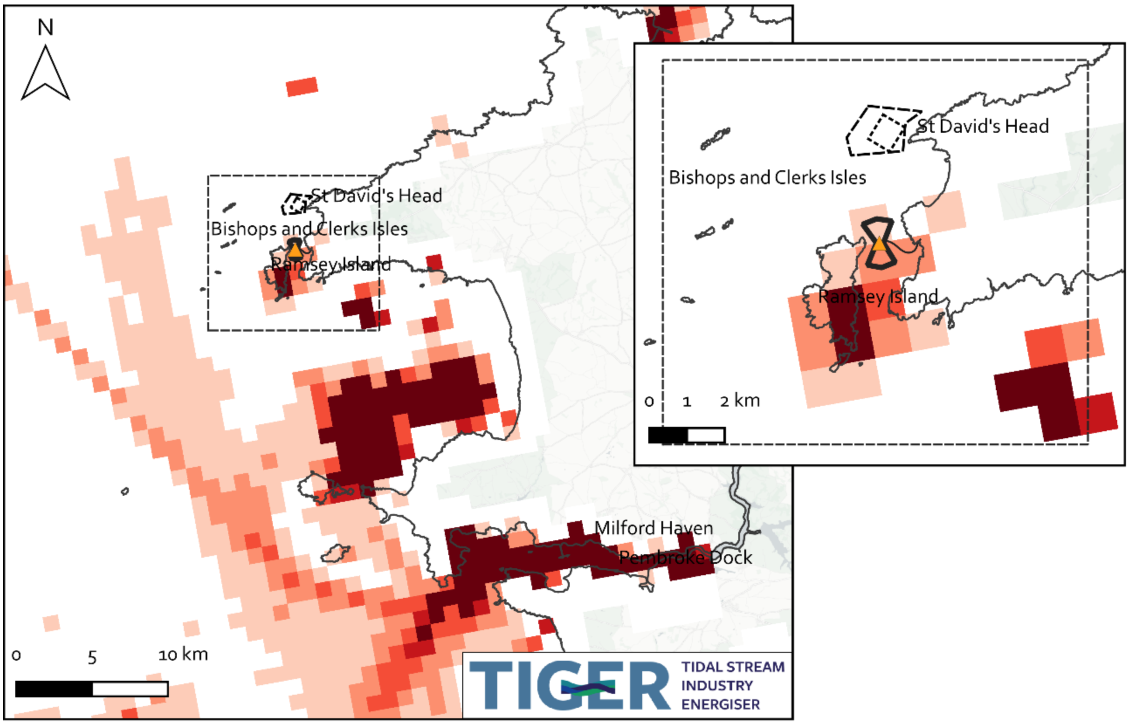
6.2.3 Fishing activity

Figure 11 (top) indicates the fishing activity traffic in the oceans surrounding Pembrokeshire. Two different data sources are presented, with MMO overlaid over data from Global Fishing Watch. There is very low fishing activity in the analysis area, so this is not deemed a constraint to tidal farm developments.

6.2.4 Seabed sediment

Figure 11 (bottom) shows the seabed sediment types in the waters surrounding Pembrokeshire. Generally the seabed is coarse grained sediment, with some interspersed areas with alternative classifications. Coarse grained sediment is generally suitable for monopiles. The dataset is fairly low resolution, and a full survey campaign would be required to fully characterise the seabed. Additionally, only the top layer is shown. The depth to bedrock is a crucial metric for designing monopile foundations, which could also be obtained from geotechnical surveys.

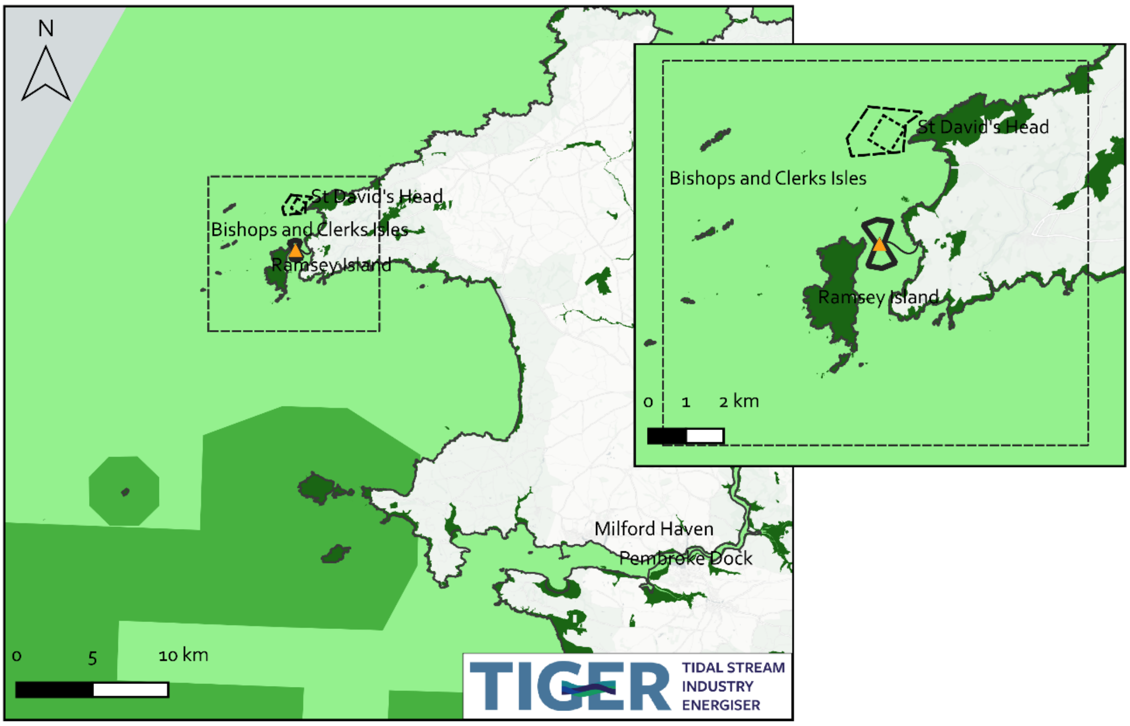
Offshore wind monopiles are generally less suited for gravel seabeds, as they are more difficult to pile [63]. Monopiles for tidal turbines are much smaller, and so this would be less of a problem. The seabed sediment dataset is indicative, and foundations could be designed and turbines placed to mitigate local issues. For this reason the sediment type was not considered as a hard constraint.



Vessel density 2019 (average hours per month)

< 1.0 | 1.0 - 2.5 | 2.5 - 5.0 | 5.0 - 7.5 | 7.5 - 10.0 | > 10.0

Data obtained from the European Marine Observation and Data Network (EMODnet). The maps are based on AIS data yearly purchased from Collecte Localisation Satellites (CLS) and ORBCOMM.

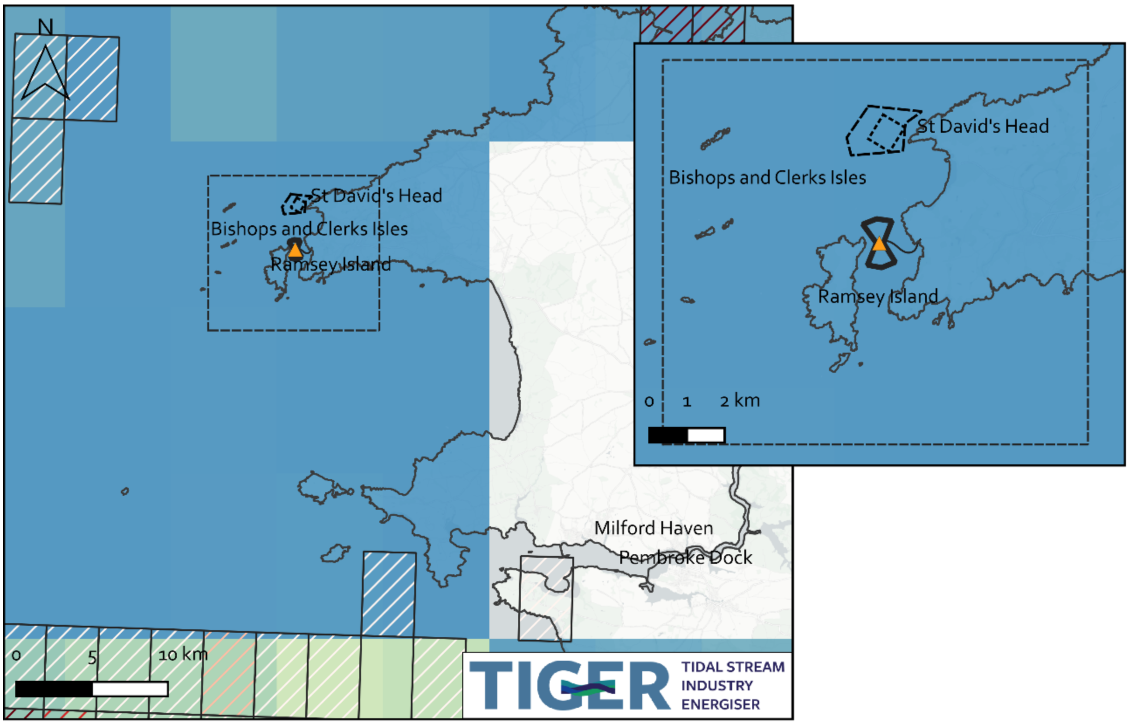


Protected areas

SSSI[1] | SPA[2] | SAC[2]

1: Contains Natural Resource Wales data © copyright and database right [2018].
2: Contains Joint Nature Conservation Committee data © copyright and database right [2020].

Figure 10 – Vessel density (top) and designated environmental protection areas (bottom) in the Ramsey Sound region and across the Pembrokeshire coast.



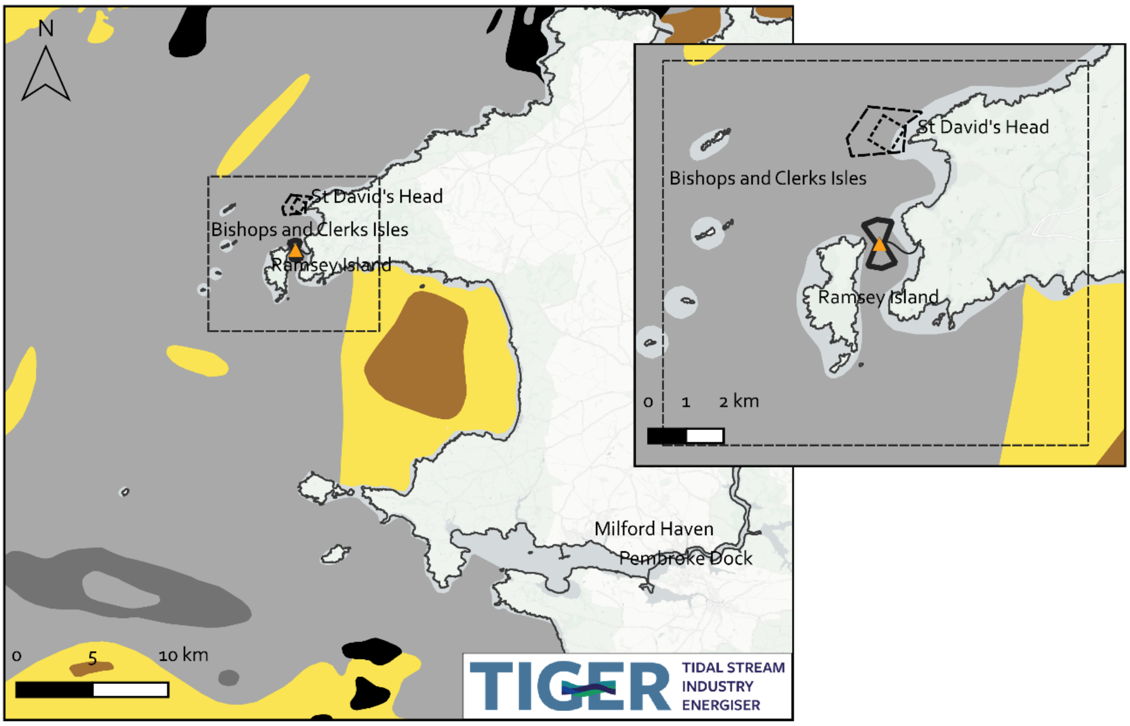
Fishing % of year (2016-2019)[1]

0% 3% 5%

Fishing catch 2019 (tonnes, vessels > 15m)[2]

<0.5 0.5 - 1.0 1.0 - 1.5 1.5 - 2 >2.0

1: Data derived using the Global Fishing Watch data portal.
2: Data obtained from the Marine Management Organisation (MMO) under Open Government Licence.

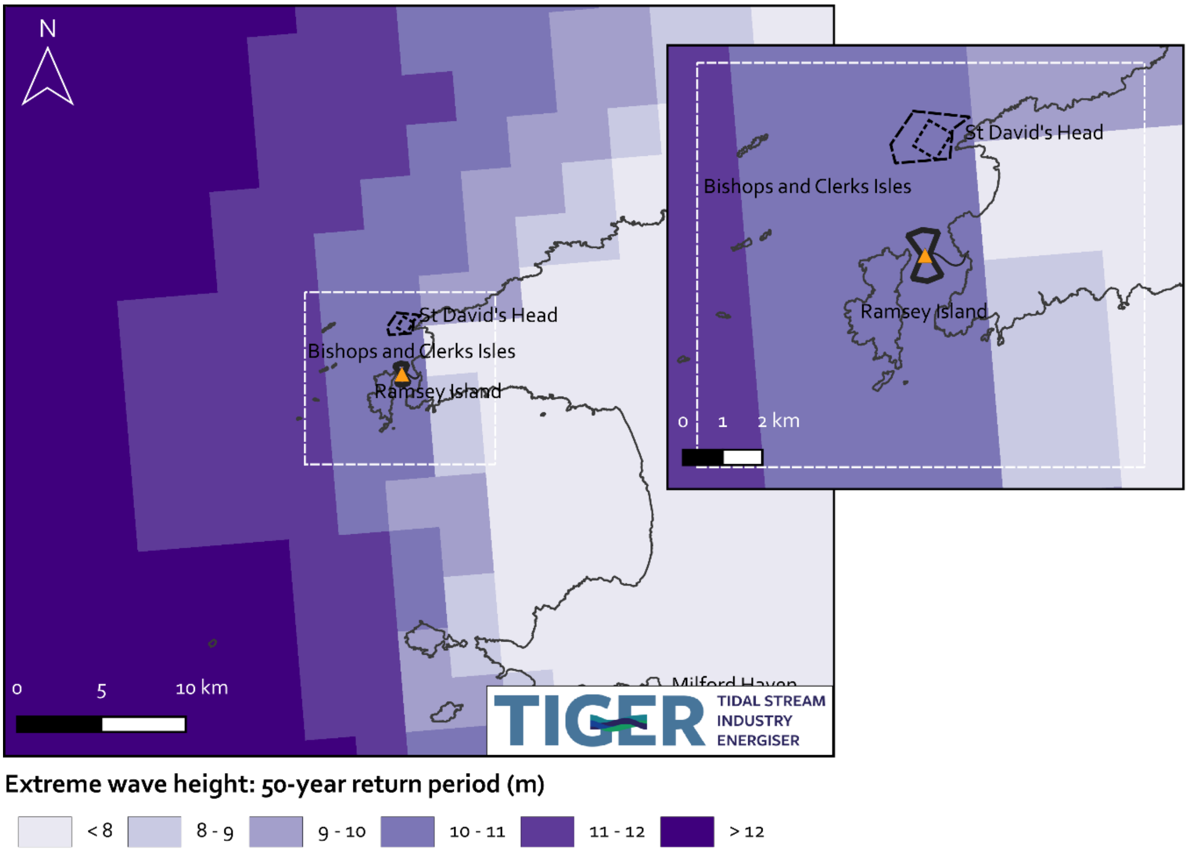


Seabed sediment type

1. Mud to muddy sand 2. Sand 3. Coarse-grained sediment 4. Mixed sediment 5. Rock & boulders

Data made available by the EMODnet Geology project, http://www.emodnet-geology.eu funded by the European Commission Directorate General for Maritime Affairs and Fisheries.

Figure 11 – Commercial fishing activity (top) and FOLK5 seabed sediment classification (bottom) in the Ramsey Sound region and across the Pembrokeshire coast.



Data provided by ABP Marine Environmental Research Ltd

Figure 12 – Extreme significant wave height (50-year return period) in the Ramsey Sound region and across the Pembrokeshire coast.

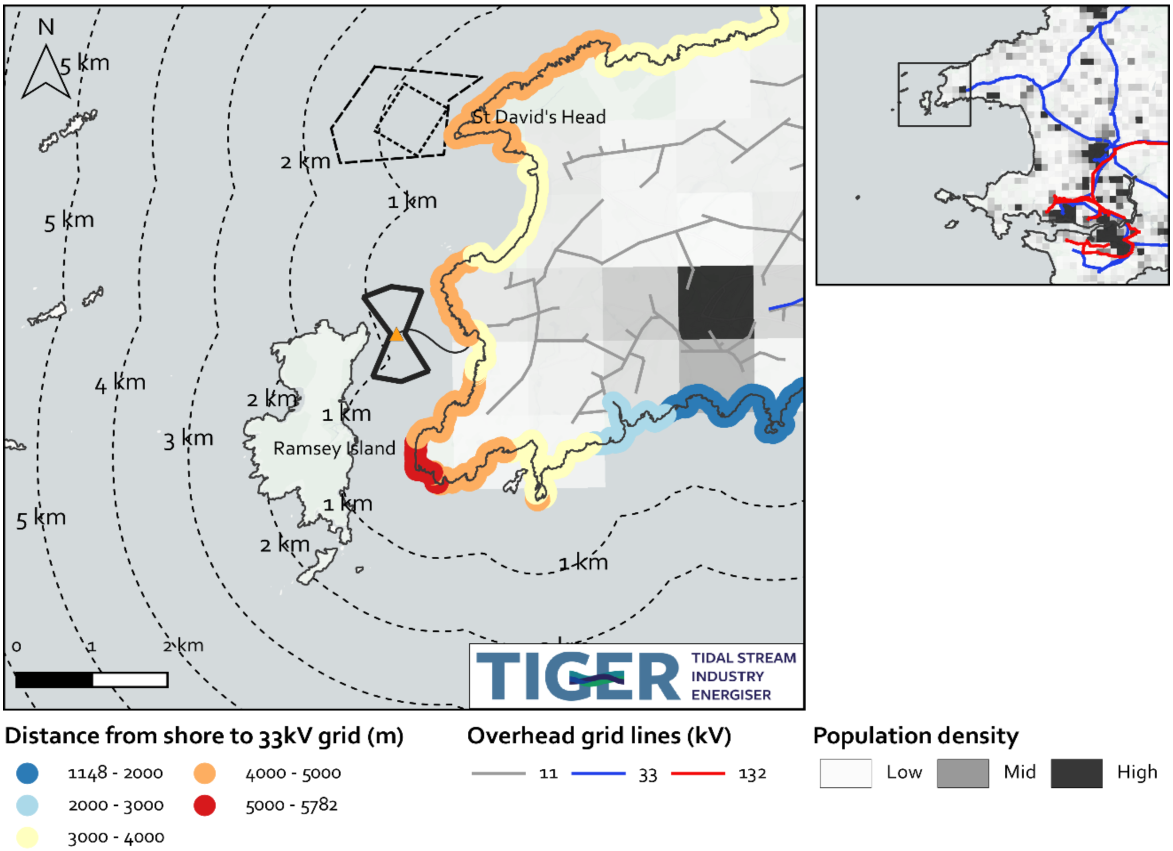
6.2.5 Extreme wave heights

Figure 12 shows the extreme significant wave heights in the region, the 1 in 50 year extreme. This dataset was provided by ABPmer, who generated it using their SEASTATES North West European Shelf Wave Hindcast Model. The estimates are considered to be realistic, with similar patterns of variance compared to other data sources, however are not locally validated and are hence treated as indicative estimates. Data is interpolated to a 3km^2 grid. The SEASTATES model is primarily a deep water model, and as a result does not adequately represent model shallow water effects (e.g. shoaling, refraction, wave breaking).

With these caveats in mind, the map indicates that 1 in 50 year extreme waves are in the range of 8-12m in the analysis area. Tidal turbines would have to be designed with this in mind to ensure survivability.

6.2.6 Distance to shore and grid

Figure 13 (top) shows distance contours to the mainland and distance from the coastline to the 33kV power line going into St Davids. These are straight line distances and exclude specific cable routing issues that might occur (e.g. if cables need to route around Ramsey Island or onshore infrastructure).



1: Data from Western Power Distribution.
2: Center for International Earth Science Information Network - CIESIN - Columbia University. 2018. Gridded Population of the World, Version 4 (GPWv4): Population Density, Revision 11. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC).

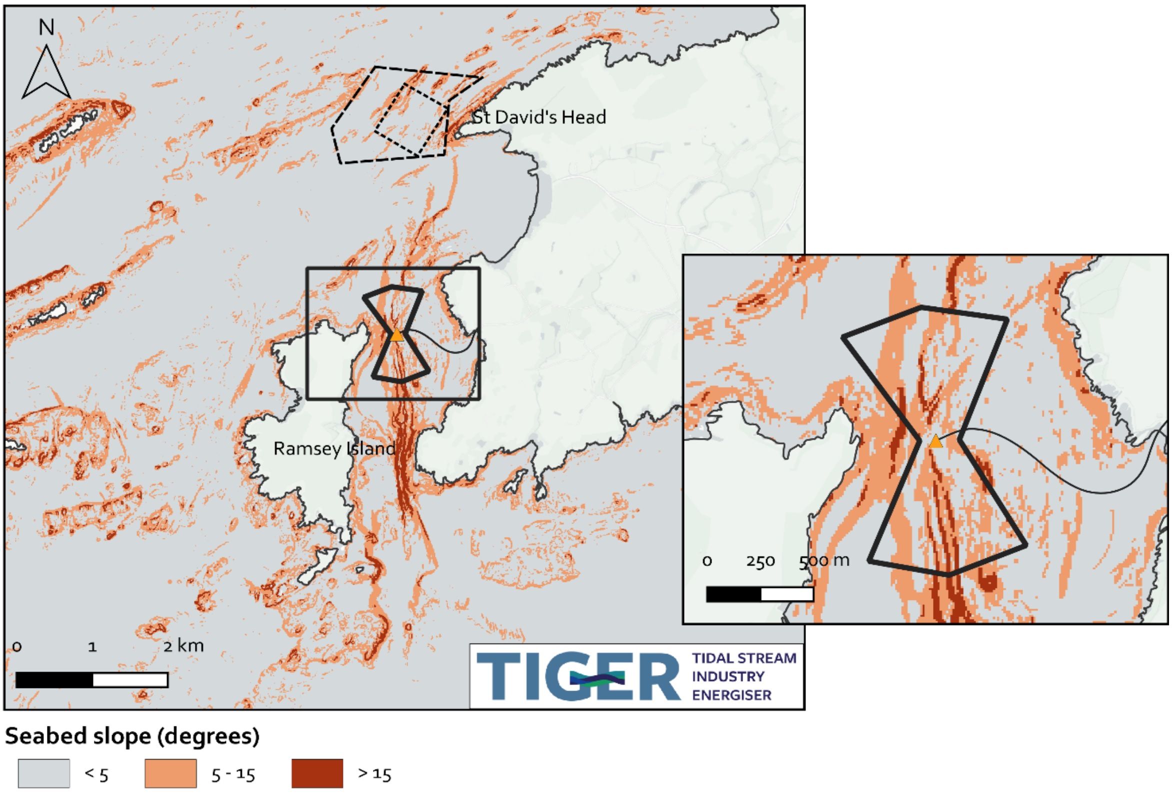


Figure 13 – Distance to shore (contours) and distance 33kV substation (colours) (both top) and seabed slope (bottom) in the Ramsey Sound region.

The vast majority of the analysis area lies within 6km of the mainland. This is a short distance compared to e.g. offshore wind (where farms are typically 40km+ from shore). For smaller tidal projects closer to shore it might be economic to forgo use of a subsea hub and instead bring each turbine to shore with its own cable. While cabling costs would be higher, redundancy in the system would be improved and money would be saved in the supply and maintenance of the subsea hub.

As Ramsey Sound is a protected SSSI it is unclear whether cables could be landed on the island and routed through to the mainland; this is something that would have to be investigated for any project being developed to the west of the island.

Distances from the coastline to the 33kV grid were found to be less than 6km, with the furthest straight-line distance from the south-west of the mainland. While there are potential 11kV connection points closer to shore, these would only be possible for smaller demonstration arrays and it is likely that connection would need to be made to the 33kV substation for a commercial scale project (10MW+).

Other than the town of St Davids, the area is generally of a low population density. It is mainly made up of fields, small hamlets and a significant number of holiday sites (camping and caravan parks). This, combined with the fairly short distance to the 33kV grid, means that connection would likely be straightforward, although there would need to be discussions with the DNO Western Power Distribution to understand the grid capacity available.

6.2.7 Seabed slope

Figure 13 (bottom) shows the seabed slope across the region. This was derived from the bathymetry data, resampled to a resolution of 10m (deemed to be an appropriate length scale for a tidal device).

Within Ramsey Sound there is significant variation in the seabed, with some steep drops of over 15 degrees. Outside the sound there exist larger flatter areas, with some steeper declines out to the west and near to St David's Head. Generally gravity bases would be suitable for slopes less than 5 degrees, with piled foundations required for steeper slopes beyond this. For an area like Ramsey Sound a piled foundation would likely make more sense.

Detailed foundation design would require further analysis, including analysis of array configuration. For the purposes of this higher level study, we assume that turbines could be sited and foundations designed to mitigate the slope variation, thus we do not consider it a hard exclusion for a tidal farm.

6.3 Maps: hard constraints

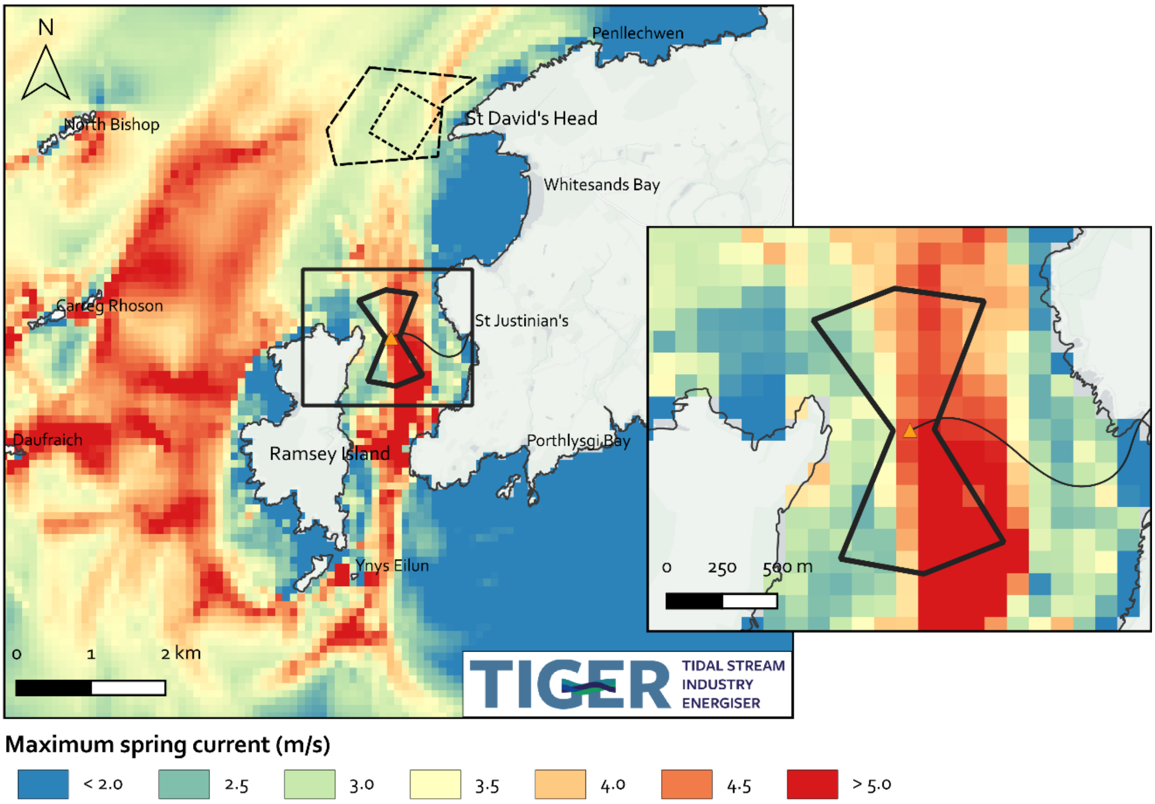
6.3.1 Flow speed

Figure 14 (top) shows the maximum spring tidal velocities across the Ramsey Sound analysis area. As expected the resource is very high within the Ramsey Sound itself, the water channeled between Ramsey island and the mainland. The resource at the St David's Head site is fairly weak by comparison, the main advantage being its proximity to shore and less extreme seabed variation.

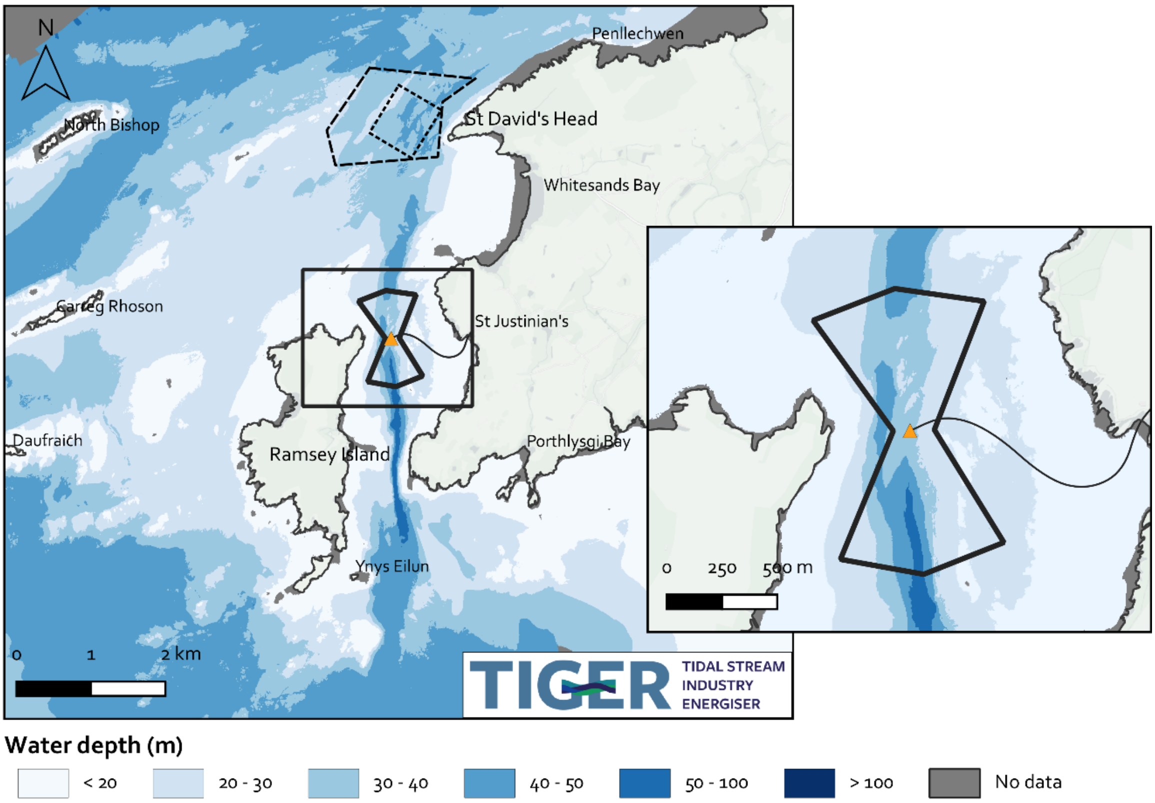
To the west of Ramsey Island there is also a significant tidal flow, particularly around the Carreg Rhoson and Daufraich outcrops.

6.3.2 Bathymetry

Figure 14 (bottom) shows the bathymetry across the region. The depth within Ramsey Sound reaches about 80 m in the central trench running through the middle of the sound. As previously mentioned, the seabed is also fairly uneven which explains the fairly turbulent flows as mentioned in several studies.

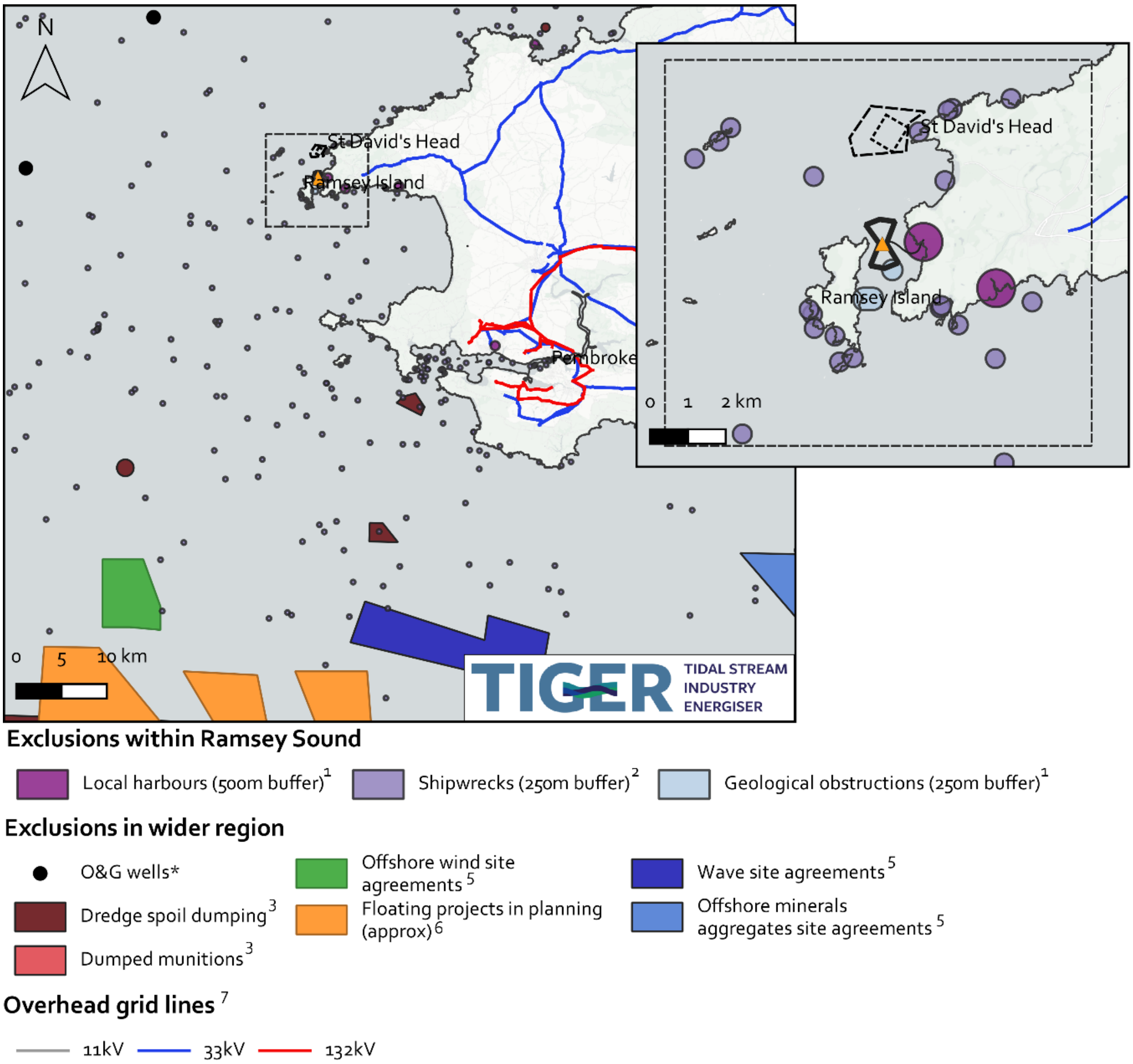


Flow speed data provided by University of Plymouth. Generated using coastal flow solver Thetis.



Bathymetry data sourced from the following:
Admiralty data portal, made available by the UK Hydrographic Office.
IMARDIS portal, built and operated by Bangor University and supported by the European Union's Regional Development Fund.
SMMNR project, made available by the Welsh Government.

Figure 14 – Maximum spring current (top) and bathymetry (bottom) in the Ramsey Sound region.



* All abandoned in exploration phase

1: Devised using local maps and knowledge
2: Contains public sector information, licensed under the Open Government Licence v3.0, from the UK Hydrographic Office
3: Data obtained from the European Marine Observation and Data Network (EMODnet)
4: Data from the Oil and Gas Authority (OGA)
5: Contains data provided by The Crown Estate that is protected by copyright and database rights
6: Data derived from 4COffshore Global Offshore Wind Farms Database
7: Data from Western Power Distribution.

Figure 15 – Hard constraints and exclusion zones in the Ramsey Sound region and across the Pembrokeshire coast.

The area to the west of Ramsey Island is fairly shallow, with a large shelf shallower than 30 m. This would only be suitable for smaller rotor devices. There is limited deep water across the region which reduces the potential for larger rotor devices (25m+).

6.3.3 Exclusion areas and grid

Figure 15 shows the exclusions and grid within the Pembrokeshire seas. The map is zoomed out, compared to the previous shown, to highlight the oil and gas wells (abandoned during exploration stage), the offshore wind (Erebus floating wind farm) and aggregate extraction to the south. As can be seen, none of these larger hard exclusion zones lie within the analysis region.

There are some shipwrecks in the analysis area, although none in the Ramsey Sound itself. There are two small, local ports, as mentioned in 3.2.2. We applied exclusions of 500m around these, but more work would need to be done with local stakeholders to determine how significant these would be in reality. There are also buffers applied around two geological features: Horse Rock and The Bitches, as these would be navigational hazards for service vessels.

The 33 kV and 132 kV lines are also shown. There is a 33 kV line at St David's Head, which could be used to connect arrays of tens of MW (as was planned by TEL for their St David's Head project). The 132 kV line connects to the power station at Milford Haven. At its closest point it is located 25 km from the Ramsey Sound (about 15 km to the coast and 7 km onshore to the 132 kV line). While further than the 33 kV substation, this is very close compared to offshore wind, where farms are typically 40 km and greater from the shore (and many far greater, for example Dogger Bank A and B will be about 131 km from shore at the closest point, with export cable lengths of 172-191 km [64]).

6.4 Device regimes

Figure 16 shows the viable areas for the four representative device classes.

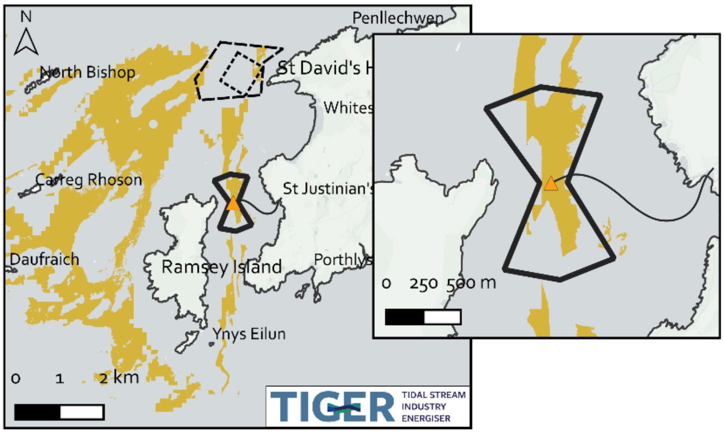
- The small-scale fixed device has potential in Ramsey Sound, particularly to the north, and also to the West of Ramsey Island.
- The utility scale fixed device requires deeper water, and as a result has much less potential in and around Ramsey Sound. This device class would be best suited to the south west of Ramsey Island. While the flow speeds here are lower, the water is a sufficient depth for a 20m rotor and the modelling does indicate hotspots. Blockage effects in this area would have to be considered if farms of smaller devices were deployed further north.
- With a similar depth profile considered, the floating device has a similar trend to the fixed, but with increased coverage within Ramsey Sound. As previously mentioned, the channel has a highly variable gradient so would likely require piled anchors. A larger floating array could cause an obstruction for recreational activities in the region which would have to be considered. Outside Ramsey Sound there isn't a lot of deep water in the analysis area considered, but floating arrays could be suitable as an alternative to fixed devices. The exposed western waters could cause issues from wave loading.
- The larger next generation device has a smaller area available as it can't be deployed in the more promising shallower areas. Hotspots exist to the west of North Bishop Island, to the south west of Ramsey Island and limited areas in Ramsey Sound.

Generally, based on these maps, we believe that a small-scale technology is most promising for the Ramsey Sound site as it has the largest viable area of the four technologies and would not have the navigational issues associated with a floating technology. The area to the wets of Ramsey Island also looks promising for a similar scale of technology, but cabling options would need to be explored.

The other three utility scale technologies all indicate hotspots to the east of Bishop Island and to the south west of Ramsey island. These areas warrant further investigation as part of future studies. The flow speeds are not as good as in Ramsey Sound, and so they might be better suited for devices designed for lower flows or as future sites for next generation devices, when regional supply chains are more developed and LCOE is lower.

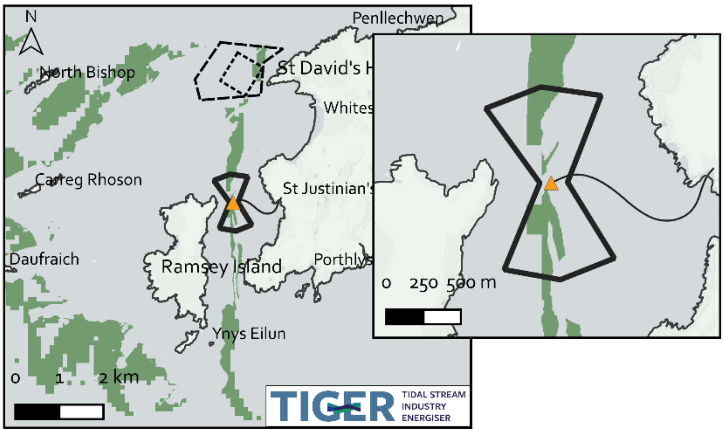
A. Small scale fixed

Flow speed: >3.5m/s
Water depth: 25-40m (15m rotor diameter)



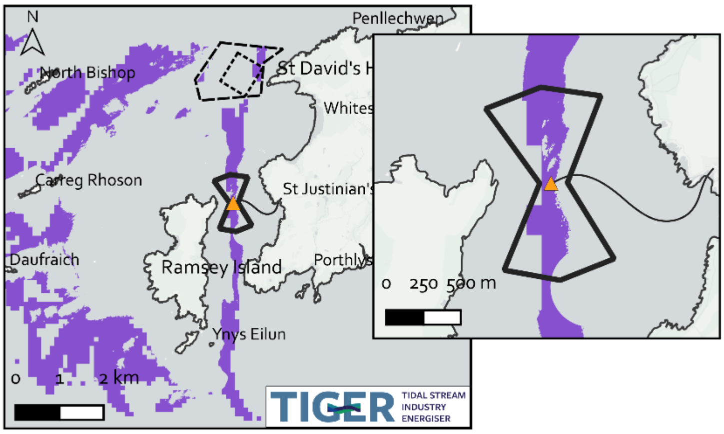
B. Utility scale fixed

Flow speed: >3.5m/s
Water depth: 35-50m (20m rotor diameter)



C. Utility scale floating

Flow speed: >3.5m/s
Water depth: 30-80m (20m rotor diameter)



D. Next gen utility fixed

Flow speed: >3.5m/s
Water depth: 40-55m (25m rotor diameter)

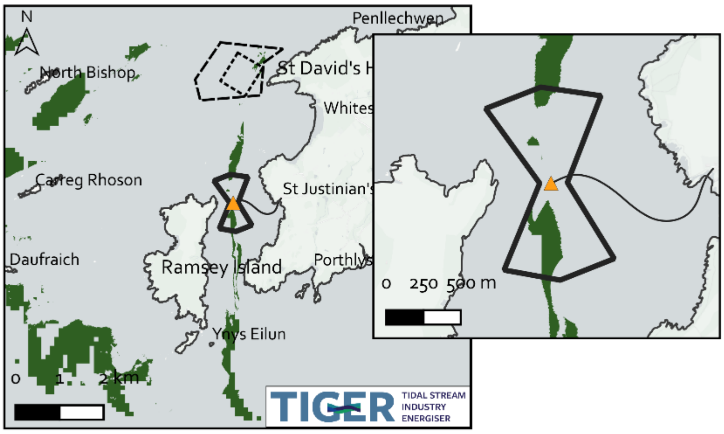


Figure 16 – The viable deployment areas for the four reference technologies.

6.5 Summary

This geospatial analysis has brought together over 50 different datasets to make an assessment of the Ramsey Sound region and determine which areas could be viable for TSE projects. The results can be summarised as follows:

- The Ramsey Sound region itself is largely free from other sea users (e.g. fishing, commercial activity). The only significant activity is regular recreational boat tours round Ramsey Island, with no commercial shipping through or close to the sound.
- The whole region lies within an SAC and Ramsey Island is designated a SSSI and owned by the RSPB. These did not stop leases from being granted for TEL's Ramsey Sound and St David's Head projects (the latter a 10MW project), however further work would need to be done to establish the feasibility of larger commercial arrays.
- Seabed sediment and extreme wave heights are considered acceptable for a TSE project. Both of these datasets are low resolution and indicative in nature and surveys would be required for detailed project feasibility study (e.g. geophysical/geotechnical survey, wave buoy measurements).
- There are no significant hard exclusions that would need to be considered. Within Ramsey Sound there are geological features (The Bitches and Horse Rock) that could prove to be navigational hazards without due care and consideration. St Justinian's lifeboat station would also need to be considered in project planning.
- The majority of the coastline is within 5km of a grid connection point at St David's. The offshore sites are generally within 5km of the shore, not considering potential cable routing around Ramsey Island for sites to the west. This aspect would need investigated for any of these prospective sites.
- The flow speeds within Ramsey Sound are decent (modelling indicating maximum spring currents exceeding 5m/s). There are also promising areas to the west of Ramsey Island, although this area is somewhat shallow and might only be suitable for smaller turbines.
- A notable, known feature of Ramsey Sound is the uneven bathymetry, as can be seen both in the seabed slope (Figure 13) and bathymetry (Figure 14). This results in a somewhat turbulent flow through the sound (as mentioned in Section 4.1.2). For a larger farm it also has implications for foundation choice and array layout, likely making a piled foundation more suitable.
- Across the region there are sites suitable for a myriad of different devices or various shapes and sizes. The sites associates with larger utility scale devices (both fixed and floating) tend to be in the lower flow areas and thus would be more suitable for future generations of devices optimised to improve yield in these conditions. Within Ramsey Sound a small-scale device is most suitable as the water is generally shallower than 40m.

7 Techno-economic assessment

In this section the economic potential of the Ramsey Sound site is investigated. This includes the potential capacity available, the LCOE, and the revenue support that would be required to enable further developments beyond the TIGER project.

7.1 Methodology

The analysis consisted of four steps:

1. Estimate the number of turbines that could be deployed in the vicinity of the TIGER site, for an appropriate scale of technology.
2. Run hydrodynamic flow models to confirm number of turbines and estimate gross AEP
3. Feed AEP and turbine specification into techno-economic model to calculate LCOE
4. Identify an appropriate CfD for the TIGER site, based on appropriate deployment timescales and project IRR.

Based on the GIS analysis, as discussed in the previous section, we decided that a small scale technology was most appropriate. Previous studies have indicated that a rotor diameter of 15m is appropriate for the Ramsey Sound site [65], in agreement with the plans of TEL, so we assumed a 500kW, 15m rotor diameter device as a starting point.

Within GIS we created a regular grid of points, to represent turbine locations. We spaced these 2.5x10 rotor diameters (37.5x150m) apart as advised by TIGER project partners (EMEC and technology developers). We found the points that intersected the small scale device deployment regime (this regime is shown in Figure 16A).

We drew a shape around the selected turbines (orange border), as the calculated seabed area was too detailed for the flow modelling software. This farm shape was given to University of Plymouth who modelled the flow in Thetis. They applied a uniform drag coefficient to the farm area to simulate the impact of the turbines on the flow. They compared this to the ambient flow to determine the energy extracted from the flow by the hypothetical farm. They examined different farm densities by modelling different numbers of turbines (hence drag coefficients) to investigate how this would impact the effective energy production per turbine.

The farm density with the highest average AEP per turbine was used for the techno-economic analysis. We devised representative costs for the technology using data from TIGER project partners and calculated LCOE using standard industry assumptions at an appropriate commissioning date. We produced an LCOE trajectory showing how the costs of the technology deployed at the site could change with time, informed by anticipated industry-wide learning rates. For a farm deployed in 2025, 2030 and beyond we calculated an appropriate CfD strike price by analysing the lifetime revenue and costs and benchmarking the strike price to a project IRR. We back calculated the CfD revenue support required to achieve different levels of project IRR (excluding debt financing) to determine an appropriate strike price. We calculated LCOE and IRR metrics for three scenarios: Baseline, Optimistic and Pessimistic, modelled with different input assumptions, to indicate the uncertainty.

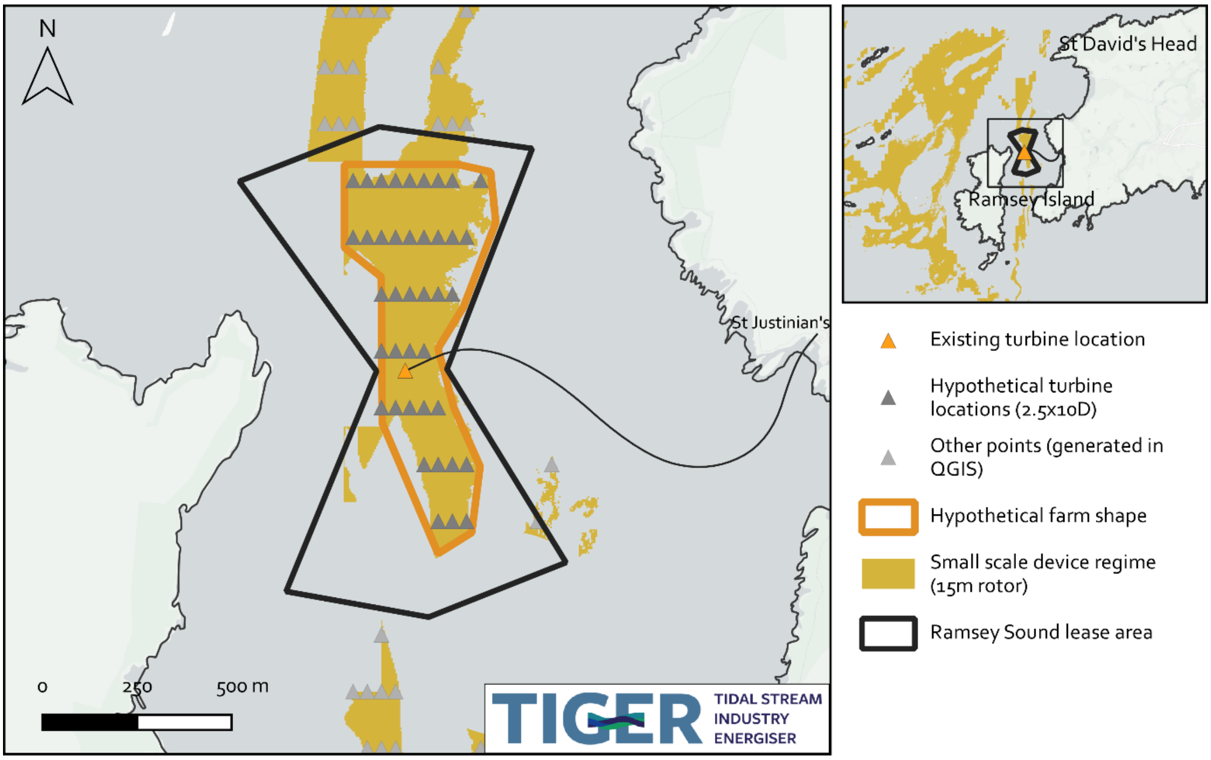


Figure 17 – Hypothetical turbine positions and farm size considered for the site techno-economic analysis.

7.2 Hypothetical farm shape and AEP evaluation

Figure 17 shows the hypothetical farm that was considered for the techno-economic analysis. We counted 40 turbine locations within the vicinity of the existing TEL device, this indicating the number of turbines that could be deployed technically. This would be equivalent to a 20MW farm. The COSW lease area is 0.6km^2 so this is equivalent to a farm density of 33.3 MW/km^2. We excluded potential locations to the north, south and east (light grey “other points”) as these were outside the lease area.

7.2.1 AEP assessment

For the 40 rotors, the University of Plymouth calculated an average capacity factor of 40% for the array. Capacity factors across the area ranged from 24-48% and so array performance and economics could hypothetically be improved by removing the poor performing turbines.

Table 5 shows the results for the different array densities examined. As the farm size is increased the blockage effect also increases, resulting in a lower farm capacity factor. While larger farms could reduce costs through economies of scale, this would be counteracted by the lower yield per MW installed and so the LCOE would not necessarily be better. With this in mind we decided to stick with the 40 device farm with gross capacity factor of 36% for the techno-economic assessment.

Table 5 – Energy yield calculated for the four farm densities.

Number of turbines	Array density (MW/km^2)	Array AEP (GWh/yr)	Capacity factor (%)
20	16.7	34.8	40%
40 (base case)	33.3	63.3	36%

60	50.0	87.4	33%
80	66.6	103.6	30%

7.3 Techno-economic assessment

7.3.1 Modelling assumptions

Table 6 shows the project assumptions that were chosen for the analysis. We assumed a commissioning date of 2030 that would coincide with a CfD allocation Round in 2025-27. As previously mentioned, we considered a 500kW, 15m rotor diameter device, with four devices connected into a subsea hub for export to shore. These assumptions were fixed for all of the scenarios examined.

Table 6 – Device and farm assumptions used for the techno-economic analysis.

Property	Unit	Value
Commissioning year	-	2030
Device rated power	MW	0.5
Device rotor diameter	m	15
Foundation type	-	Monopile
Farm size	MW	20
Number of devices	units	40
Number of subsea hubs	units	10

Table 7 shows the market and financial assumptions that were considered. To model the 2030 commissioning date we first derived the present day, 2022 case. Data sources included bills of materials from TIGER partners, data from ORE Catapult cost models and wider industry knowledge. The market forecast aligns with projections from organisations like the MEC and European Commission[2] and considers the likely buildout based on current sites with consented capacity.

Turbine CAPEX was largely sourced from TIGER partners and adjusted to represent the 0.5MW, 15m rotor diameter device being considered. Monopile foundation costs were devised by assuming appropriate pile sizes and material costs (i.e. “cost per tonne”) and comparing with offshore wind costs. Transmission costs were determined using ORE Catapult datasets used for offshore wind, modifying for the smaller farm size. Development (DEVEX), insurance, contingency and decommissioning (DECEX) were modelled as percentages of the total CAPEX, in line with estimates from both the TSE and offshore wind industries.

[2] The MEC want the UK government to adopt a target of 1GW of marine energy (wave and tidal) by 2035. The European Commission have a deployment target of 100MW of wave and tidal by 2025 and 1GW by 2030 [75].

Installation, planned O&M and unplanned O&M were calculated using a purpose built model. This model was created in Microsoft Excel. It uses a frequency-based approach, calculating the costs of marine operations by calculating the timescales of the operations and multiplying by the charter rate of a suitable vessel. The model also includes costs of vessel mobilization and demobilization, spare parts and considers the distance that vessels need to travel to and within the farm. For the unplanned O&M the model assumes a fixed failure rate (and hence number of interventions) per year. The model can choose whether to mobilise a vessel each time, or to keep a permanent vessel on a long term charter, selecting the cheapest option.

Vessel costs were obtained from ORE Catapult models and cross-checked with TIGER partners. We assumed that a MPSV vessel with DP2 capability would be suitable for installation and devices and for major repair, as is used by Sabella for their device operations. As the devices are small we assumed that a multicat with diver/ROV support could be used for inspection and minor repair on site.

Reductions in CAPEX and OPEX were modelled by applying a learning rate-based reduction. For the Baseline scenario this was set at 13%, reflecting the longer-term learning rate as has been seen historically for other renewables [66]. Learning reduction was not applied to transmission charges, hence why the effective OPEX learning rate is at 12%. For the Optimistic and Pessimistic scenarios these were set to 17% and 9% respectively to encompass the typical range of learning rates [66].

Losses were applied to the 36% gross capacity factor as supplied by the University of Plymouth. These consisted of unavailability (downtime), wake losses and electrical losses. The combined loss was 14.8%. While this appears high, it does represent an early stage array. We applied a “learning rate” of negative 2% to simulate both technological and operational efficiencies that would improve yield and reduce downtime in the future.

Table 7 – Market and financial assumptions used for the techno-economic analysis.

Property	Unit	2022 value	2030 value (commissioning year)	Effective learning rate
Cumulative tidal industry deployment (whole UK market)	MW	10	470	-
WACC	%	7.5%	5.6%	5.0%
Project lifetime	years	25	25	0.0%
CAPEX	£k/MW	8,412	3,881	13.0%
OPEX (inc. transmission charges)	£k/MW/year	388	191	12.0%
Net capacity factor	%	30%	33%	-2.0%

7.3.2 Techno-economic assessment at commissioning date

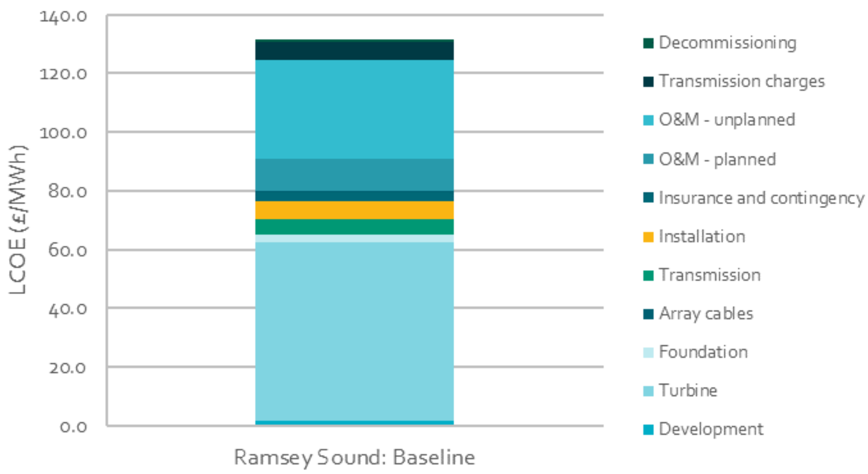


Figure 18 – LCOE breakdown for the Baseline scenario. Note that this is quoted in 2012 terms to be consistent with the base year for strike prices

Figure 18 shows the breakdown of LCOE as calculated in 2030 for the Baseline scenario. The total LCOE, at £134/MWh in 2021 terms (£165/MWh in 2021 currency), is largely made up of the device costs and the unplanned O&M cost. The device cost is fairly high for the size of turbine due to the large rotor relative to the rating of the turbine. A project developer could optimize rated power and rotor diameter for the real site to reduce LCOE, so we believe that this cost is conservative. The cost of the blades represents about 25% of the device CAPEX, and so an argument could be made for reducing these and settling for a lower AEP if this led to lower LCOE over the project lifetime.

The unplanned O&M cost makes up 26% of the total LCOE. A significant contributor to this cost is in vessel mobilization/demobilization, as the model assumes that a vessel must be mobilized each time a failure occurs. In reality the project developer may choose to optimize vessel usage by waiting for several concurrent failures before repairing, to minimize vessel cost, although this would incur higher farm downtime. Moreover, as these turbines are small, it is possible that a larger project developer might own their own vessel to do some of these operations, greatly reducing the costs and market fluctuations associated with the vessel market.

Figure 19 shows the CfD strike price that would be required to achieve different levels of project IRR (excluding tax effects). A 10% IRR would require a CfD strike price of over

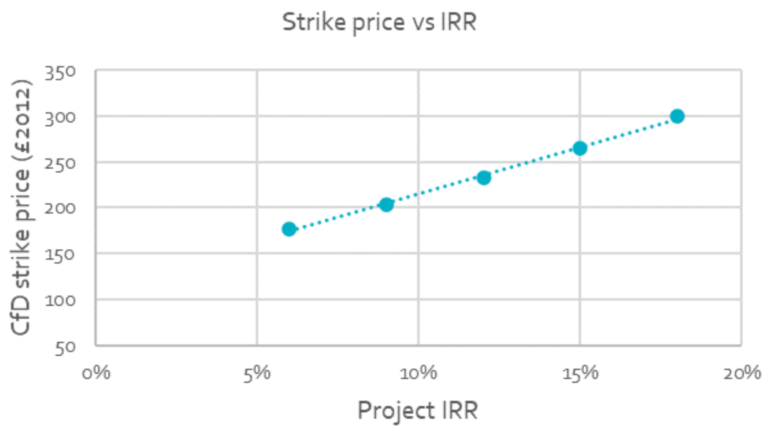


Figure 19 – The CfD strike price required to achieve different project IRR

£200/MWh. For context, the administrative strike price announced for AR4 was £211/MWh for projects to be installed in 2026/27. This shows that the site is fairly expensive and would require a generous subsidy to entice a project developer. It must be noted, however, that subtle changes to the input assumptions can change this picture. Aspects like a higher learning rate, cheaper technology or larger farm could make this site more attractive and bring it in line with better regarded sites like Meygen and PTEC. Moreover, tidal brings other benefits that might warrant a pricing premium (for example bringing local employment to the region and stable, reliable power generation).

The uncertainty in this analysis is addressed in the next section where trajectories are presented.

7.3.3 LCOE and CfD strike price trajectory

Figure 20 shows the calculated LCOE trajectory for the 40 turbine, 20MW Ramsey Sound project. The yellow line shows the baseline scenario, as showed for 2030 in Figure 18. The blue band indicates the uncertainty, the lower part of the range equal to the optimistic scenario and the upper part the pessimistic scenario.

The curve shows that this project LCOE is estimated at £283-412/MWh in 2021 (2012 cost basis) with a central estimate of £348/MWh. This is above the approx. £250/MWh LCOE that has been estimated in other studies (e.g. [66]), the main reason being because it is a small turbine (0.5MW vs the currently 2MW utility scale turbines available on the market). The flow speeds on the site are also lower than more popular sites (as mentioned in Section 4.1.2) which limits the AEP potential.

We anticipate that costs of TSE technology will continue to come down rapidly, with learning rates as seen for other industries. The LCOE in 2030 is estimated at £85-195/MWh. If a 17% learning rate could be achieved, with 10% lower CAPEX and OPEX estimates than our Baseline, then an LCOE at the lower end of our trajectory (£85/MWh) could be achieved. This value, achieved at a UK market size of 470MW (Table 7), aligns well with the £100/MWh by 500MW cumulative deployment as predicted by the ORE Catapult 2018 industry trajectory [67]. Towards the upper limit of our estimation it would be difficult for the project to compete at a CfD auction without material changes to the project (for example using larger turbines, increasing the project size or obtaining e.g. grant funding from Welsh Government).

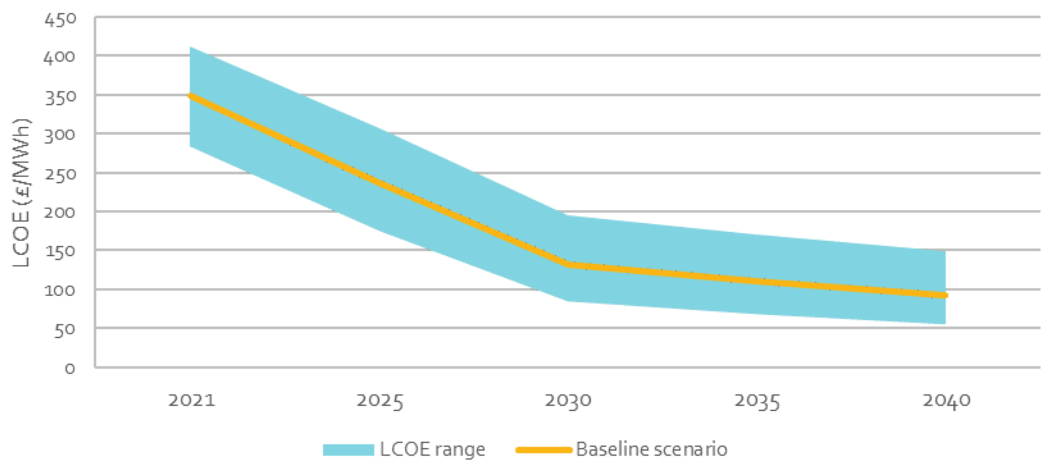


Figure 20 – LCOE trajectory for the 40 turbine Ramsey Sound project. Note that this is quoted in 2012 terms to be consistent with the base year for strike prices

Figure 21 shows the CfD strike price required to obtain 5-15% project IRR for the Baseline scenario over time (orange band). The dark orange line shows the strike price at what we believe would be an appropriate IRR for a project developer to target. This IRR is shown on the secondary axis by the black dashed line. For context, offshore wind project developer Equinor in 2021 stated a target of 4-8% IRR for their projects, the lower end for more mature markets (e.g. Western Europe) and the higher for emerging markets [68].

If the project was being installed in 2021 we believe that the CfD would have to be above £500/MWh, unreasonably high considering the £211/MWh strike price offered for TSE. The main reason for the high subsidy is because of the relatively small turbines and the high return that a developer would need to de-risk the investment.

By 2030, the commissioning date considered appropriate for the Ramsey Sound array, a strike price of £169-265MWh would be needed for a 5-15% IRR. Despite 470MW of TSEdeployed by this date, the technology would still require a high IRR to attract investors as it would still be less proven than options like offshore wind. An IRR of 7.5% would require a strike price of £191/MWh. This is 9.7% lower than the AR4 £211/MWh strike price.

If the optimistic LCOE scenario is considered instead the strike price to achieve 7.5% IRR falls to £120/MWh, 43% lower than the AR4 strike price. A 2030 commissioning date would require a CfD in approximately 2025/26 to be delivered with FID in 2027/28 (equivalent to AR7/AR8 assuming annual CfD allocation rounds are maintained).

It is possible that some developers would settle for a lower IRR. This could be the case for tidal technology developers, who might be more interested in the opportunity to deploy their technology at scale and learn from the findings than generate high returns.

7.3.4 Summary

We have analysed the LCOE and IRR for a hypothetical 40 turbine, 20MW farm in the Ramsey Sound, which can be summarized as follows:

- We selected 0.5MW, 15m rotor diameter turbines and assumed a commissioning date of 2030. These were deemed appropriate given the environmental conditions and current status of the site.

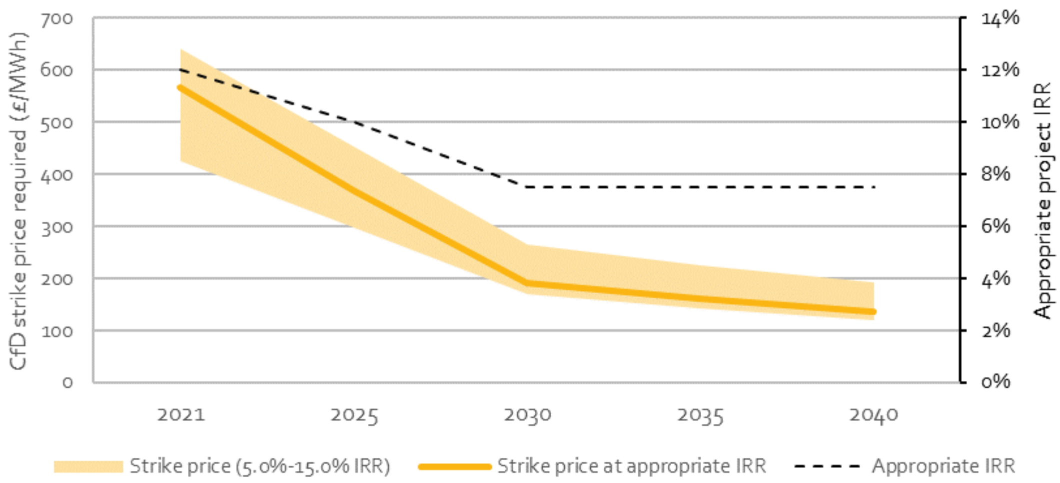


Figure 21 – CfD strike price over time for the Baseline scenario to achieve a 5-15% IRR. The orange line shows the strike price for what we consider an appropriate IRR level (shown on the secondary axis).

- We estimate the LCOE of the project in 2030 to be £131/MWh, with upper and lower bound of £85-195/MWh. We acknowledge that this is a fairly large range of uncertainty, due to the hypothetical nature of the project. This will reduce as the industry matures and more knowledge is gained, particularly around the learning rates that can be accessed in reality. More government certainty and support would allow a greater pace of turbine deployments in UK waters and allow the lower end of the LCOE estimate to be accessed.
- A 7.5% project IRR would require a CfD of £191/MWh for our Baseline scenario. This reduces to £120/MWh for the Optimistic scenario (assuming a higher learning rate and lower initial costs). As we track the progress of the industry over time we will gain a better understanding of how device costs and performance are improving.
- To encourage investment at the Ramsey Sound site in 2030, we believe that a CfD in the range £120-190/MWh would need to be accessed by 2025/26. While this is lower than the £211/MWh administrative strike price offered by the government in 2022 (AR4) it would still likely be on the high side compared to other tidal projects in this timeframe (e.g. Meygen, PTEC, Morlais). This site might require additional funding streams to be fully competitive (e.g. regional grant funding).
- Our analysis was for a hypothetical, representative project. It is certainly plausible that a more cost effective project could be deployed, for example by increasing the size of the turbine or farm capacity.

8 Summary and Recommendations

In this study we have analysed the potential for TSE at Ramsey Sound in Pembrokeshire, Wales. We have examined a number of different issues including past track record, ports of interest, summary of the flow conditions, geospatial analysis of the available area and techno-economic viability. In this section we summarise the study and provide recommendations of areas to focus on to ensure that the regional benefits of TSE are captured.

8.1 Summary

Socio-economic viability

The Welsh Government have indicated strong support for marine renewable energy. This is evidenced by schemes such as The Welsh Government Coastal Communities Fund [11], SMARTCymru and the £100m allocated to marine energy via European Structural Funds. MEW is a leading organisation in Wales dedicated to advancing the marine energy narrative and is managing the META test sites for developers to test scale models and innovations.

Together, the Welsh Government and MEW make Wales a desirable location for marine energy projects. The Ramsey Sound project would also have potential synergies with the tidal projects happening in North Wales (Morlais, Minesto's Holyhead Deep, Bardsey Sound) and a project develop could utilise the same Welsh supply chain. This, however, could present competition to the Ramsey Sound site and make access to revenue support more difficult. The advantage of Ramsey Sound is that it would unlock benefits in a completely different part of Wales (the three other notable TSE projects are all close to Anglesey) which could be attractive to policymakers looking to spread the benefit across Wales.

The Milford Haven port is in close proximity to the Ramsey Sound and would be a natural port to use for installation (and potentially O&M). This industrial hub is expanding its renewable offerings as seen by projects like the £60M Pembroke Dock marine programme and the £4.5M Milford Haven Energy Kingdom project. While there could be competition from the increasing interest in floating wind projects in the Celtic Sea, this offers more of an opportunity than a threat and the growing supply chain will be able to offer opportunities for TSE (particularly manufacturing support and vessels).

In 2020 Pembrokeshire had the joint highest unemployment rate in the whole of Wales and has seen a general outmigration of young people. A tidal energy project at Ramsey Sound could invigorate the community, bringing employment and skills to local people and providing a net positive benefit. The Ramsey Sound itself is fairly inhospitable with the only significant activity being boat trips round Ramsey Island. A submerged tidal concept would be unseen and therefore would not materially impact the reputation of the area as a popular tourist destination. The largest town, St David's, is relatively small (1,600 people). While there would need to be excavation civil works to connect a tidal array into the 11kV substation, the disruption would be low.

Environmental viability

The wider Ramsey Sound location falls within a SAC, with Ramsey Island and the coastline at St David's Head designated as an SSSI. Academic studies have indicated that larger arrays (>10MW) with Ramsey Sound would need more assessment to ensure that environmental impacts, notably impact on sediment transport, were kept low [42].

The RSPB-owned Ramsey Island would also need to be factored into any project development; any project would need to keep impact on diving birds to a minimum. This, combined with the potential impacts on tourism and boating within the Ramsey Sound means that fixed bottom devices would be most suitable.

Tidal developer TEL were able to secure leases both within Ramsey Sound at St David's Head (the latter a 10MW array). This implies that the potential environmental issues could be mitigated with careful project design. For such a project it is clear that engagement with the community and local stakeholders such as the RSPB would be paramount to a project's success. A slower project buildout over time, rather than deploying a >10MW farm all at once, would help to bring the community onside and build up learning to ensure that the project can be installed at one with the environment.

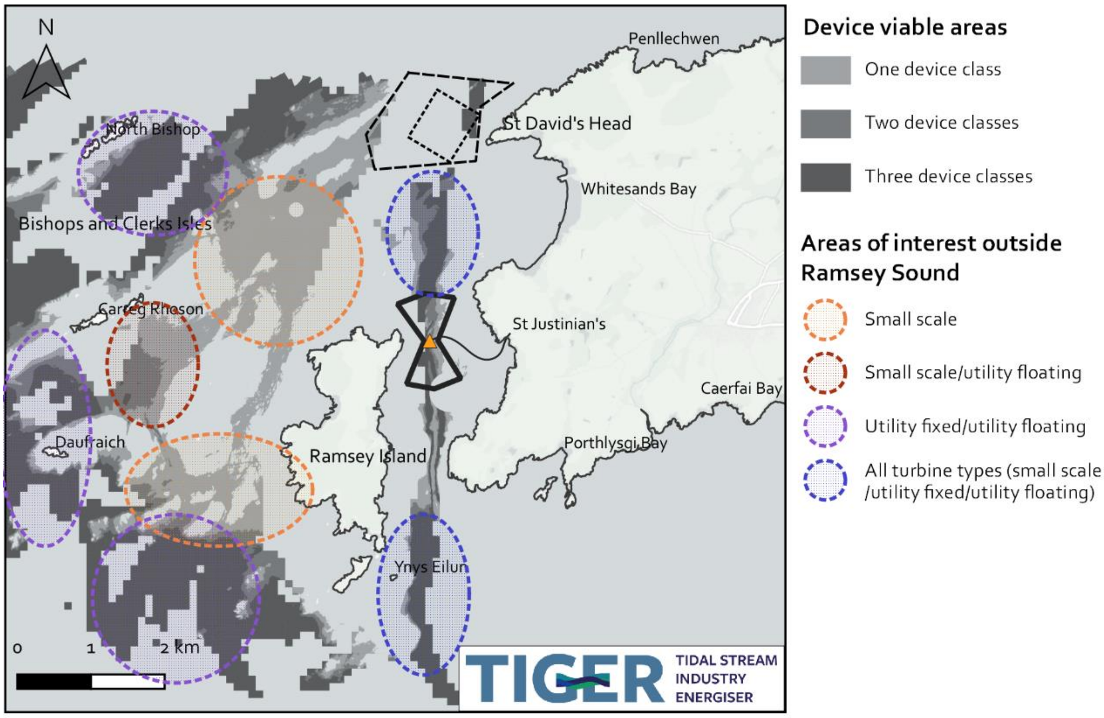


Figure 22 – Promising areas outside Ramsey Sound as identified by the GIS analysis. The device classes refer to the four reference devices described in Table 4 (the viable areas for each individually are shown in Figure 16).

Geospatial viability

The GIS analysis indicated several promising areas for TSE deployment. These are summarised in Figure 22. While the area is most suited to a smaller device (rotor diameter <15m), there are areas to the north-west and south-west that could be suited for larger utility scale devices and warrant further investigation. This would likely be after local supply chains are developed and higher flow UK sites are developed first.

The main limiting factors for deployment are the uneven bathymetry, particularly within Ramsey Sound itself, and the flow conditions. There is no significant commercial activity/presence of other sea users that would cause issues for a TSE project, as previously shown in the maps within Section 6.

Ramsey Sound is characterised by its uneven bathymetry, including features like a deep trench exceeding 75m and the surface piercing Horse Rock and The Bitches reef. This impacts the flow, which is generally regarded as turbulent but sufficient for tidal energy extraction. This makes siting within the sound crucial. The significant gradients mean that a piled foundation is likely the best solution. We believe that interest in this site will increase as other commercial tidal sites are developed (e.g. Meygen, Morlais) and as piled foundations and smaller turbine technology becomes more economical.

Techno-economic viability

At the present time we believe that the LCOE would be high for a large commercial project. By 2030 the technology will have improved, with cost reduction achieved through deployment and technological improvements, and so we see this as a reasonable commissioning date for a commercial array in Ramsey Sound.

By 2030 our model indicates that a 20MW farm (40x0.5MW turbines) could be deployed at an LCOE of £85-£195/MWh with a central estimate of £131/MWh (2012 cost basis). At this central estimate we believe that £191/MWh would be a sufficient level for a CfD. This would ensure a 7.5% project IRR and hence offer a reasonable prospect for private funding streams. For a deployment in 2030 such a project would need to secure CfD by 2026. While this level seems relatively high compared to the £211/MWh strike price offered by government in 2022, there are other regional benefits to Wales and Pembrokeshire that could provide motivation for a pricing premium (e.g. local employment, improving grid stability and predictable power).

Moreover, our study considers one hypothetical farm example. There are numerous project options that could unlock greater levels of cost reduction, bringing the LCOE down to our optimistic £106/MWh estimate. These could include greater economies of scale from larger farms, techno-economic optimisation of rotor diameter and turbine rated power and improved O&M strategy, among other things.

Overall summary

From our analysis we believe that Ramsey Sound is a site with the potential to provide meaningful amounts of predictable low carbon energy. The success of the site could depend on the cost trajectory of small, sub 1MW turbines. The commercial prospects of this site will improve once we see TSE deployed on a larger scale, and it will likely be a site of interest by 2030 as other commercial locations are developed and lessons are learnt. The unique location of this site gives it regional economic advantages, and the proximity to Milford Haven and Pembroke Dock could unlock significant manufacturing and operational cost efficiencies. The support of the Welsh Government and MEW will be helpful in helping the wider site realise its full potential, potentially 50-100MW considering neighbouring areas outside the Ramsey Sound.

8.2 Recommendations

From this study we recommend the following future steps:

- **Engage with turbine suppliers and academia:** Within the TIGER project we have seen effective collaboration between Cambrian Offshore and University of Plymouth in assessing the Ramsey Sound site. The history of TEL at the site is well documented, and it is important to bring turbine suppliers on side to ensure that interest in the site is maintained and improved.

  There are several companies testing technology at a suitable scale for the site including Sabella, SIMEC Atlantis, Verdant Power and Nova Innovation. Keeping good lines of communication with these suppliers will ensure that there is adequate competition to choose from which will lead to lower turbine costs in the long run.

- **Establish grid viability:** WPD manage the distribution network at the regional level. Data from their online portal indicates that there is potentially limited capacity at the St David's 33kV substation connection point. Larger scale projects are necessary to reach economic levels, and so WPD need to be brought into discussion to ensure that there is sufficient grid capacity for future projects.
- **Grow links with Milford Haven port:** As mentioned, Milford Haven and Pembroke Dock are a hub of industrial activity and represent an impressive opportunity for a project at Ramsey Sound. It will be necessary to secure berths and quayside space for a future commercial project, especially given the high level of interest in Celtic Sea floating wind projects. As the commercial opportunity increases, TSE project developers will need to ensure that they have examined how best to tap into the supply chain within the port vicinity.

While Milford Haven port would be ideal for manufacturing and operations, it might be somewhat far away to serve as an operations base. We recommend analysing more local port options to see if there are any more viable local solutions, which could especially be the case for smaller devices.

- **Establish feasibility of neighbouring sites:** Ramsey Sound and St David's Head are well known as previous commercial targets of TEL. This analysis has indicated other sites of interest (Figure 22), especially for larger utility scale devices. While the flow speeds are less than other commercial sites (e.g., Meygen) they could be suitable as second-generation site, especially when considering the synergies and learning gained from a smaller project within the Ramsey Sound. We recommend that these sites are analysed further from a techno-economic perspective to understand what the yield and key cost drivers would be. Flow modelling will also be crucial to understand how wake and blockage effects from individual farms would impact those in neighbouring areas.
- **Bring the local community on side:** The region is a popular tourist destination, and a tidal farm would offer improvements to local employment, diversifying the local economy. The community will be aware of the problems with the TEL deployment and might be reluctant for future TSE projects. We recommend engaging with the community early on to understand their opinions and encourage support. A community ownership model, whereby the community has a stake in a tidal project and can benefit financially, could be a way to increase support and awareness.

References

[1] PEMBROKESHIRE COAST NATIONAL PARK, "Supplementary Planning Guidance: Seascape Character Assessment: Ramsey Island coastal waters: S," 2013.

[2] PMSS on behalf of the Welsh Development Agency, "Wales Marine Energy Site Selection," 2006.

[3] TIDAL ENERGY Limited, "DeltaStream Demonstration: Ramsey Sound, Pembrokeshire," 2008.

[4] E.ON, "E.ON and Lunar Energy announce proposal to build one of the world's largest tidal stream power stations off the Welsh coast," 25 October 2007. [Online]. Available: https://www.eonenergy.com/about-eon/media-centre/eon-and-lunar-energy-announce-proposal-to-build-one-of-the-worlds-largest-tidal-stream-power-stations-off-the-welsh-coast/. [Accessed 6 July 2021].

[5] Regeneris Consulting, "The Economic Impact of the Development of Marine Energy in Wales," 2013.

[6] BBC, "Failed Ramsey Sound tidal energy scheme 'faulty for months'," 12 December 2016. [Online]. Available: https://www.bbc.co.uk/news/uk-wales-politics-38236014. [Accessed 6 July 2021].

[7] Tidal Energy Ltd., "DeltaStream Demonstrator Project: Non-technical summary," 2009.

[8] Tidal Energy Ltd., "Tidal Stream Energy Demonstration Array St David's Head, Pembrokeshire: Environmental Scoping Report," 2012.

[9] Cadw, "Pan-Wales heritage interpretation plan: Wales – the first industrial nation," 2011.

[10] T. M. a. L. Kitson, "The End of Coal Mining in South Wales: Lessons learned from industrial transformation," International Institute for Sustainable Development, 2017.

[11] The National Lottery Community Fund, "The Welsh Government Coastal Communities Fund," The National Lottery Community Fund, [Online]. Available: https://www.tnlcommunityfund.org.uk/funding/programmes/coastal-communities-fund. [Accessed 8 July 2021].

[12] Welsh Government, "Small Scale Coastal Infrastructure Scheme," Welsh Government, 2021.

[13] Energy Wales Marine Energy Task and Finish Group, "Marine Energy Plan for Wales - Unlocking the Energy in Our Seas," 2015.

[14] Marine Energy Wales, "State of the Sector 2020: Economic Benefit for Wales," Marine Energy Wales, 2020.

[15] Welsh Assembly Government, "Marine Renewable Energy Strategic Framework: Approach to Sustainable Development," 2011.

[16] Welsh Government, *Kery Facts: SMARTCymru,* 2017.

[17] Business Wales, "SMART Cymru supports Bombora to develop mWave, a membrane driven wave energy generator.," [Online]. Available: https://businesswales.gov.wales/expertisewales/product/bombora-wave-power-europe-limited/smart-cymru-supports-bombora-develop-mwave-membrane. [Accessed 8 July 2021].

[18] Swansea-Based Company Raises GBP 1 Mln for Wave Device Development, "OffshoreWIND.biz," 8 July 2014. [Online]. Available: https://www.offshorewind.biz/2014/07/08/swansea-based-company-raises-gbp-1-mln-for-wave-device-development/. [Accessed 8 July 2021].

[19] Bloomberg, "Welsh Government Awards €14.9 Million of EU Funding to Leading Marine Energy Developer Minesto," 31 May 2019. [Online]. Available: https://www.bloomberg.com/press-releases/2019-05-31/welsh-government-awards-14-9-million-of-eu-funding-to-leading-marine-energy-developer-minesto. [Accessed 8 July 2021].

[20] Marine Energy Wales, "WEST ANGLESEY TIDAL DEMONSTRATION ZONE," [Online]. Available: https://www.marineenergywales.co.uk/marine-energy-in-wales/demonstration-zones/anglesey-demonstration-zone/. [Accessed 8 July 2021].

[21] Morlais Energy, "Partners," [Online]. Available: https://www.morlaisenergy.com/partners/. [Accessed 8 July 2021].

[22] Minesto, "Deep Green Holyhead Deep Project Phase 1 (0.5MW): Non-technical Summary," 2016.

[23] Minesto, "Holyhead Deep – the world's first low-flow tidal stream project," [Online]. Available: https://minesto.com/projects/holyhead-deep. [Accessed 8 July 2021].

[24] PACEC, "Economic Profile of Pembrokeshire: Final Report from PACEC," Pembrokeshire County Council, 2015.

[25] Welsh Government, "Summary statistics for South West Wales region," 2020.

[26] Cambrian Offshore South West Ltd, "Ramsey Sound site description," Not published, 2020.

[27] Marine Energy Wales, "Marine Energy Test Area secures Marine Licence," 25 January 2021. [Online]. Available: https://www.meta.wales/news/marine-energy-test-area-secures-marine-license/. [Accessed 7th July 2021].

[28] A. Ajdin, "EMEC strengthens alliance with META," Offshore Energy, 6 May 2020. [Online]. Available: https://www.offshore-energy.biz/emec-strengthens-alliance-with-meta/. [Accessed 7 July 2021].

[29] A. Garanovic, "META tidal stream resources up for assessment," Offshore Energy, 15 jUNE 2021. [Online]. Available: https://www.offshore-energy.biz/meta-tidal-stream-resources-up-for-assessment/. [Accessed 7 July 2021].

[30] Wave Hub Ltd., "Pembrokeshire Demonstration Zone: Advancing Offshore Renewable Energy," Wave Hub Ltd,.

[31] Port of Milford Haven, "Oil & Gas," [Online]. Available: https://www.mhpa.co.uk/oil-and-gas/. [Accessed 9 July 2021].

[32] Carbon Trust, "Future Potential for Offshore Wind in Wales," Welsh Government, 2018.

[33] Cardiff University, "An analysis of economic activity dependent on the Milford Haven Waterway," Milford Haven Port Authority, 2012.

[34] Port of Milford Haven, "PEMBROKE PORT DEVELOPMENTS," [Online]. Available: https://www.mhpa.co.uk/pembroke-port-developments/. [Accessed 9 July 2021].

[35] Pembroke Port, "PORT SUBMITS PLANNING APPLICATION TO PREPARE SITE FOR MAJOR £60M MARINE RENEWABLE ENERGY DEVELOPMENT," 18 December 2020. [Online]. Available: https://www.pembrokeport.com/news/port-submits-planning-application-to-prepare-site-for-major-60m-marine-renewable-energy-development/. [Accessed 9 July 2021].

[36] Offshore Renewable Energy Catapult, "Benefits of floating offshore wind to Wales and the South West," 2020.

[37] M. Dolman, W. Nock and S. King, "Hydrogen development in Wales," Element Energy, Cambridge, 2020.

[38] European Marine Energy Centre (EMEC), "HYDROGEN R&D FACILITIES," [Online]. Available: http://www.emec.org.uk/facilities/hydrogen/. [Accessed 12 July 2021].

[39] R. Flynn, "EMEC's Hydrogen Journey," 2019.

[40] Business Live, "Stena Line cancels Fishguard-Rosslare sailings for a week," 12 February 2021. [Online]. Available: https://www.business-live.co.uk/ports-logistics/stena-line-cancels-fishguard-rosslare-19825963. [Accessed 13 July 2021].

[41] RWE, "RWE launches its Pembroke Net Zero Centre to help drive decarbonisation in South Wales," 26 May 2021. [Online]. Available: https://www.rwe.com/en/press/rwe-generation/2021-05-26-rwe-launches-its-pembroke-net-zero-centre. [Accessed 13 July 2021].

[42] D. Haverson, J. Bacon, H. C. Smith, V. Venugopal and Q. Xiao, "Modelling the hydrodynamic and morphological impacts of a tidal stream development in Ramsey Sound," *Renewable Energy,* vol. 126, pp. 876-887, 2018.

[43] M. Harrold, P. Ouro and T. O'Doherty, "Performance assessment of a tidal turbine using two flow references," *Renewable Energy,* vol. 153, pp. 624-633, 2020.

[44] Tidal Energy Ltd., "DeltaStream Demonstration: Scoping report," 2008.

[45] P. Evans, S. Armstrong, C. Wilson, I. Fairley, C. Wooldridge and I. Masters, "Characterisation of a highly energetic tidal energy site with specific reference to hydrodynamics and bathymetry," in *EWTEC*, Aalborg, 2013.

[46] M. Harrold and P. Ouro, "Rotor loading characteristics of a full-scale tidal turbine," *Energies,* vol. 12, p. 1035, 2019.

[47] E. Bell, "The recovery of seabird populations on Ramsey Island, Pembrokeshire, Wales, following the 1999/2000 rat eradication," in *Island invasives: scaling up to meet the challenge*, Gland, Switzerland, IUCN, 2019, pp. 539-544.

[48] P. A. Gillibrand, R. A. Walters and J. McIlvenny, "Numerical simulations of the effects of a tidal turbine array on near-bed velocity and local bed shear stress," *Energies,* vol. 9, p. 852, 2016.

[49] University of Strathclyde, "Methodology for a Decision Support Tool for a Tidal Stream Device," 2014. [Online]. Available: http://www.esru.strath.ac.uk/EandE/Web_sites/13-14/Tidal/site.html. [Accessed 15 July 2021].

[50] M. Togneri and I. Masters, "Micrositing variability and mean flow scaling for marine turbulence in the Ramsay Sound," *J. Ocean Eng. Mar. Energy,* vol. 2, pp. 35-46, 2016.

[51] ABPmer, "Sustainable management of marine natural resources - Mapping natutral resources," Welsh Government, 2020.

[52] PEMBROKESHIRE COAST NATIONAL PARK, "Pembrokeshire Coast National Park Seascape Character Assessment: St David's Head," 2019.

[53] S. L. Ward, M. R. Hashema and S. P. Neill, "Characterising the tidal energy resource of Pembrokeshire," in *4th Oxford Tidal Energy Workshop*, Oxford, 2015.

[54] IRENA, "FUTURE OF WIND: Deployment, investment, technology, grid integration and socio-economic aspects," International Renewable Energy Agency, Abu Dhabi, 2019.

[55] T. Karna, S. C. Kramer, L. Mitchell, D. A. Ham, M. D. Piggott and A. M. Baptista, "Thetis coastal ocean model: discontinuous Galerkin discretization for the three-dimensional hydrostatic equations," *Geoscientific Model Development,* vol. 11, p. 4359–4382, 2018.

[56] F. Rathgeber, D. A. Ham, L. Mitchell, M. Lange, F. Luporini, A. T. McRae, G. T. Bercea, G. R. Markall and P. H. Kelly, "Firedrake: Automating the finite element method by composing abstractions," *ACM Transactions on Mathematical Software,* vol. 43, 2016.

[57] A. Avdis, A. S. Candy, J. Hill, S. C. Kramer and M. D. Piggott, "Efficient unstructured mesh generation for marine renewable energy applications," *Renewable Energy,* vol. 116, p. 842–856, 2018.

[58] Bangor University, "UKHO Tide Gauge Data Network," 2017.

[59] Seazone Solutions Ltd, "Edina Digimpa Service. Hydrospatial one. Gridded bathymetry," 2014.

[60] L.Mackie, P.S.Evans, M.J.Harrold, T.O’Doherty, M.D.Piggott and A.Angeloudis, "Modelling an energetic tidal strait: investigating implications of common numerical configuration choices," Applied Ocean Research, 2021.

[61] Voyages of Discovery, "Ramsey Island Voyage," 2022. [Online]. Available: https://www.ramseyisland.co.uk/boat-trips/ramsey-island-voyage/. [Accessed 26 5 2022].

[62] Pembrokeshire Coast National Park, "Seascape Character Area Descriptio: St Brides Bay," 2013.

[63] ICF Incorporated, L.L.C., "Comparison of environmental effects from different offshore wind turbine foundation," U.S. Department of the Interior Bureau of Ocean Energy Management (BOEM), Fairfax, VA, USA, 2021.

[64] Dogger Bank Offshore Windfarm, "Dogger Bank Offshore Wind Farm: Decommisioning Programme," 2020.

[65] D. S. Coles, M. Lucas, D. White and J. Miles, "Cost modelling and design optimisation of tidal stream turbines," in *European Wave and Tidal Energy Conference (EWTEC)*, Plymouth, UK, 2021.

[66] D. Coles et al., "A review of the UK and British Channel Islands practical tidal stream energy resource," *Proc. R. Soc. A,* vol. 477, no. 20210469, 2021.

[67] Offshore Renewable Energy Catapult, "TIDAL STREAM AND WAVE ENERGY COST REDUCTION AND INDUSTRIAL BENEFIT," Glasgow, 2018.

[68] O. K. Helgesen, "Equinor and Orsted see green energy ambitions hit profitability headwinds," Upstream, 1 7 2021. [Online]. Available: https://www.upstreamonline.com/energy-transition/equinor-and-orsted-see-green-energy-ambitions-hit-profitability-headwinds/2-1-1031016. [Accessed 27 6 2022].

[69] SEENEOH, "Tidal site development guidelines: Site Selection Methodology (deliverable WP T1.1.3)," TIGER project, 2021.

[70] A. Iyer, S. Couch, G. Harrison and A. Wallace, "Variability and phasing of tidal current energy around the United Kingdom," *Renewable Energy,* vol. 51, pp. 343-357, 2013.

[71] NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY, "WORLD PORT INDEX: TWENTY-SEVENTH EDITION," THE UNITED STATES GOVERNMENT, Springfield, Virginia, 2009.

[72] Marine Scotland, "ectoral marine plan for offshore wind energy: social and economic impact assessment scoping report," Scottish Government, 2018.

[73] The Offshore renewable Energy Catapult, "Floating offshore wind constraint mapping in the Celtic Sea," 2020.

[74] M. Glarou, M. Zrust and J. C. Svendsen, "Using Artificial-Reef Knowledge to Enhance the Ecological Function of Offshore Wind Turbine Foundations: Implications for Fish Abundance and Diversity," *J. Mar. Sci. Eng.,* vol. 8, p. 332, 2020.

[75] Rémi Collombet and Donagh Cagney, "Last stop to 2025: a 2022 action plan to deliver on the Offshore Strategy's Ocean Energy Target," Ocean Energy Europe, 2022.

Appendix A. Constraints

Table A1. 1 – Constraints considered to estimate the technical and economic potential of the region. Orange items are hard constraints, yellow are soft constraints that were considered more qualitatively.

Dataset	Data source/s	Rationale	Constraint considered
Tidal velocity	University of Plymouth (THETIS model)	The kinetic energy in the tidal flow is proportional to the cube of the tidal velocity. This means that the tidal flow is arguably the most important factor when siting as project,. to ensure that it can generate lots of electricity. The mean spring peak velocity is the peak tidal velocity that is observed for a mean spring tide. It is an indicator of the overall resource at the location, and can be used as a high level site screening metric. For typical devices, the minimum level for economic power extraction is recommended as 2.5 m/s [69]. Sometimes the metric maximum spring current is considered instead, in the range 2 m/s [49] to 2.5 m/s [70].	Mean spring peak velocity
Bathymetry	IMARDIS portal Admiralty data portal	The suitable water depth for early stage, first generation devices is usually assumed to be in the 20-60 m range [70] [69]. Deployment is limited in shallow waters as suitable clearance is needed above rotor blades for safety reasons. Deployment in deeper water will add cost and complexity for installation and recovery of devices (particularly those fixed to the seabed). Hence, such deep water sites would be de-prioritised compared to shallower and easier to access areas.	Shallow water Deep water

Dataset	Data source/s	Rationale	Constraint considered
		As the examined Ramsey Sound region is relatively shallow, with maximum water depths of 80 m, no deep water constraint was applied.	
Seabed slope	Calculated in GIS from bathymetry data	The seabed gradient can have an impact on the foundation type that is a suitable. Gravity base foundations, historically more common for tidal stream devices, require a level seabed. Monopiles can be deployed in more extreme gradients. This will depend on the specifics of the design and seabed conditions and would require detailed technical analysis to determine. A representative value of 15^{o} was used based on expertise within OREC.	Extreme gradients
Offshore renewable lease areas	The Crown Estate	This includes areas of the sea that are licensed for offshore wind and wave projects.	Close to offshore renewable lease areas
Ports	World Port Index [71]	Tidal turbines can be navigational hazards. This is especially the case for arrays of floating devices, although could also apply to fixed devices, depending on the water depth, as suitable clearance is required above the rotors. Fishing traffic is higher around ports, and so a 1 km buffer was applied to the floating device concept. Restrictions on the fixed devices are accounted for by the bathymetry, and so are not included here. Port locations were sourced from the World Port Index, and supplemented with smaller local ports and jetties that were identified using satellite imagery and maps.	Close to ports

Dataset	Data source/s	Rationale	Constraint considered
Aggregate extraction	The Crown Estate	These are areas where aggregates are extracted for the construction industry. Areas are licensed from The Crown Estate.	Within aggregate extraction areas
Dredge spoil dumping	EMODnet	These are areas where dredged sediment is dumped. This material is produced when ports are dredged, periodically required to ensure the port channel is a suitable depth for vessels. In reality, the development of a tidal farm within these areas would require a full socio-economic study, with no laws explicitly prohibiting this (for example [72]). These areas are, however, considered hard exclusions for the purposes of this study as they would add extra complications and considerations.	Within dredge spoil dumping areas
Munition disposal areas	EMODnet	This is where munitions have been dumped at sea. Includes both conventional and chemical munitions.	Within munition disposal areas
Oil and gas infrastructure	Oil and Gas Authority (OGA)	Includes active oil and gas wells, cables and lease areas.	Close to oil and gas infrastructure
Natural gas and CCS site agreements	The Crown Estate	There are some projects that have licenses to storage natural gas or carbon dioxide from carbon capture and storage (CCS). None of these coincide with the Ramsey Sound area considered, with only three sites having such agreements in England, Wales and Northern Ireland.	Within agreement areas
Vessel traffic	IMO	IMO traffic separation scheme and recommended areas to avoid were included as constraints.	Within designated areas and separation schemes

Dataset	Data source/s	Rationale	Constraint considered
	EMODnet	Vessel density layers, derived from AIS data, were also used as a soft constraint.	Where vessel traffic is high
Shipwrecks	Admiralty data portal	Shipwrecks can be historically significant and potentially hazardous to operations. A 500m buffer around shipwrecks is considered, in line with similar studies (for example [73]).	Close to shipwrecks
Distance to shore	Calculated in GIS	Distance to shore can be considered a proxy for export cable length. If the export cable to shore is too long then projects will be uneconomic, as too much energy will be lost in the cables. Floating tidal devices could be considered a visual impairment, negatively impacting local communities and tourism. This has not been a factor for previous tidal projects, and would likely only become an issue for large farms near to more populous areas, and so is not considered as a factor.	Close to shore Far from shore
Seabed type	British Geological Society	The seabed geology will influence the choice of foundation. Generally gravity bases are more suitable for rocky and harder foundation types, where the seabed requires less preparation. They are less suitable for very soft sediments [63]. Conversely, monopiles are better suited for softer foundations, where it is easier to pile into the seabed. If there is shallow bedrock then pre-drilling is required, which adds time, cost and requires more specialist equipment. Coarse gravels can make monopiles more difficult to pile [63].	Within areas with certain seabed sediment types

Dataset	Data source/s	Rationale	Constraint considered
Protected areas	EMODnet	The wider Pembrokeshire area coincides with several protected areas: SPA SAC SSSI The majority of the promising tidal areas are within one of more of these areas. Because the Ramsey Sound and St David's Head sites obtained licenses within these areas, it is assumed that they do not present a barrier to TSE deployment.	Within environmental protection areas
Fishing activity	Global Fishing Watch	Offshore renewable energy and commercial fishing do not tend to coincide. There are synergies that are being researched, for example blue economy, multi-use applications where fish farms could be co-located with offshore wind farms. This is especially the case for countries with small EEZs, for example Belgium. Offshore wind farms can also act as spawning or nursery areas [74], with reefs forming around the offshore infrastructure. Generally offshore renewable energy developments are believed to have negative impacts on fishing. Examples include displacement native fish populations due to noise and disturbance in the construction and O&M activity, and the presence of subsea cables which prohibits trawling. As the moving rotor is submerged, tidal turbines arguably are more problematic for fishing. Due to a lack of commercial tidal farms, there	Within high fishing activity areas

Dataset	Data source/s	Rationale	Constraint considered
		is little information about what fishing activity could be permitted within tidal farm boundaries. As this study is a high level scoping study, fishing is considered as a soft constraint, with high density fishing areas avoided where possible.	
Distance to grid	Calculated in GIS using data from WPD	If the cable landfall is too far from a suitable substation or cable then grid upgrades will be required, which can be very costly. For the early stage projects expected at Ramsay Sound, it is assumed that the projects will need to be close to grid to be economically feasible.	Far from grid (onshore)