ICE report: Assessment of the marine energy resources at Lundy and the Isles of Scilly in the UK, Chausey and Molène in France

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About ICE

Supported by Interreg VA France (Channel) England, the Intelligent Community Energy (ICE) project, aims to design and implement innovative smart energy solutions for isolated territories in the Channel area. Islands and isolated communities face unique energy challenges. Many islands have no connection to wider electricity distribution systems and are dependent on imported energy supplies, typically fossil fuel driven. The energy systems that isolated communities depend on tend to be less reliable, more expensive and have more associated greenhouse gas (GHG) emissions than mainland grid systems. In response to these problems, the ICE project considers the entire energy cycle, from production to consumption, and integrates new and established technologies in order to deliver innovative energy system solutions. The ICE consortium brings together researcher and business support organisations in France and the UK, and engagement with SMEs will support project rollout and promote European cooperation. This report examines the marine renewable energy resource options for four separate remote island communities in the Channel region, specifically Lundy, the Scillies, Isles Chausey, and Molène.

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1. Introduction

Many remote Islands and isolated communities face unique energy challenges, because they have no connection to wider electricity distribution systems, and are dependent on imported energy supplies, which are typically fossil fuel based. What makes the problem more severe is that the energy systems these isolated communities depend on tend to be more expensive, less reliable and have more associated greenhouse gas emissions than mainland grid systems.

The British islands of Lundy and the Isles of Scilly (IoS), and the French islands Chausey and Molène are specific examples of Islands supporting Isolated Communtiies that are facing these energy challenges. In terms of electricity supply, Lundy, Chausey and Molene are not connected to the mainland grid. The IoS is connected to the mainland electricity system via a single 33 kilovolt (kV) cable installed in 1989 [1]. In spite of this, there are still serious energy challenges for the Scillies – the high societal cost of providing energy, reliance on diesel fuel and electricity, and a high share of fuel poverty (22.4% against the national average of 10.4%) [1].

For the islands of Lundy, the IoS, Chausey, Molène , and also some other remote Islands and isolated communities, marine energy is a potentially useful renewable energy sources. Marine energy has the potential of providing a substantial amount of new renewable energy around the world. Tidal stream power and wave power are two typical parts among the various types of marine energy.

A first step towards exploiting marine energy is the assessment of marine energy around the Islands, which helps select the areas with the greatest potential and predict the energy production that can be achieved. The objective of the present report is to study tidal and wave dynamics around the islands of Lundy, the IoS, Chausey, Molène , and identify proper sites for marine energy conversion.

1.1 Tidal stream power

Tidal streams are created by the constantly changing gravitational pull of the moon and sun on the world's oceans. As a kind of renewable energy, tides never stop with water moving first one way, then the other, the world over. Tidal stream technologies are developed to capture the kinetic energy of the currents flowing in and out of the tidal areas.

Tidal stream resources are generally largest in areas where a good tidal range exists, and where the tidal current speed is amplified by the funnelling effect induced by the local coastline and seabed, such as in narrow straits and inlets, around headlands, and in channels between islands [2].

Although the tidal current is highly sensitive to the chosen position, the tidal hydrodynamics can be predicted with great accuracy over very long periods based on the knowledge of the astronomical forces which drive the tides. Tidal stream generation will depend on the tide generating forces and, very roughly, will have a period of 12.42 hours between tides and so will gradually move the generation curve each day.

Various different approaches to in-stream tidal power have been explored. The instream tidal energy device works rather like a wind turbine, positioned under the water in the current. An example of this is the Sabella device, deployed off Ushant as part of the ICE project. Sabella comprises of a 3 bladed design, with a rotor diameter in the order of 10 m, working in typical depths of 30 m. The in-stream tidal turbine is not to be confused with the tidal barrage or tidal lagoon approach (such as at the Rance estuary), which uses the tidal range to drive turbines mounted in a low head dam structure. The in-stream turbines have the advantage for remote island communities that they are relatively easy to deploy (compared to building a barrage) and have a much lower environmental footprint.

Tidal stream energy has the potential to offer an important part of a mixed supply strategy for future UK and French energy systems. The UK and France lead the rest of the world in the development of tidal devices, though they are all generally pre-commercial at the time or writing. In stream tidal energy generation may be attractive to remote Islands and isolated communities due to the reliability of supply, however the industry needs to move towards getting the technology more ready for the general market [3].

1.2 Wave power

Waves are formed by winds blowing over the surface of the sea. The size of the waves generated will depend upon the wind speed, its duration, and the distance of water over which it blows, bathymetry of the seabed and currents. Ocean waves are a huge, largely untapped energy resource. The resultant movement of water carries kinetic energy which can be harnessed by wave energy devices [2]. The potential for extracting energy from waves is considerable.

The best wave resources occur in areas where strong winds have travelled over long distances. Nearer the coastline, the process of shoaling leads to an increase in wave height, which is accompanied by a reduction in wave speed.   The wave height gives energy in a form that can be used by many different designs of wave energy converters. [2]. Wave energy resources can be assessed by making wave measurements at the position of interest. Numerical simulation with the employment of global/local wave models presents another way to assess the wave energy resources.

There are a large number of designs and concepts being pursued and investigated by developers to harness the power of waves, but most of them are at the Research and Development (R&D) stage, with only a small range of devices having been tested at large scale and deployed in the oceans. Shoreline mounted Oscillating Water Column devices have been successful on the Islands of the Azores, but require considerable infrastructure to be inplace, and the turbines may also be noisy. Offshore devices include wave surface following devices, such as the snake like Pelamis deployed off Portugal. Despite considerable research and development, the concepts for converting wave motion (a slow, high-force, reciprocating motion) to one useful for generating electricity show limited signs of converging to a single preferred solution. Questions arise over which concept to use, how best to optimize its performance, and how to control such a system [4]. Compared to wind turbines and tidal turbines, wave energy extraction systems are at a much lower maturity level in terms of commercial readiness [5]. However, as the technology improves, wave energy converters may provide an important contribution to local energy supply at isolated islands and isolated coastal communities.

1.3 Marine renewable energy in the UK and France

The United Kingdom (UK) and French governments have both identified tidal stream power and wave power as technologies that will play an important part in meeting European Union targets to expand renewable energy capacity and reduce greenhouse gas emissions, as well as providing jobs and export opportunities [6].

The UK Marine (Wave & Tidal) Energy Deployment Strategy and Technology Development Targets are illustrated in Figure 1-1, which were set by the Energy Technologies Institute (ETI) and the UK Energy Research Center (UKERC) in 2014.

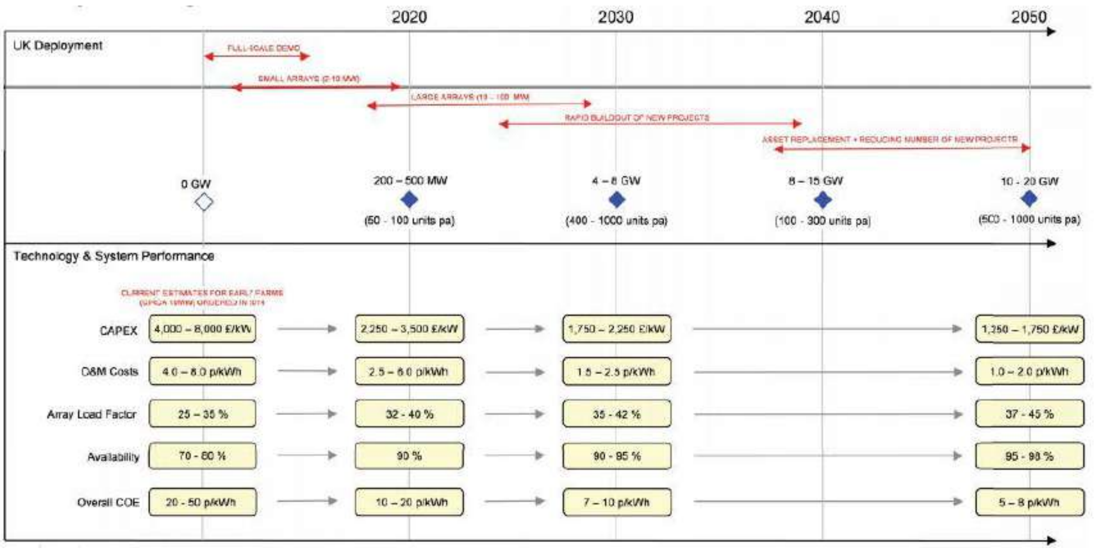


Figure 1-1: UK Marine (Wave & Tidal) Energy Deployment Strategy and Technology Development Targets [3]

On the French side of the channel, Prime Minister Manuel Valls visited Ushant to meet the Mayor of Ushant and the Mayors from two other French islands, including Molène. They signed a pledge to be using only renewable energy by 2030. [7]

1.4 Introduction of Lundy, the IoS, Chausey and Molène

Figure 1-2 presents the locations of Lundy, the IoS, Chausey and Molène to be considered in the present report. More specifically, Lundy is located at the Bristol Channel (see Figure 1-3), whereas the IoS, Chausey and Molène are located at the English Channel (see Figure 1-4).

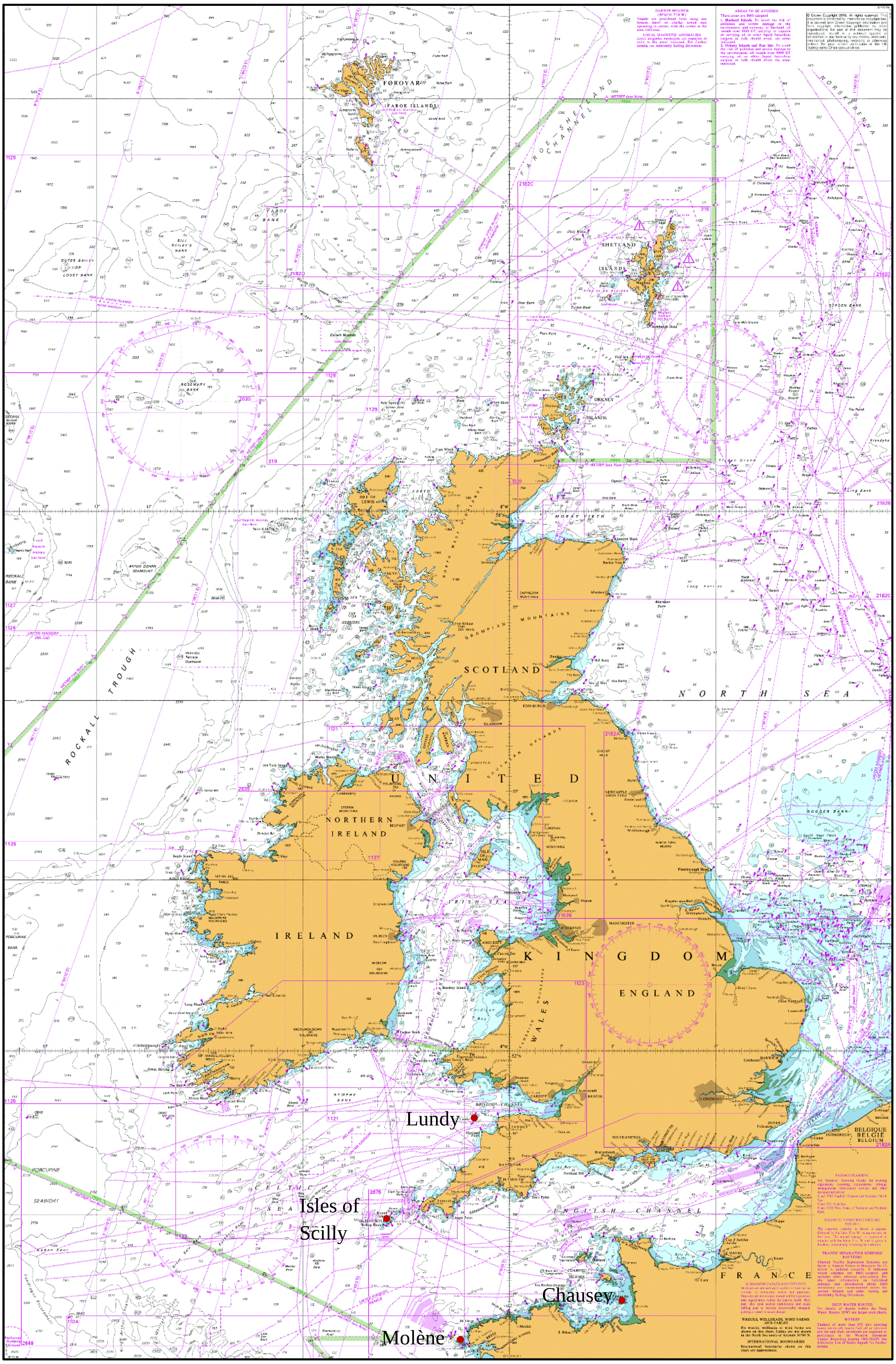


Figure 1-2: Chart of Ireland, United Kingdom and North-West part of France annotated to show the positions of Lundy, the Isles of Scilly, Chausey and Molene. (adapted from UK Admiralty Chart [8])

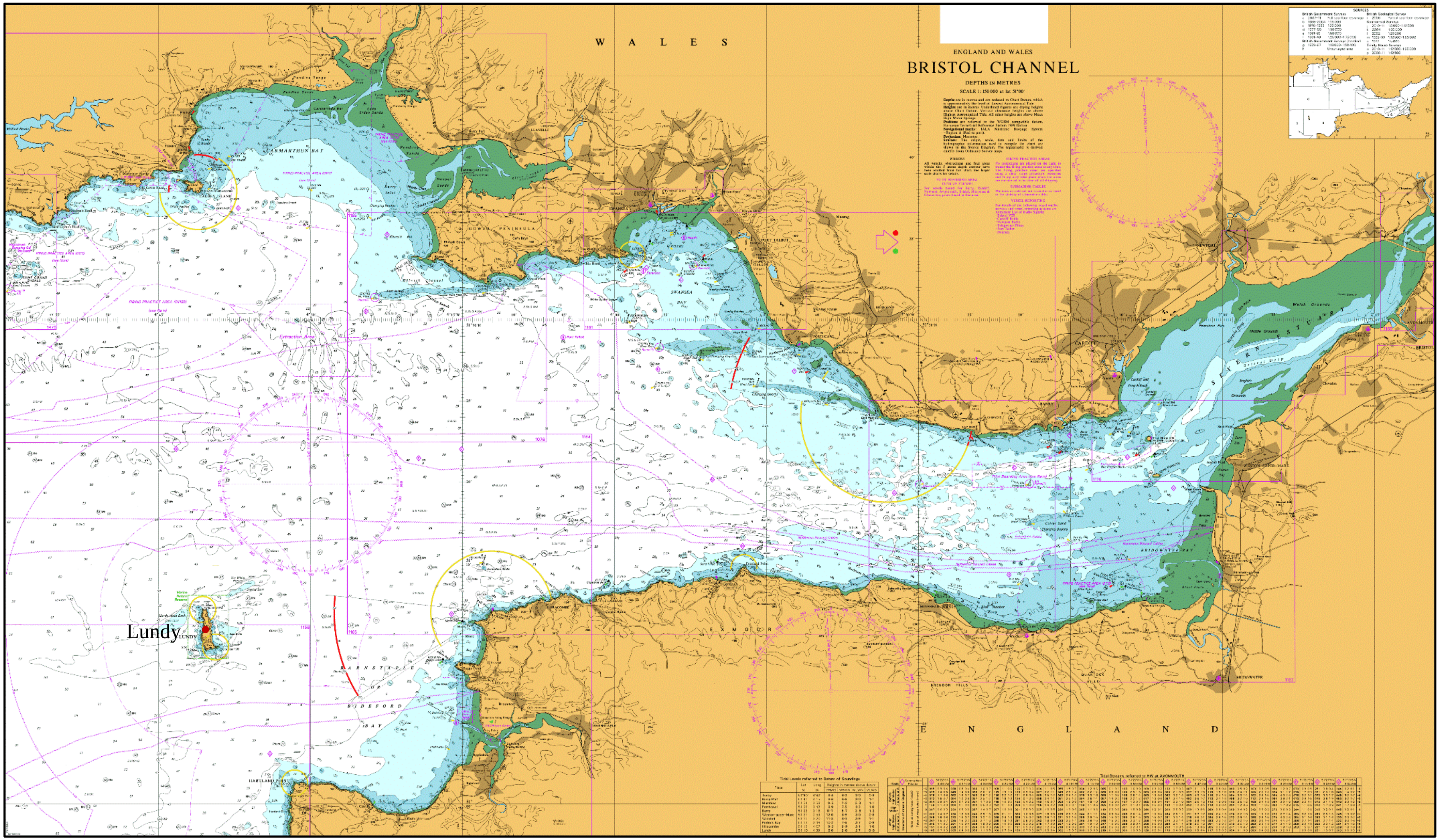


Figure 1-3: Chart of the Bristol Channel showing the position of Lundy (adapted from UK Admiralty Chart [8])

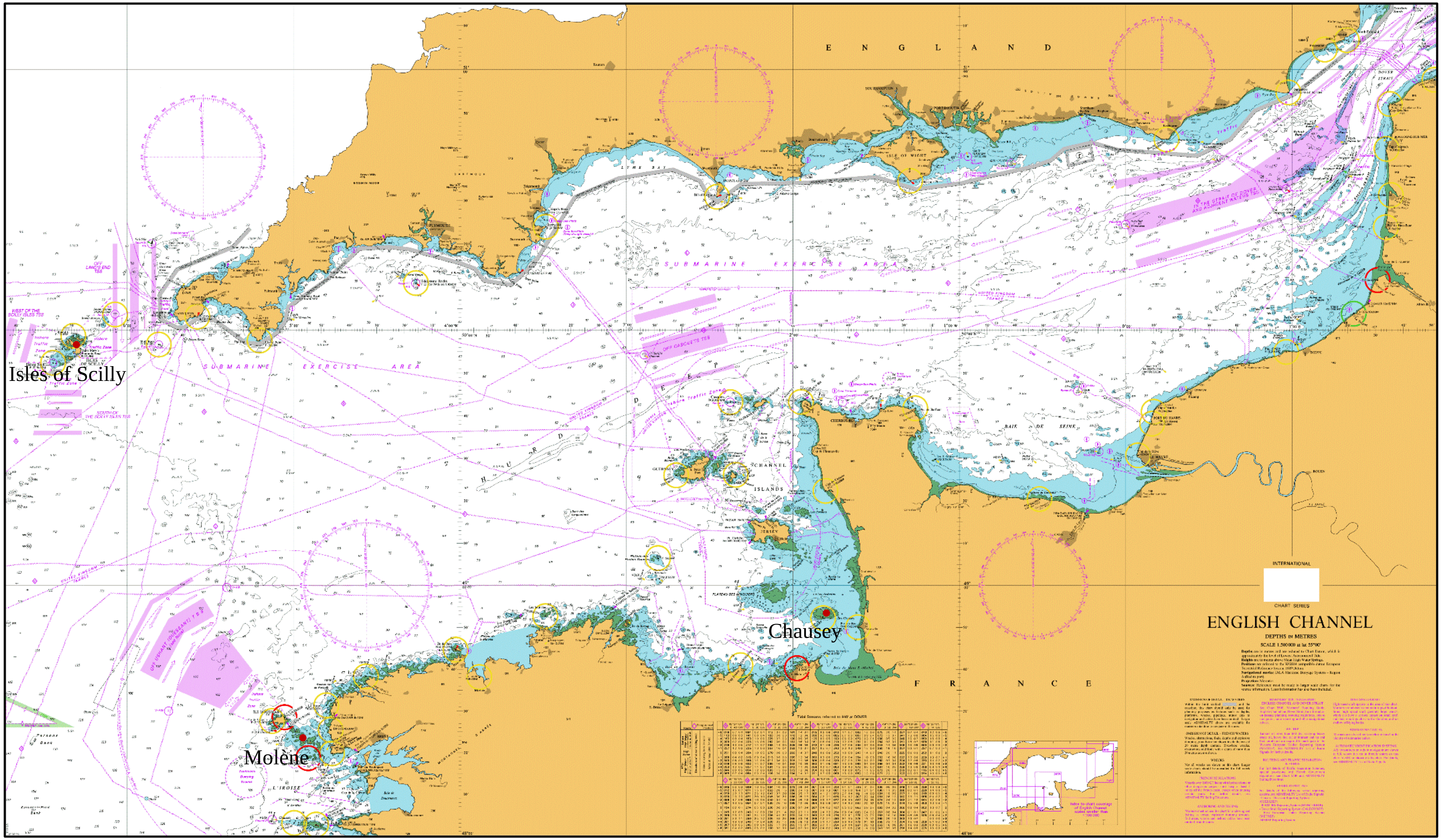


Figure 1-4: Chart of the English Channel showing the positions of Molene and Chasey (adapted UK Admiralty Chart [8])

The water depth and bathymetry has an impact on choice of marine energy device. Tidal turbine rotors can be much smaller than wind turbine rotors, thus they can be deployed much closer together [9], however at low tidal depths close to shore generation capacity may be limited [10]. For wave power exploitation, the R&D regarding mooring system is strongly dependent on water depth as well. Hence the bathymetry around these remote islands is also given in the following subsections (1.4.1 – 1.4.4) [11].

1.4.1 Lundy

Lundy, about three miles (4.8 km) long and 0.6 miles (1.0 km) wide (see Figures 1-5 and 1-6), is the largest island in the Bristol Channel. It lies 12 miles (19 km) off the coast of Devon, England [12].

There is a Marine Conservation Zone (MCZ) at Lundy designated for its granite and slate reef system. The range of physical conditions experienced at Lundy gives rise to the presence of a diverse complex of marine habitats and associated communities within a small area. The reefs of Lundy extend well over 1 km offshore and drop steeply into deep water in some areas [13].

The largest tidal currents exist in the vicinity of the northward boundary of the MCZ and in the south eastern corner of the MCZ. Installation of tidal stream devices in these areas could therefore potentially impact on this MCZ although the extent and magnitude of such impacts would be dependent on detailed project design [13].

There is potentially a good wave energy resource around Lundy Island and it may be possible to develop some areas to the south west of Lundy. The possible effects of reduced wave resource on sensitive habitats arising from the installation of devices would need to be considered [13].

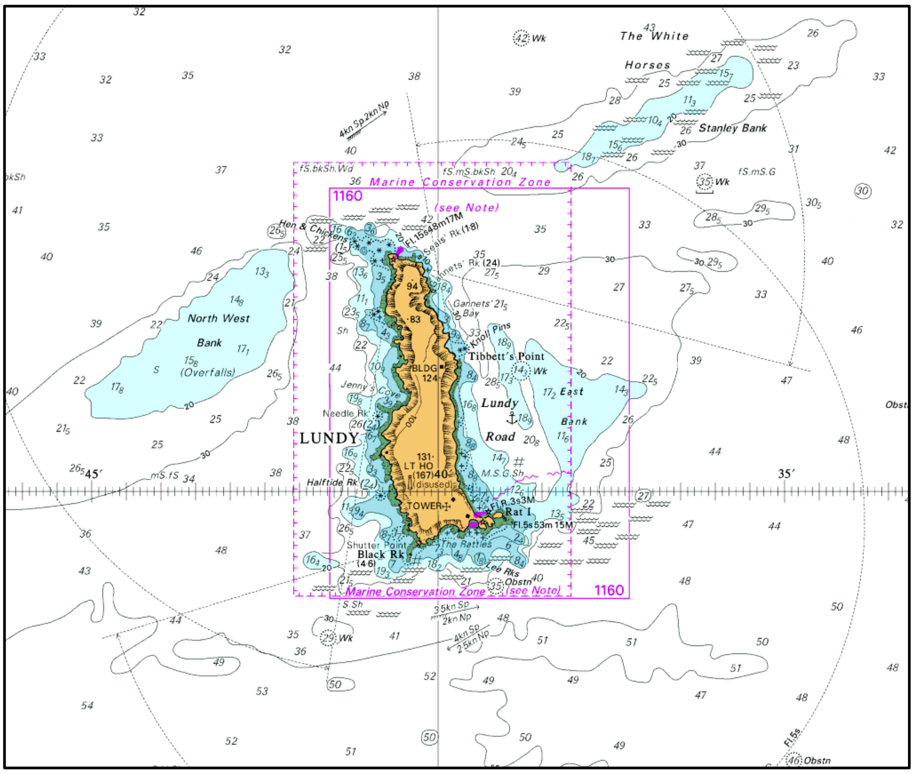


Figure 1-5: Chart of Lundy area (adapted from UK Admiralty Chart [8])

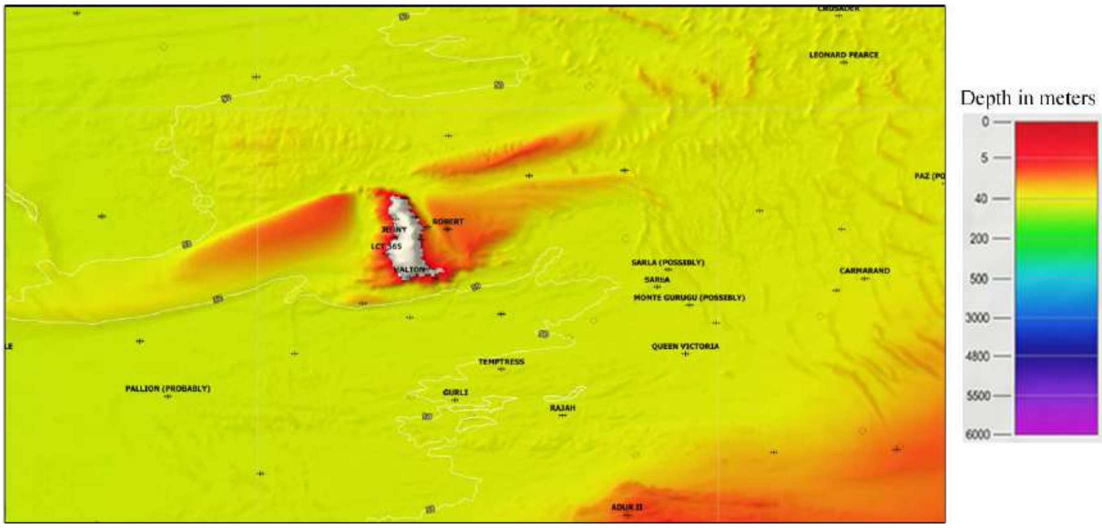


Figure 1-6: Bathymetry around Lundy [11]

1.4.2 IoS

The Isles of Scilly (IoS) are an archipelago off the southwestern tip of Cornwall, England, with five inhabited islands and numerous other small rocky islets lying 45 km off Land's End (Figures 1-7 and 1-8) [14].

The islands' position produces a place of great contrast in terms of the local weather. The ameliorating effect of the sea, greatly influenced by the North Atlantic Current, means they rarely have frost or snow. Exposure to Atlantic winds also means that spectacular winter gales lash the islands from time to time [15].

The bathymetry around the IoS quickly drops to depths of 60-90 m within a few kilometres of the coast [16]. The bedrock topography is typically steeply sloping and irregular, with many gullies and ledges. Boulder areas are present on the slopes and there are ledges at depths around 50 m, some of which are cut by sediment filled gullies [17]. Eggleton and Meadows (2012) found extensive sediment banks (East Bank and West Bank) to the north-west and south-east of the Isles, which are covered with sand waves and megaripples [16].

The tidal range at the IoS is high for an open sea location; the maximum for St. Mary's is 5.99 m. Additionally, the inter-island waters are mostly shallow, which at spring tides allows for dry land walking between several of the islands. Many of the northern islands are connected to Tresco, including Bryher, Samson and St. Martin's (requires very low tides). The sand levels at the region from St. Martin's White Island to Little Ganilly and Great Arthur are close to Chart Datum. The sound between St. Mary's and Tresco, The Road, is fairly shallow, and it never becomes totally dry. Several minor islands are attached around St. Mary's , including Taylor's Island on the west coast and Tolls Island on the east coast. Gugh is connected to St. Agnesat each low tide, via a tombolo [15].

Exposure to wave action varies greatly around the islands, from very exposed to sheltered, due to the direction of the prevailing wind [17]. Sites on the east of the Isles are generally more sheltered whereas those on the west are more exposed, resulting in a great diversity of marine communities [18].

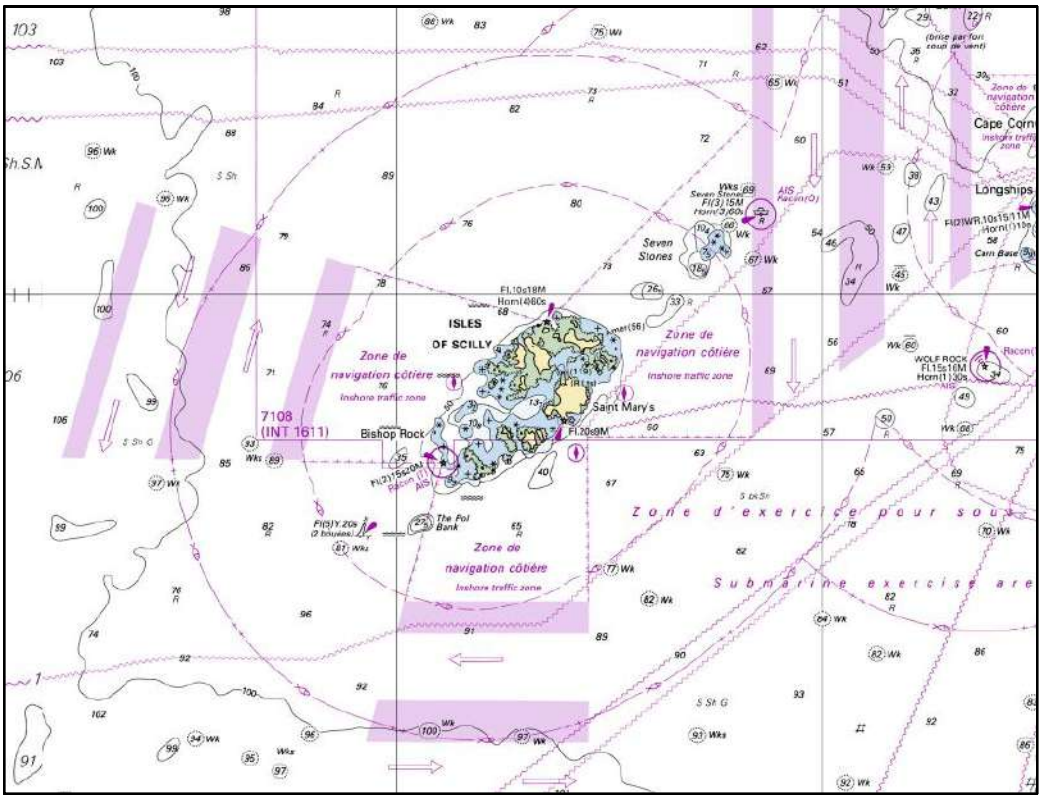


Figure 1-7: Chart of the IoS (Source: UK Admiralty Chart [8])

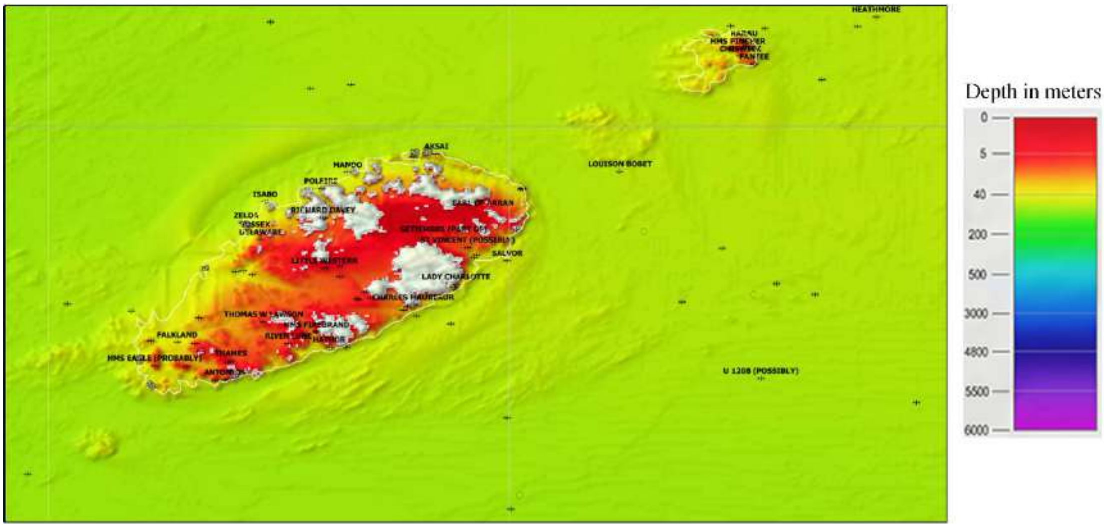


Figure 1-8: Bathymetry around the IoS [11]

1.4.3 Chausey

Chausey is a group of small islands, islets and rocks off the coast of Normandy, in the English Channel (Figures 1-9 and 1-10). It lies 17 km from Granville and forms a quartier of the Granville commune in the Manche département [19]. Chausey is close to the Channel Islands from a geographical point of view, butunder French jurisdiction.

The main island, called Grande-Île, is 1.5 km long and 0.5 km wide at its widest, though this is just the tip of a substantial and complex archipelago which is exposed at low tide. The archipelago comprises 365 islands at low tide, compared to only 52 islands at high tide. From a few dozen hectares of ground above the high tide line, the archipelago increases to around 2,000 hectares (4,900 acres) at low water, within an area roughly 6.5 by 12 km [20]. The islands consist of a granitic geological formation, which has been subjected to erosion by sea and wind. Sandbars connect several parts of Chausey [19].

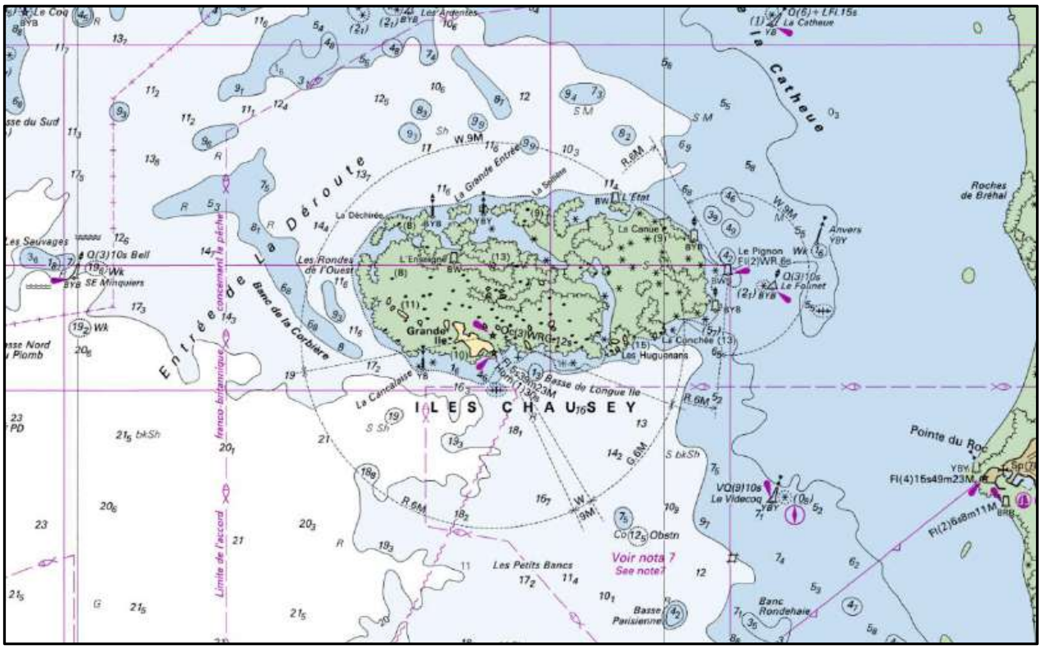


Figure 1-9: Chart of Chausey

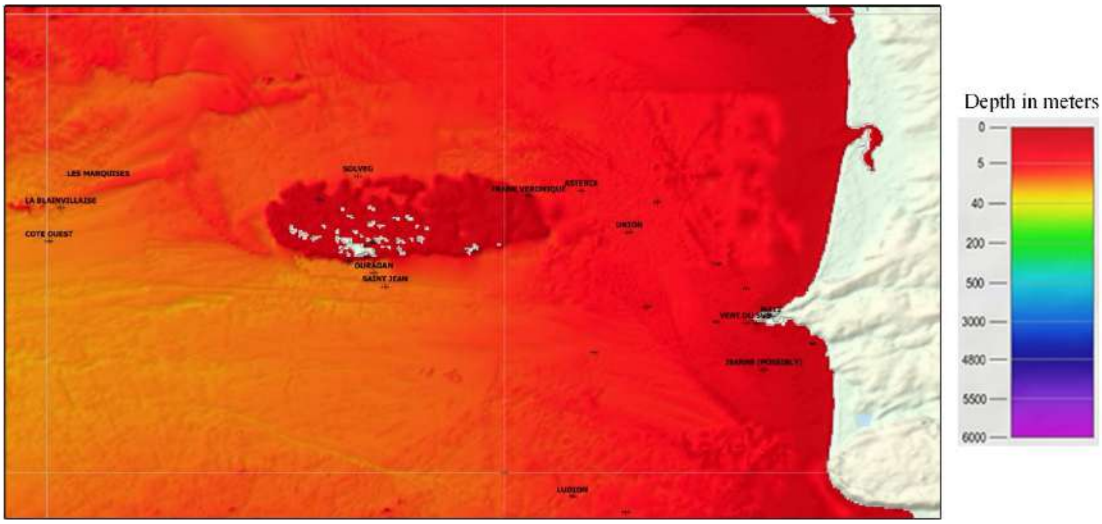


Figure 1-10: Bathymetry around Chausey [11]

1.4.4 Molène

Molène is an island off the west coast of Brittany and one of the Ponant Islands, the largest of an archipelago of some twenty islands (Figures 1-11 and 1-12). Administratively, it is part of a commune of the Finistère department of Brittany in north-western France, the commune of Île-Molène, which also comprises several neighbouring islets [21].

The island is small, less than 1 by 0.9 km, and has an area of 75 hectares. The community and only port are located to the east of the island, opposite a small island called the Lédénes of Molène that becomes connected at low tide [21].

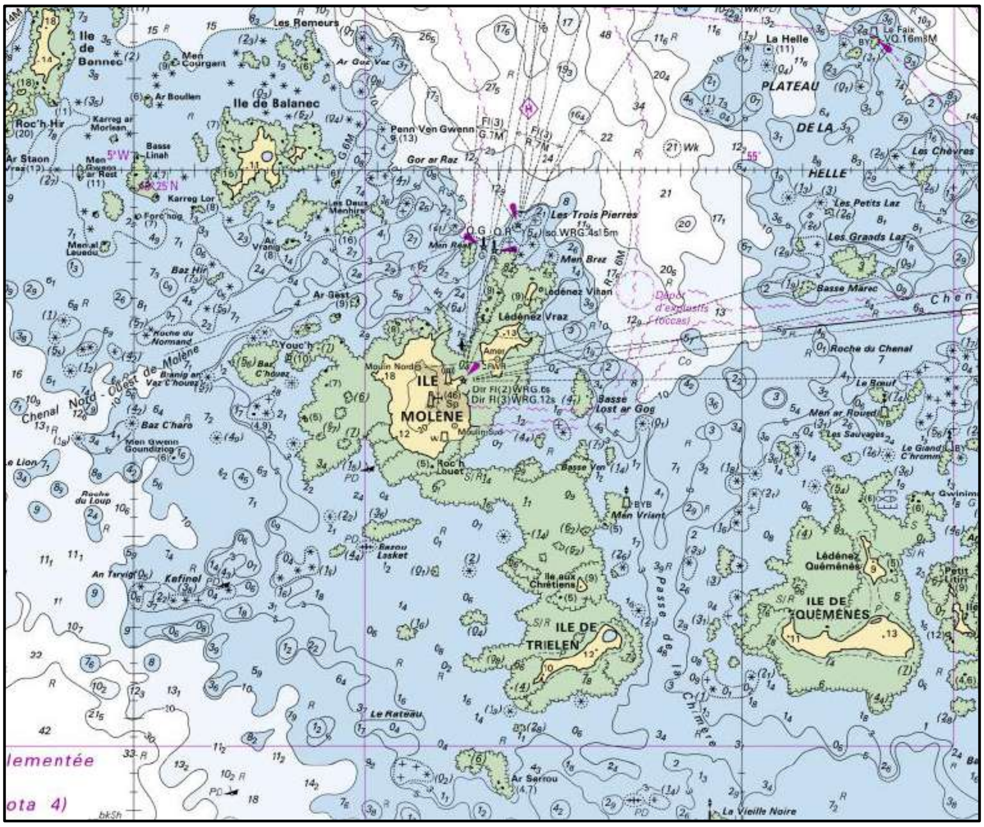


Figure 1-11: Chart of Molène

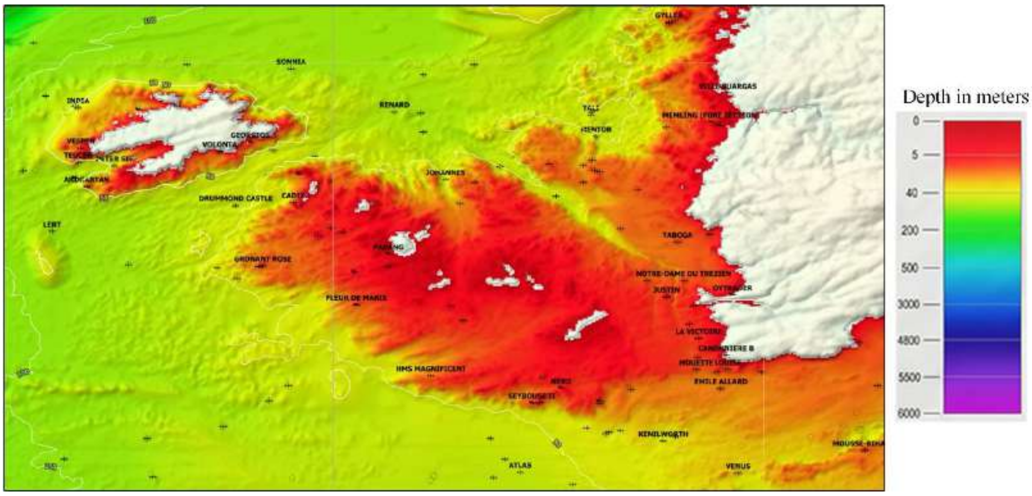


Figure 1-12: Bathymetry around Molène [11]

2. Constraint

Tidal stream power and wave power have benefits such as low visual impact, economic activity and stimulus in remote Islands and isolated communities. Some potential disadvantages are the environmental impact on wildlife and disruption to shipping navigation and other marine economic activities. In order to reduce the disadvantages to the minimum, the constraints for location of the marine renewable energy exploitation should be considered. Careful selection of suitable sites which balance the technical requirements (water depth and tidal flow) with marine conservation and commercial and leisure uses will be required.

2.1 UK

The marine licensing system in the United Kingdom is complex. Consents are required at various levels of central/federal and sub-national levels of government, each having different levels of responsibility in different maritime zones and thus variations in requirements [22].

Generally, consent from the Marine Management Organisation (MMO) is required to construct, extend, or operate any offshore generating stations with a capacity between 1 and 100 MW (Section 66 of the Marine and Coastal Access Act 2009; Section 36 of the Electricity Act 1989). Safety zone consents may also be required (Section 95 of the Energy Act 2004). Stations that would generate more than 100 MW are classified as Nationally Significant Infrastructure Projects (NSIPs) and require a Development Consent Order (DCO) granted by the Secretary of State. The local planning authority for each region permits onshore planning and the Department for Business, Energy and Industrial Strategy (DBEIS) regulates the decommissioning of projects under Energy Act 2004 [22].

Lundy and the IoS are located as Wales and England, respectively, hence the regimes of marine licensing system in these regions are merely given below. Information regarding the regimes in the rest part of the UK, e.g., Northern Ireland and Scotland, can be found from [22].

2.1.1 England

There are two regimes for consenting renewable energy projects in English waters which are ultimately based on the size of a proposed project [22]:

- Nationally Significant Infrastructure Project (NSIP) applications are processed by the Planning Inspectorate and recommendations are made to the Secretary of State. The Marine Management Organisation (MMO) is a key consultee in the process and responsible for monitoring compliance and enforcement of Deemed Marine License (DML) conditions.
- Projects less than 100 MW Require a marine licence from the MMO (Section 66 of Marine and Coastal Access Act 2009). Projects greater than 1 MW in 0-12 nm and greater than 50 MW outside 1 nm require Section 36 consent (Electricity Act 1989) to build and operate an energy generation site.

2.1.2 Wales

Natural Resources Wales (NRW) issues marine energy licences on behalf of Welsh ministers in compliance with the Marine and Coastal Access Act 2009. Projects must also attain a European Protected Species (EPS) Licence, which prohibits deliberate disturbing, capturing, injuring, or destroying any breeding site of resting place of an EPS, issued under Regulation 53(2) of the Conservation of Habitats and Species Regulations 2010 [22].

In March 2011, the Welsh government published a Marine Renewable Energy Strategic Framework to investigate possibilities and streamline development processes. The Marine Energy Plan for Wales was published in 2016 by the Marine Energy Task and Finish Group and describes current status, goals, and recommendations for the consenting process going forward [22].

2.2 France

Ocean energy project developers in France must address their request to the French State, which is represented by the regional Prefect, and fulfil the following permitting and licensing process [22]:

- Acquisition of a unique permit regarding environmental issues delivered by the Prefect, which includes an environmental impact assessment (EIA), if needed, an assessment focusing on Natura 2000 impacts, and one dedicated to protected species. Within this permitting procedure, a public consultation is organized by the State.
- If located in territorial waters, a license delivered by the Prefect to occupy the maritime public domain must be obtained which takes into account maritime safety and the use of maritime territories. This licensing requires a public consultation which can be combined with the preceding process.
- For farms exceeding 50 MW, acquisition of an authorization to generate electricity delivered by the Ministry of Energy is needed. This authorization is automatically delivered to the laureates of State calls for tender. In addition, the developer signs a grid connection convention with the French Transmission System Operator (TSO).

The French state is currently working on streamlining this legislative and legal framework by developing a so-called "permit envelope". This procedure would move most of the mentioned obligations upstream of the actual permit issuance, thereby considerably reducing the risk for project developers as long as the technical details of the project do not diverge from the initial plan [22].

In parallel to this simplified consenting process, France has accelerated its Marine Spatial Planning (MSP) by launching a consultation in 2016, and pursues identification of dedicated sites for ocean energy projects [22].

2.3 Environmental constraints

2.3.1 Lundy

As shown in Figure 2-1, the whole Lundy is located in a marine conservation zone (MCZ) [23]. MCZs are areas that protect a range of nationally important, rare or threatened habitats and species.

Lundy MCZ is an inshore site that covers a rectangular area of 31 km^2 around Lundy Island [12]. Geographical positions of the four corner points A, B, C and D are listed in Table 2.1 [24]. Situated 19 km off the North Devon coast, Lundy is the largest island in the Bristol Channel. The marine area around Lundy has long been recognised for its ecological importance and as such was established as England's first marine nature reserve (MNR) in 1986. Following the Marine and Coastal Access Act 2009, the site was converted from a MNR to a MCZ in January 2010 [12]. The MCZ boundary is identical to the boundary of Lundy Special Area of Conservation (SAC) and contains an existing no-take zone [25].

Table 2-1: Boundary co-ordinates of the MCZ at Lundy [24]

Point	Lat	Long

A	51°13’1.308’’N	4°42’6.817’’W
B	51°12’58.327’’N	4°38’2.832’’W
C	51°8’59.132’’N	4°38’7.390’’W
D	51°9’2.404’’N	4°42’10.332’’W

Lundy Island has a long history of marine protection and became the first MCZ in English waters. A number of activities take place around the area and are managed through a zonal scheme. This site is within the jurisdiction of the Devon & Severn IFCA, therefore all Devon & Severn IFCA District-wide byelaws will apply to this site, in addition to all relevant national and EU fisheries legislation. Further information is available at [26].

Relevant restrictions relating to this site include the proposed Potting and Shellfish Permit Byelaw and the proposed Mobile Fishing Permit Byelaw. Through these permit byelaws Devon & Severn IFCA will have a regulatory mechanism through which additional management can be introduced to specifically meet the conservation objectives for the designated features. For further information visit the Lundy MCZ website at www.lundymcz.org.uk or the IFCA website at [27].

Lundy is a granite and slate reef system which has been recognized as having and outstanding representation of reef habitats. The reefs of Lundy extend well over 1 km offshore and drop steeply into deep water in some areas. The variety of habitats and associated species on the reefs is outstanding and includes, for example, a large number of seaweeds and many rare or unusual species [28].

The mutual influence between marine renewable energy devices and marine biology should be considered.

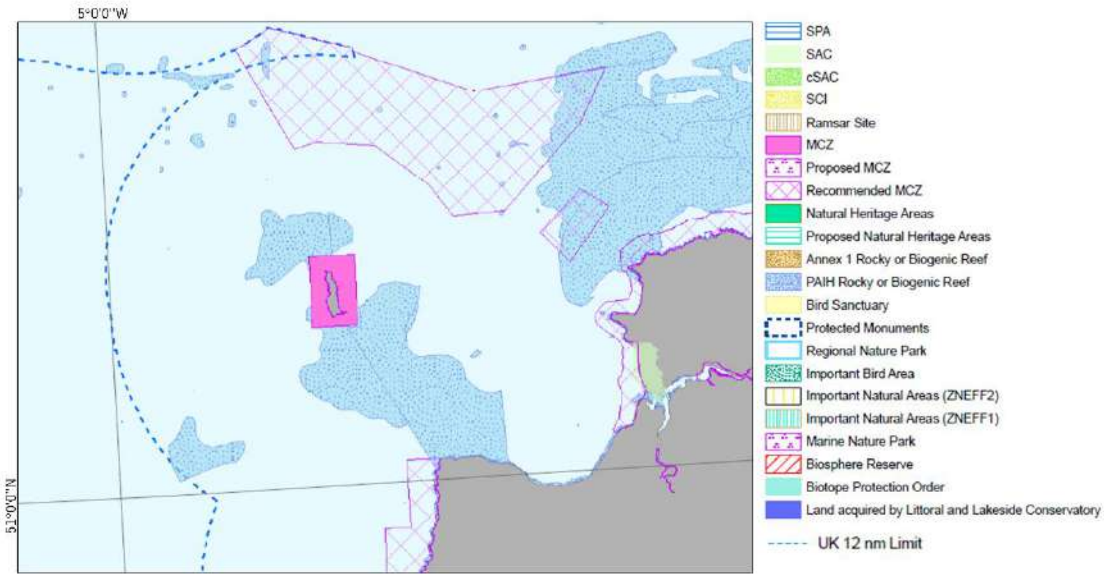


Figure 2-1: Environmental constraints at Lundy [23]

2.3.2 IoS

The IoS MCZs are a collection of inshore sites located around the IoS (see Figure 2-2). The MCZs consist of 11 separate sites covering a total area of over 30 km^2. More details regarding the boundary co-ordinates of the MCZs at the IoS can be found in [29].

Management in MCZs can take several different forms, including introducing voluntary measures, use of the existing planning and licensing framework, specific byelaws and orders. There has to be public consultation on permanent byelaws and orders. For activities that already need a marine licence, regulators consider the MCZ in their decision as soon as the site is consulted on. Further information relating to marine licensing in MCZs is given online [30].

The IoS are surrounded by reefs and rocky islets, some only extending into the shallow sublittoral, others extending well beyond 50 m depth [31]. The location of the islands, exposed to the full force of the Atlantic, leads to the development of extremely exposed communities on west-facing reefs, whilst on the east-facing coast, more sheltered and silted reefs occur. The south-westerly position of the islands leads to a range of warm-water species being present [32].

The IoS Special Area of Conservation (SAC) encompasses all of the main islands and outlying rocky islets and protects a range of habitats.

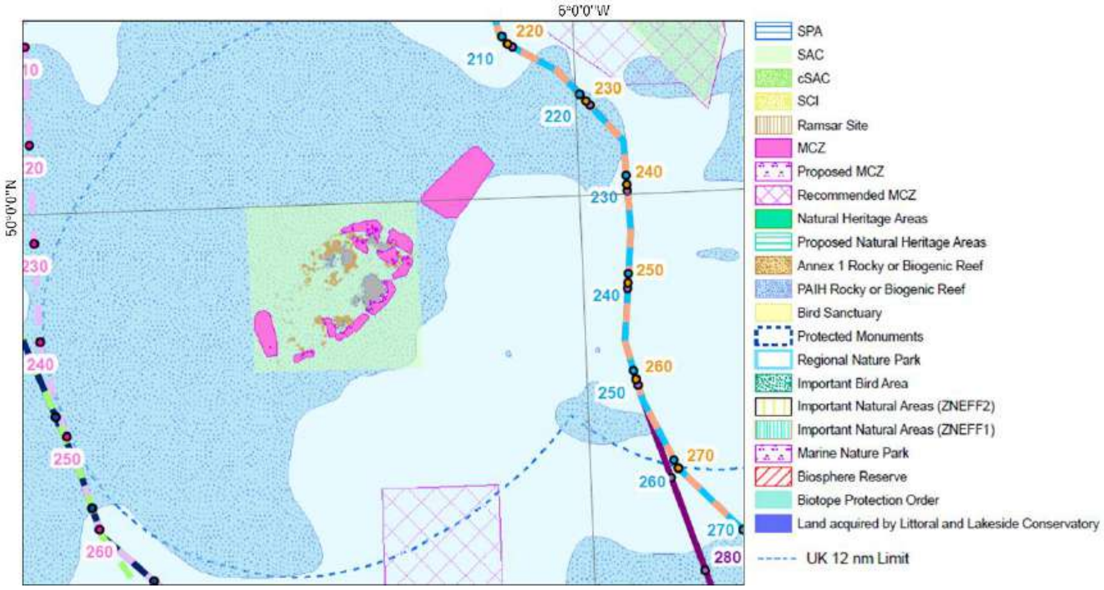


Figure 2-2: Environmental constraints at the IoS [23]

2.3.3 Chausey

Chausey is recognized as the land acquired by Littoral and Lakeside Conservatory (National Seaside and Lakeside Conservancy) (Figure 2-3). Moreover, Chausey is also located in a special protection area (birds directive) and also a Site of Community Importance (habitats directive) (not plotted in Figure 2-3) [33].

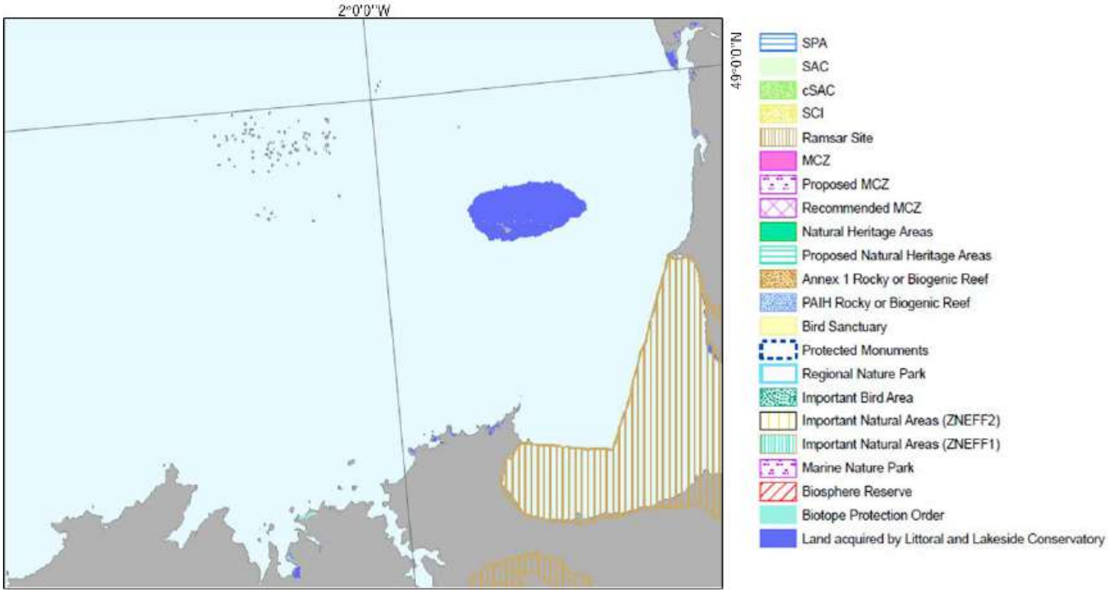


Figure 2-3: Environmental constraints at Chausey [23]

2.3.4 Molène

There is a Marine Nature Park named "Iroise Marine Nature Park" located at the most western point of France around the Molène (see Figure 2-4).

The Iroise marine park, with an area of 3,500 km^2, aims to improve understanding of the marine environment, to protect it (the seabed, bird and marine mammal species, but also cultural heritage) and to sustainably develop sea-dependent activities (island maritime activities, sustainable fisheries and seaweed farming).

As the oldest Marine Nature Park in France, created on 28 September 2007 with the publication of the establishing ministerial decree, the Iroise marine park has outstanding natural resources and plays host to traditional fishing activities. The cultural heritage is extremely varied and marked by majestic offshore lighthouses. The Iroise contains surprising biodiversity consisting of dozens of species of algae, marine mammals, birds and other less well-known or simply more discreet species. The Iroise Sea is home to a colony of grey seals. Two groups of large dolphins reside all year round in the Molène Archipelago and the Chaussée de Sein. Other species are also passing through Iroise include common dolphins, harbour porpoises and dolphins of Risso.

The Iroise Marine Nature Park relies on long-term involvement of elected representatives in the Iroise, government departments, marine professionals, associations, regular and occasional users and even simple observers, all of whom contribute to its operation. The management council of the Iroise marine park is responsible for its governance, in cooperation with government departments. Its members are thus in a position to carry out marine environment development and conservation actions as part of an integrated approach since both the challenges and solutions are considered jointly. All the members of the management council play a part in the decision process so as to continue to protect and develop a maritime territory.

In addition to being listed as a natural marine park, it is a marine protected area under the Oslo-Paris convention (OSPAR) and a large part of its perimeter is listed under the European Habitats and Birds directives (Natura 2000 network) and as a UNESCO biosphere reserve [34].

Additionally, there is a protected site named “Ouessant(Ushant)- Molène”. This is an important area for bird, and European Protected Species - harbouring 25% of the population of sea mammals in France with colonies of seals, dolphins and sea otters. Other notable species include basking shark [23].

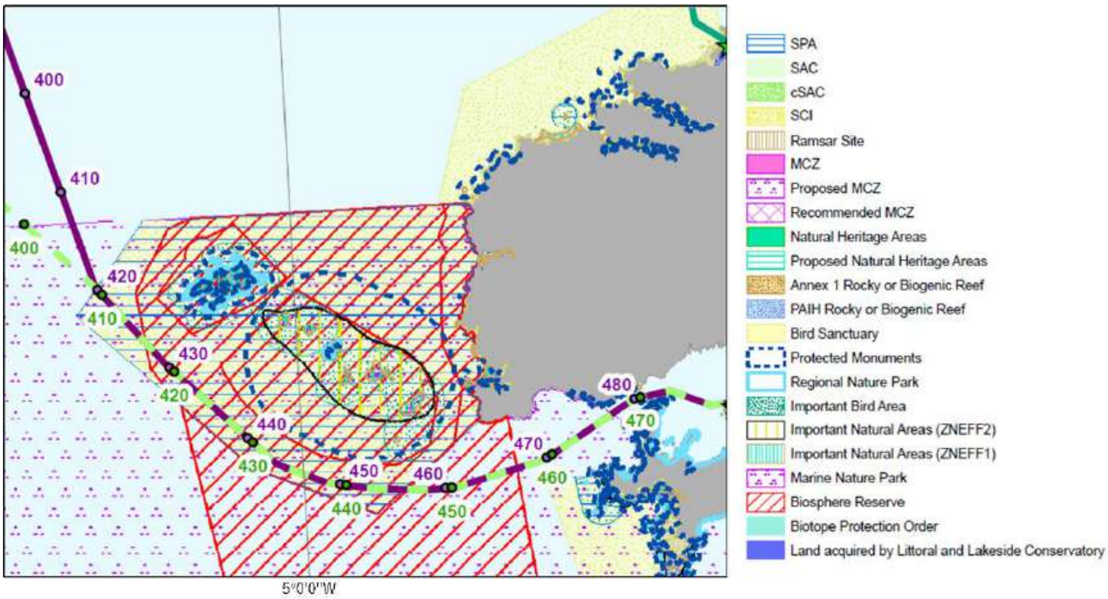


Figure 2-4: Environmental constraints at Molène [23]

2.4 Socio-economic constraints

2.4.1 Lundy

There are two anchorage areas at Lundy (see Figure 2-5). Additionally, there are eight foul grounds plotted in the plotted field, in which two are adjacent to the island. This might be a reason why Lundy belongs to a caution area for traffic regulation. Moreover, the port of Bristol plays a major part in the transportation from the ports of South Wales to national and international destinations. Indeed, Bristol Channel is a busy shipping channel. Lundy, situated mid-channel, with its dangerous rocks and tidal races constitutes a serious hazard to shipping. At the north-west and south-west directions, there are two areas for military activity. Two dredger transit routes are illustrated at the south-east of the Lundy.

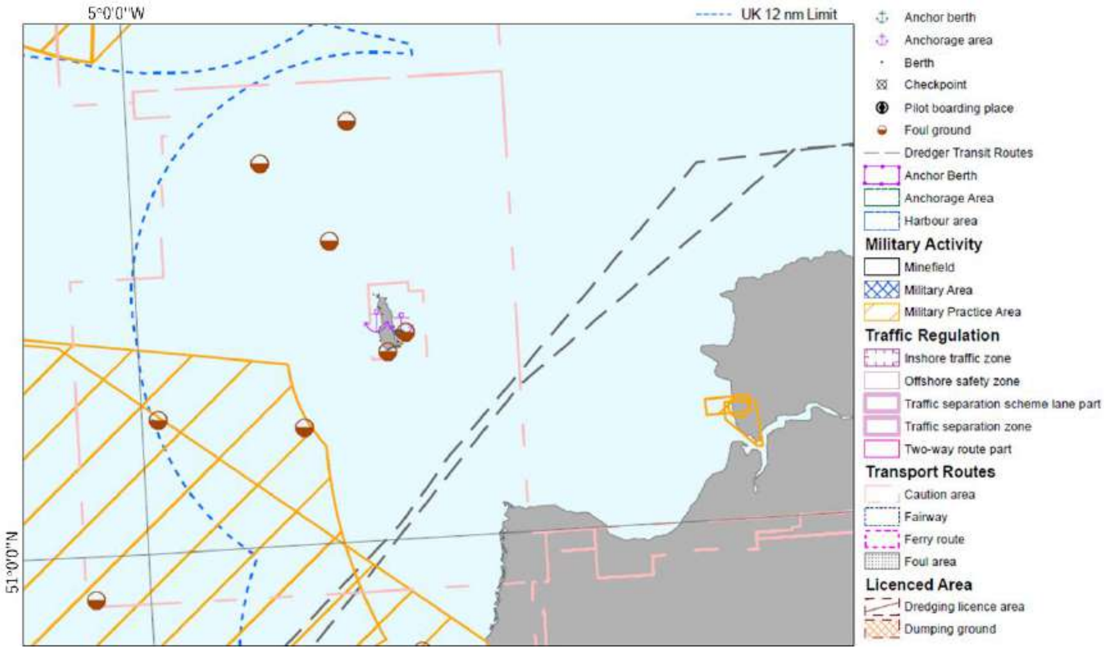


Figure 2-5: Socio-economic constraints at Lundy [23]

2.4.2 IoS

The whole IoS are located in a military practice area (Figure 2-6). At the west side, south side and north-east side of the IoS, there are a series of traffic regulation zones, e.g., inshore traffic zone and traffic separation zone. Additionally, two dredger transit routes come across the north-east side of the IoS. In the near field of the IoS, there are several anchorages areas, foul grounds, pilot boarding places, together with offshore safety zone and caution area, distributed.

The complicated socio-economic constraints at the IoS should be carefully evaluated if being considered as sites there for marine renewable energy exploitation.

Figure 2-6: Socio-economic constraints at the IoS [23]

2.4.3 Chausey

As indicated in Figure 2-7, there are no socio-economic constraints around the Chausey. In spite of this, there are some special concerns should be paid attention to.

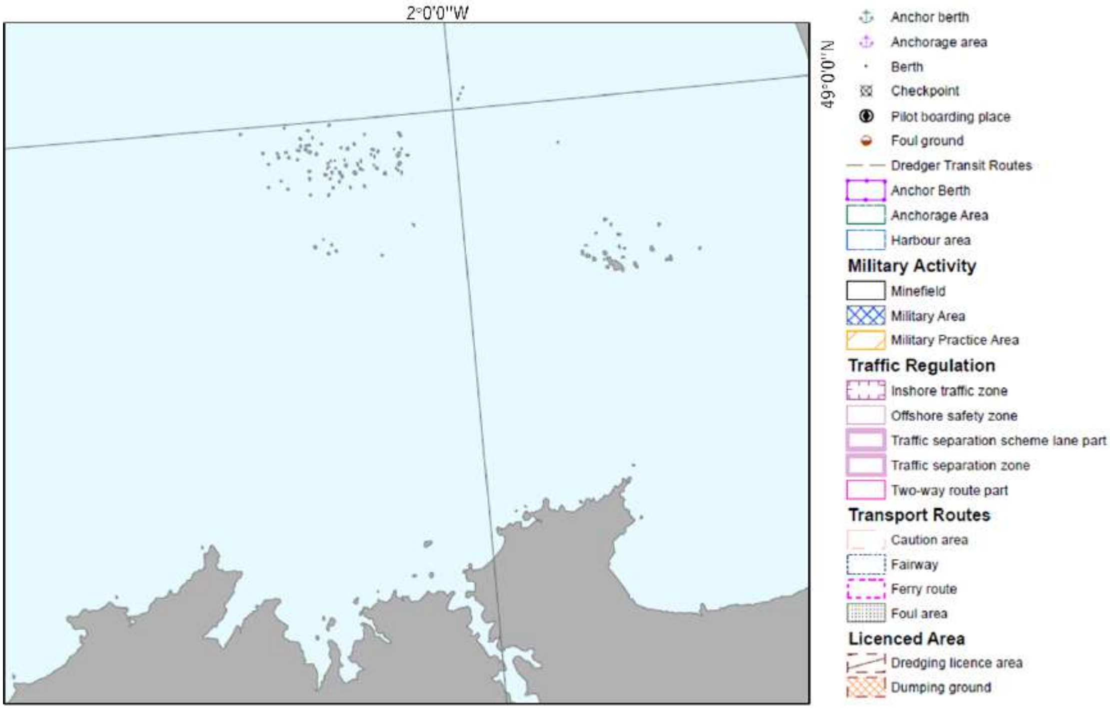


Figure 2-7: Socio-economic constraints at Chausey [23]

2.4.4 Molène

Figure 2-8 presents a map of socio-economic constraints in the region around the Molène. There are three anchorage areas at the Molène.

At the channel "Passage du Fromveur", there are no socio-economic constraints other than being marked as "caution area" from transport routes view. This is due to the large tidal current there, which could be very dangerous for shipping, however the large tidal current means a high tidal power density there, resulting in an ideal potential site for tidal power absorption.

One the north-west of Ushant island, there are inshore traffic zones, dumping grounds, and traffic separation scheme lane part/ zones together with dredger transit routes. It could therefore be very difficult to gain permission to deploy tidal current energy converters in this region.

At the east side and the north-east side, there is a dredging licence area and there are two fairway regions.

For those outside the bay of Brest, dredger transit routes, fairway, military practice area and dumping ground are also distributed, thus it should be carefully evaluated if being considered as sites there for tidal power exploitation.

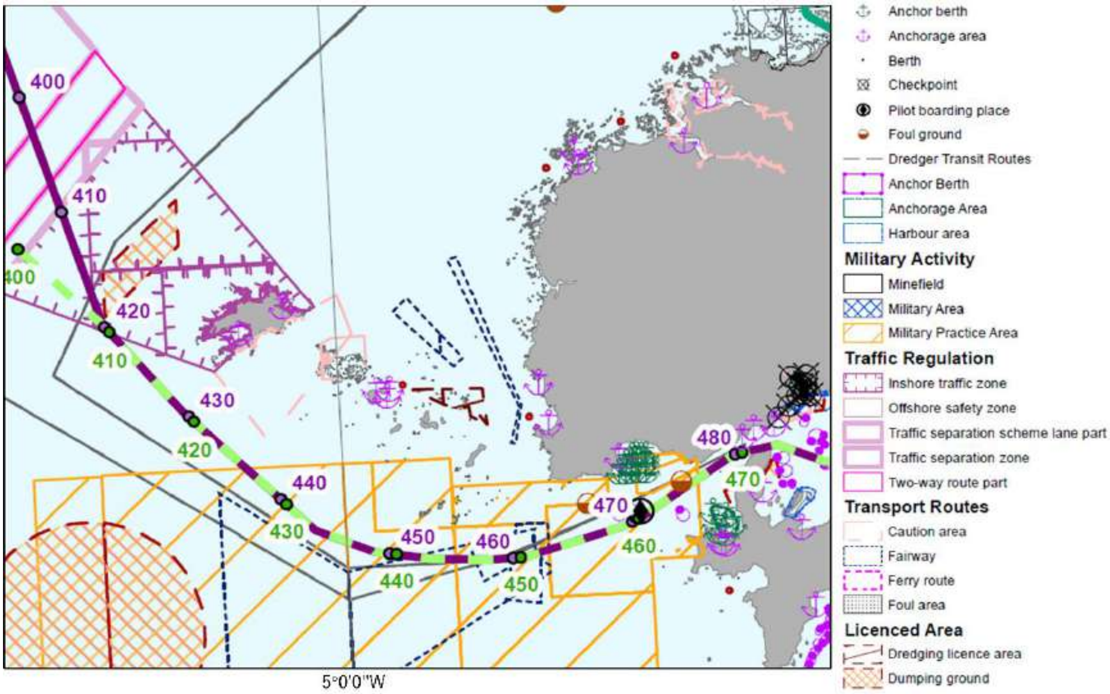


Figure 2-8: Socio-economic constraints at Molène [23]

2.5 Technical constraints

Cables, piles, wrecks and some other technical constraints are illustrated in Figures 2-9 to 2-12.

2.5.1 Lundy

It is shown that there are several cables (thin lines in pink color) locating in north and south of Lundy (see Figure 2-9). Note there are also several wrecks distributed near the Lundy island, which should be paid attention when installing marine renewable energy devices.

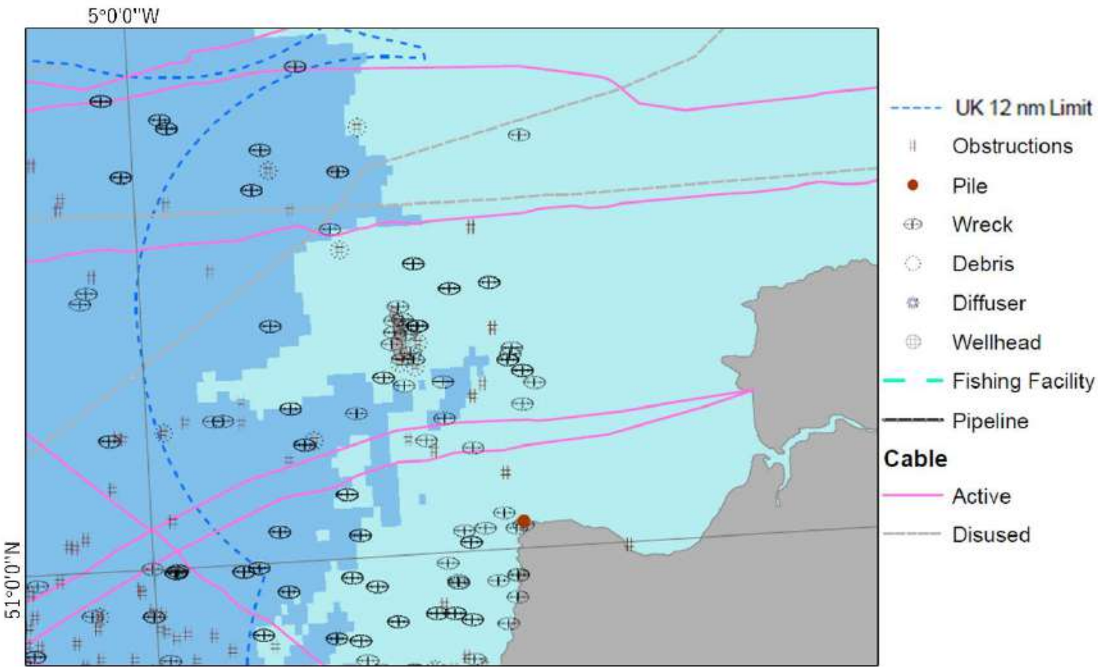


Figure 2-9: Technical constraints at Lundy [23]

2.5.2 IoS

There are two cables (thin lines in pink color) locating in south-east, and one cable locating in north of the IoS (Figure 2-10). The IoS are famous for their golden beaches and unspoilt beauty but they are also known and feared by sailors [35]. There are many wrecks at the IoS as illustrated in Figure 2-10.

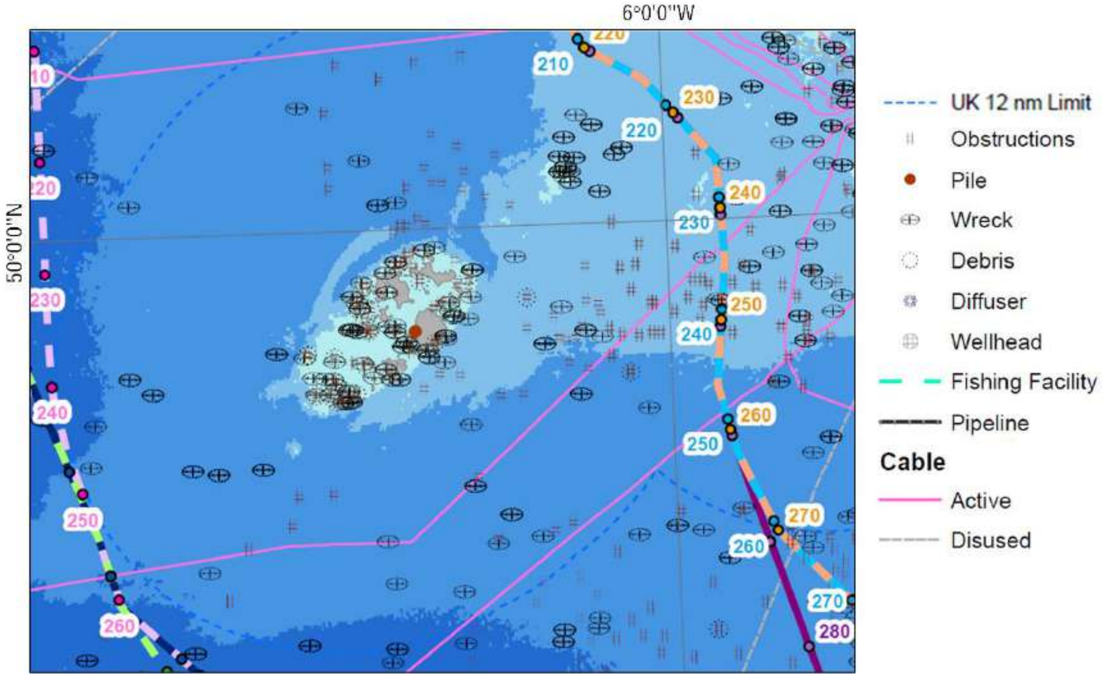


Figure 2-10: Technical constraints at the IoS [23]

2.5.3 Chausey

As shown in Figure 2-11, there are no identified wrecks or cables distributed around Chausey. However, because of the great range of tide, the appearance of the islands of Chausey is continually changing, hence the installation process must be very carefully should it be chosen as a site for marine renewable energy exploitation due to the difficulties of navigation.

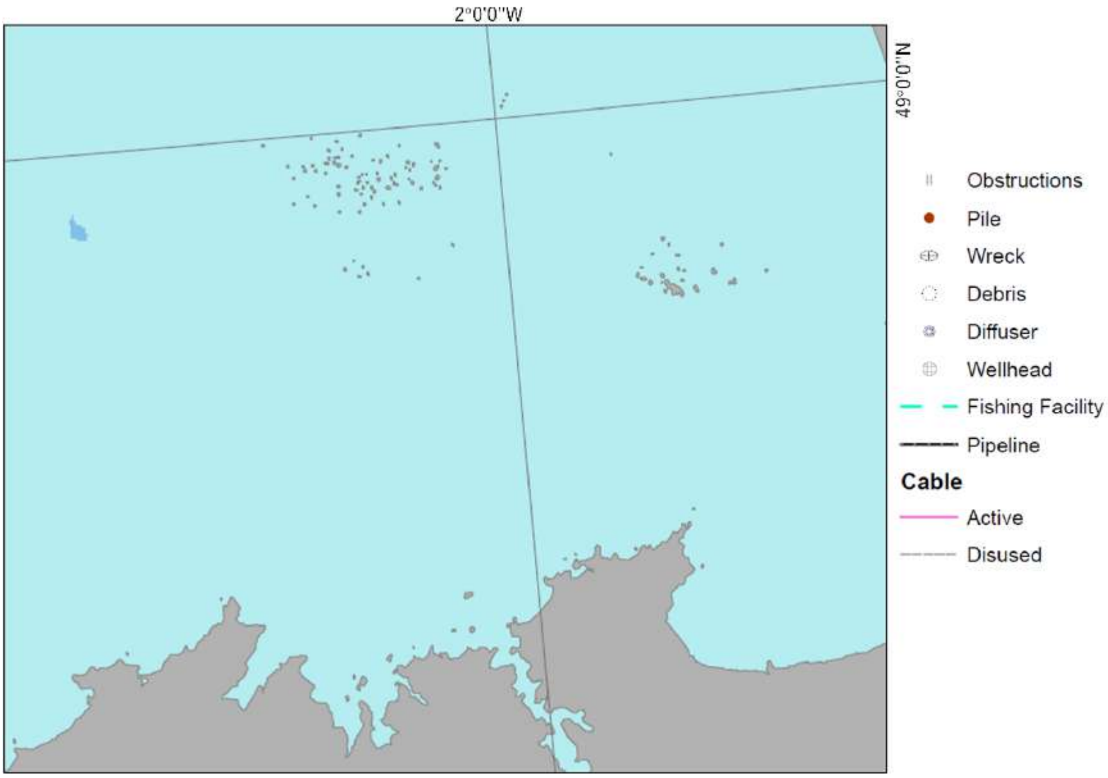


Figure 2-11: Technical constraints at Chausey [23]

2.5.4 Molène

There are various piles deployed in the bay of Brest, although these do not appear to lead to significant restraints on marine energy exploitation around Molène (see Figure 2-12). There there are also several wrecks distributed near the Molène island, which may influence installation and siting of tidal stream/wave power devices.

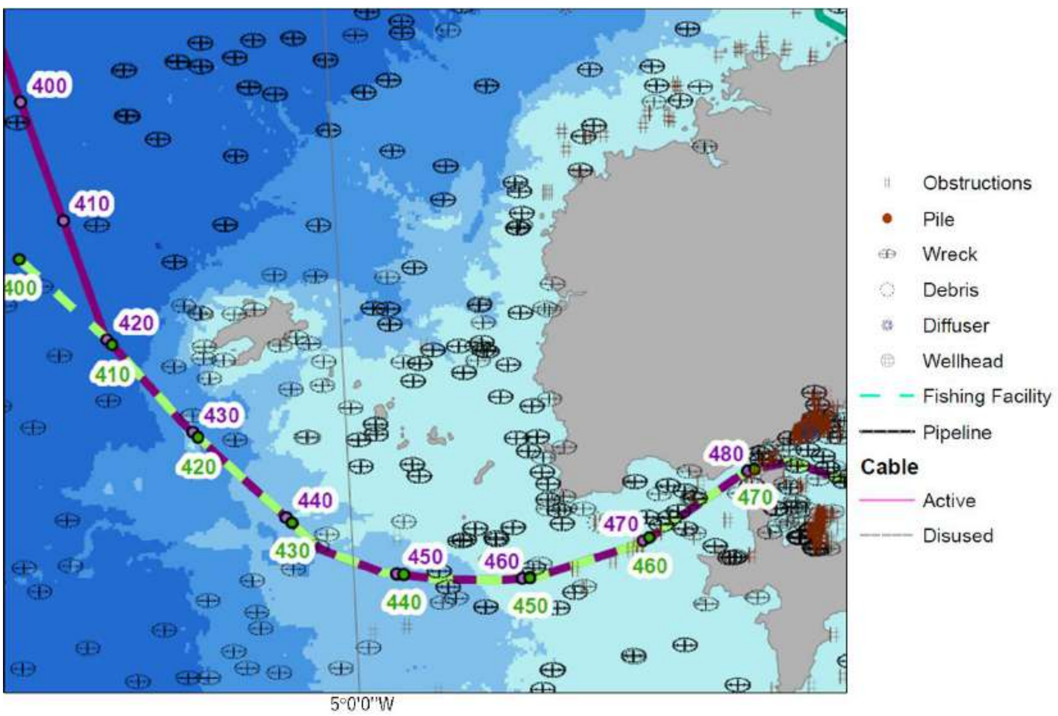


Figure 2-12: Technical constraints at Molène [23]

2.6 Geology constraints

Apart from the constraints considered above, the seabed conditions and geology near the sites are also very important in identifying ideal sites for marine energy extraction (see Figures 2-13 to 2-16).

An ideal installation site for a tidal energy site needs a bed morphology which is approximately level. The method used for attaching the device to the bed (gravity base/ piles) needs to take into account the local geology and sedimentary conditions. For wave energy converters, research and development (R&D) of the mooring system would be significantly dependent on the geology as well.

2.6.1 Lundy

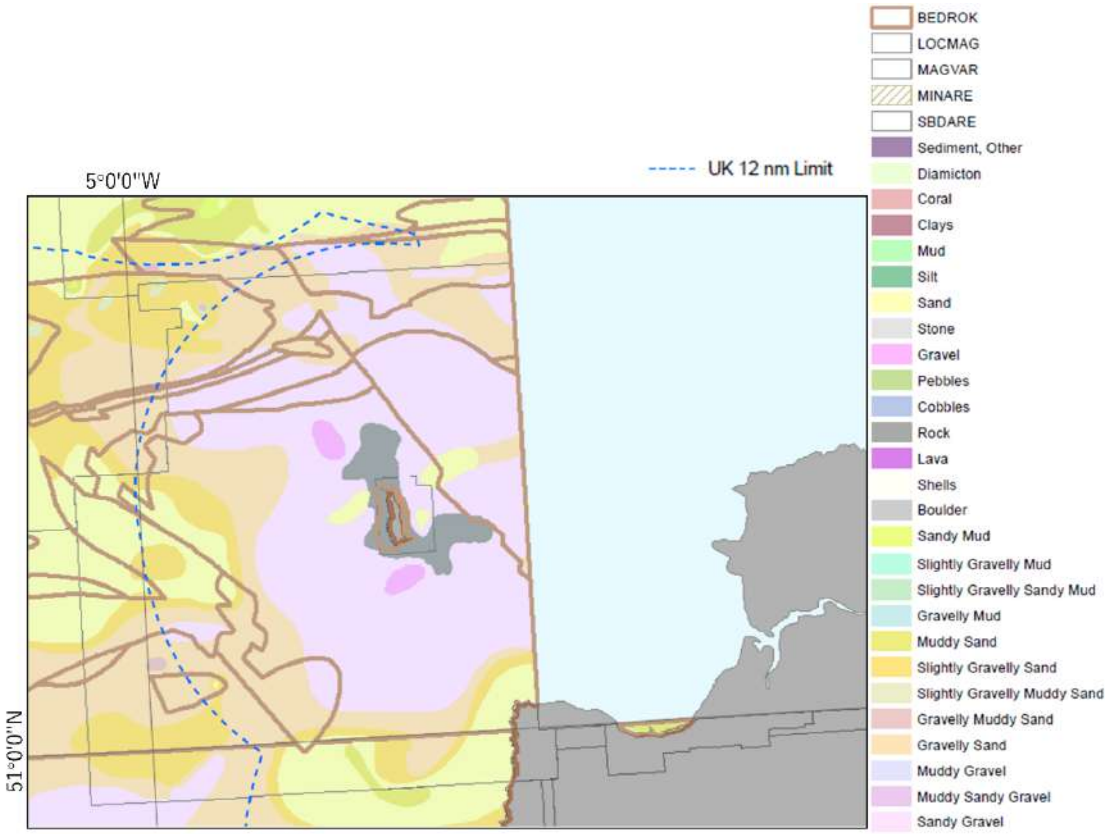


Figure 2-13: Geology constraints at Lundy [23]

2.6.2 IoS

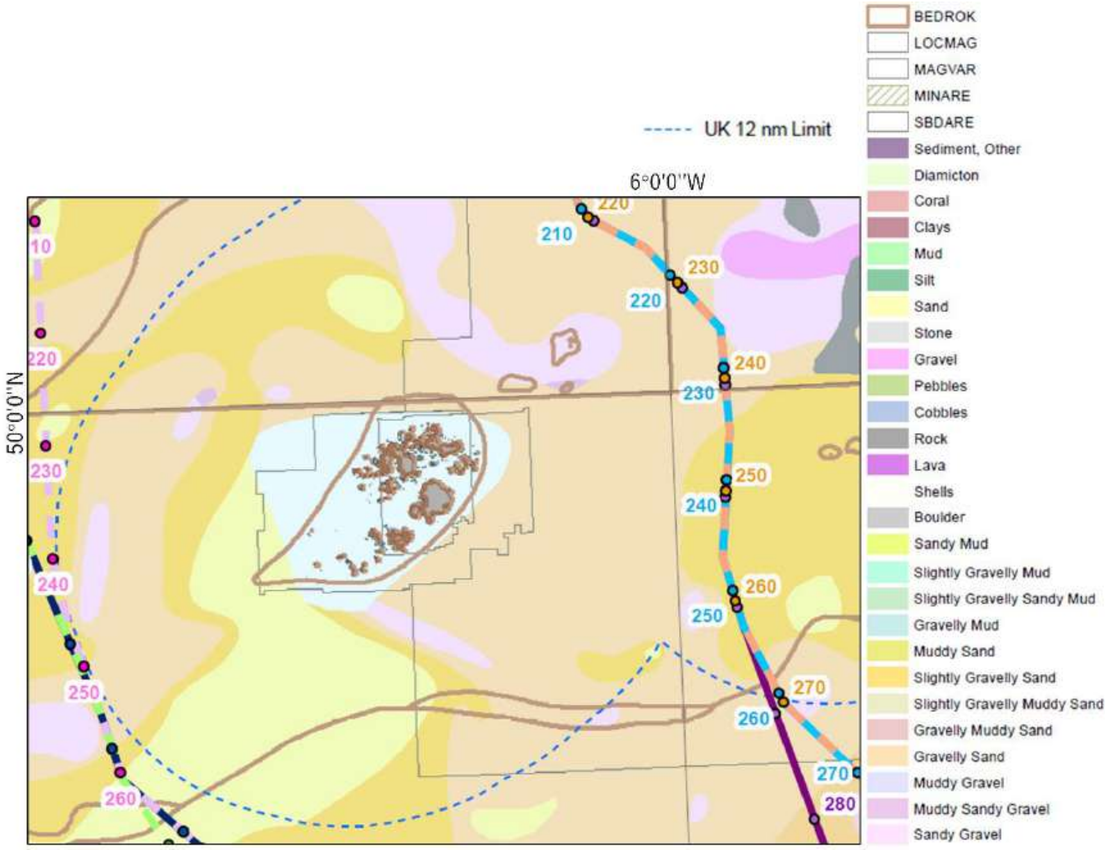


Figure 2-14: Geology constraints at the IoS [23]

2.6.3 Chausey

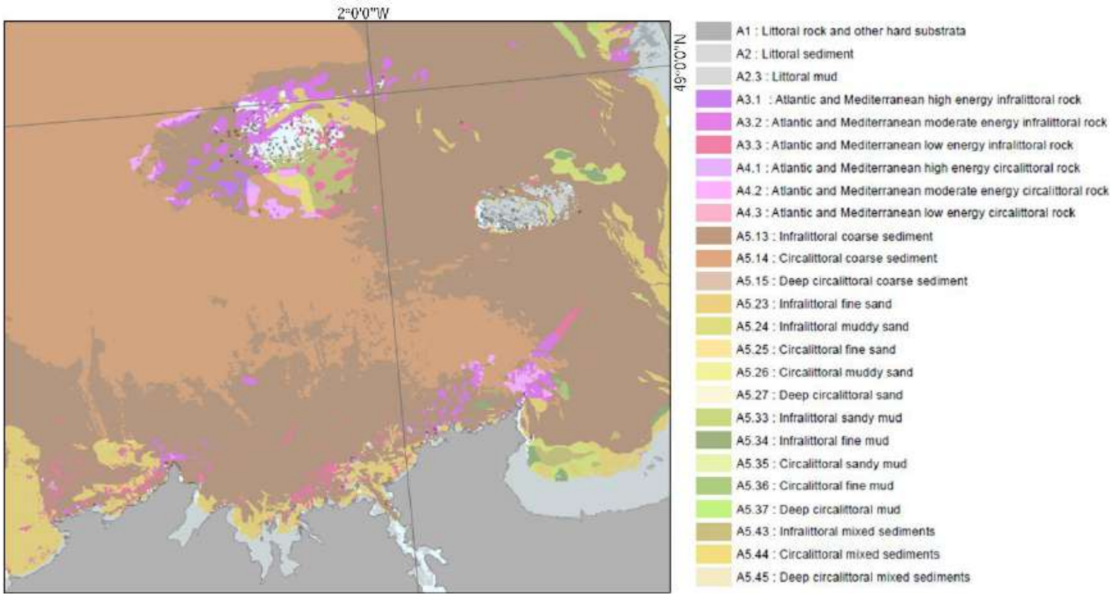


Figure 2-15: Geology constraints at Chausey [23]

2.6.4 Molène

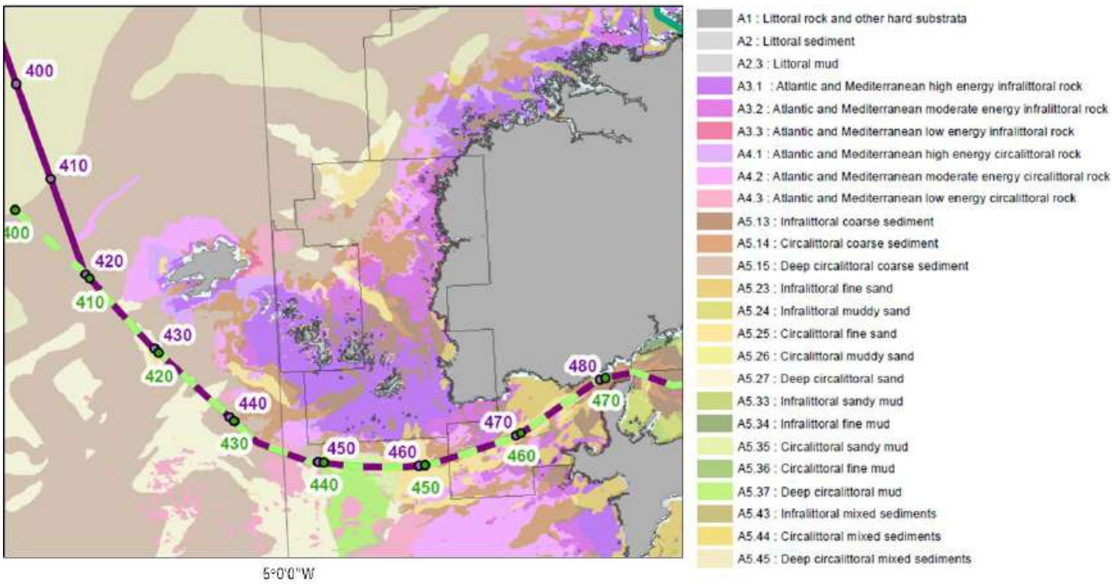


Figure 2-16: Geology constraints at Molène [23]

3. Marine Energy Resources

3.1 Tidal stream power

Tidal current devices (turbines) are installed where there are strong ocean currents that can be used to generate energy from the fast moving waters. Figure 3-1 shows the areas with greatest tidal stream potential in Europe, especially the area around the UK.

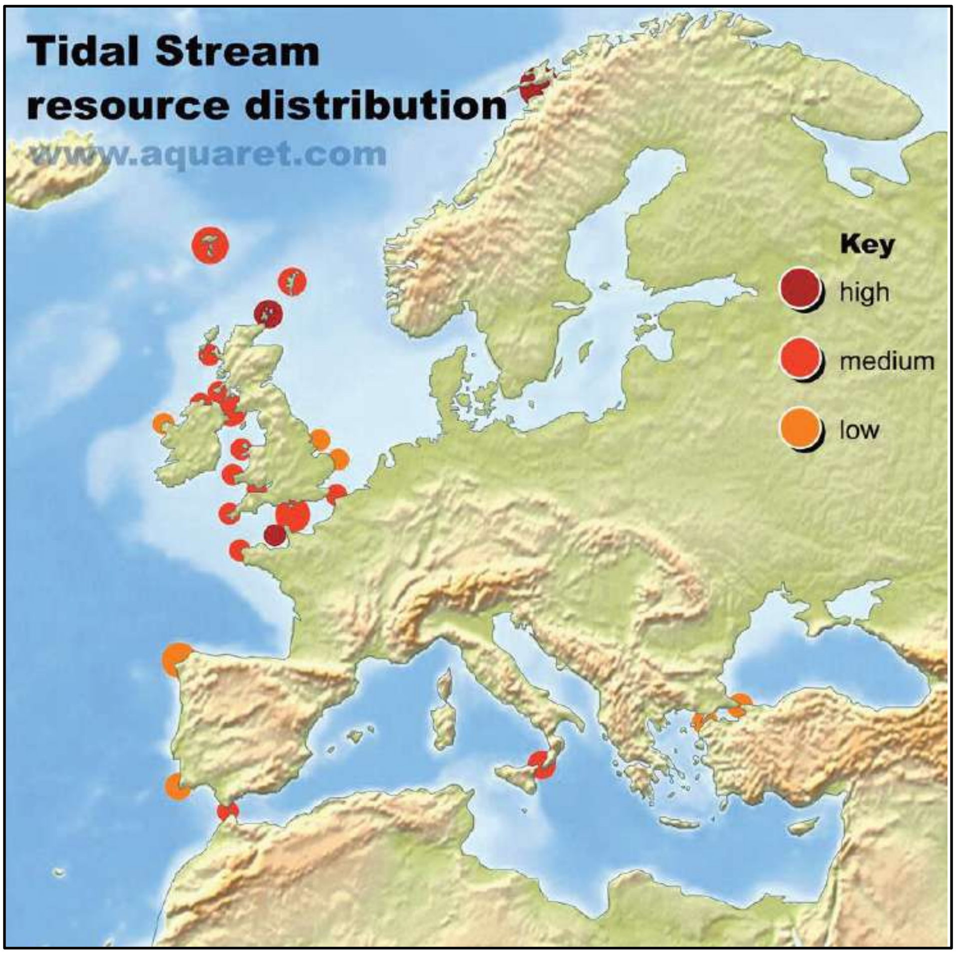


Figure 3-1: Tidal stream resource distribution in Europe [10]

The Bristol Channel and the English Channel are found to contain several potential tidal stream development areas. The Bristol Channel has significant tidal stream resource, with flow speeds in excess of 2 to 2.5 m/s along the Somerset coast and North Devon. It was identified that the inner Bristol Channel could support 600 MW of tidal energy capacity [13]. There are also some other potential tidal stream development areas including a further 200 MW in the outer Bristol Channel (including Lundy), as well as the areas around the IoS, Land's End, and in the English Channel.

The Marine Energy Atlas produced by ABPmer shows tidal flows around the UK [36], and it gives a general indication of the overall flows. Figure 3-2 presents the peak flow for a mean spring/neap tide around the peninsula of South West England. The more yellow areas the better the resource.

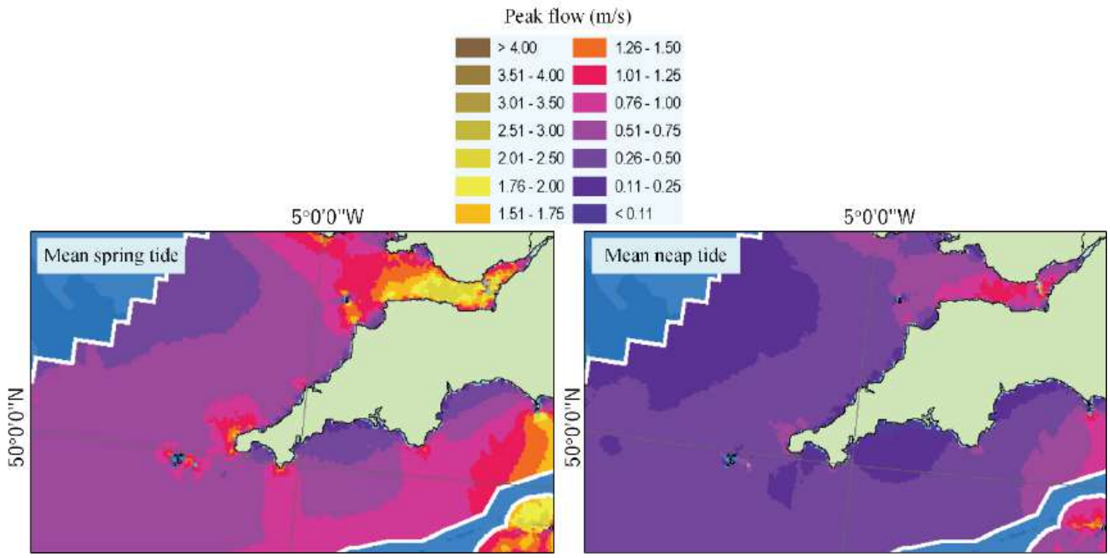


Figure 3-2: Peak flow for a mean spring/neap tide [36]

Prior to further discussion, physical meanings of the "spring and neap tides", together with the seasonal patterns are given as follows.

Spring and neap tides:

"*The relative position of the moon and sun in relation to each other has a significant effect on the daily tidal range (the difference in height between high and low tides on the same day) and tidal stream. The highest tides, or Spring tides, occur when the sun and moon are aligned with the earth (either as a Conjunction (new moon) when the sun and moon are aligned on the same side of the earth, or as an Opposition (full moon) when the sun and moon are aligned but on opposite sides of the earth). The smallest tidal range accompanies Neap tides, which occur during the first and third phases of the moon when the earth-moon axis is at 90 degrees to the earth-sun axis.*

The 28 day orbit of the moon around the earth results in Spring and Neap tides occurring twice every 28 days. Unlike the daily tide cycle, the timing of Spring and Neap tides is unaffected by geography-thus, the Spring and Neap tide pattern is experienced throughout the world at the same time." [37]

Seasonal patterns:

"*As the latitudinal position of the sun and moon vary during the year, they exert a further influence on the observed tidal range. In the UK, Spring tides occurring during the spring and autumn equinoxes are larger, whilst those occurring during the summer and winter solstice are smaller. In terms of magnitude, this is a subtle change compared to the daily and Spring-Neap tidal cycles.*" [37]

As shown in Figure 3-2, the peak flow for a mean spring tide can be as large as 1.76-2.00 m/s at the north and the south of Lundy. The corresponding peak flow for a mean spring tide around the IoS is 1.26-1.50 m/s, which occurs at the east and the west side.

As expected, the peak flow for a mean neap tide is much smaller than that for a mean spring tide (see Figure 3-2). More specifically, the peak flows at the north and the south of Lundy, and at the east and the west of the IoS are 0.76-1.00 m/s and 0.51-0.75 m/s, respectively.

The mean spring/neap tidal power and the average tidal power are illustrated in Figure 3-3. Strong ocean currents generally mean that more tidal power can be used to generate energy from the fast moving waters, hence the distribution of tidal power looks rather similar to that of the peak flow as plotted in Figure 3-2. The largest tidal power around Lundy is distributed at its north and south, which can be 2.01-3.00 kW/m^2 and 0.26-0.50 kW/m^2 for a mean spring tide and a mean neap tide, respectively, and the corresponding average tidal power is 0.51-1.00 kW/m^{2*}. For the IoS, the high tidal power resources occur at its east side and west side, where the mean spring tidal power, mean neap tidal power and the average tidal power are 1.01-1.50 kW/m^2, 0.11-0.25 kW/m^2 and 0.26-0.50 kW/m^2, respectively.

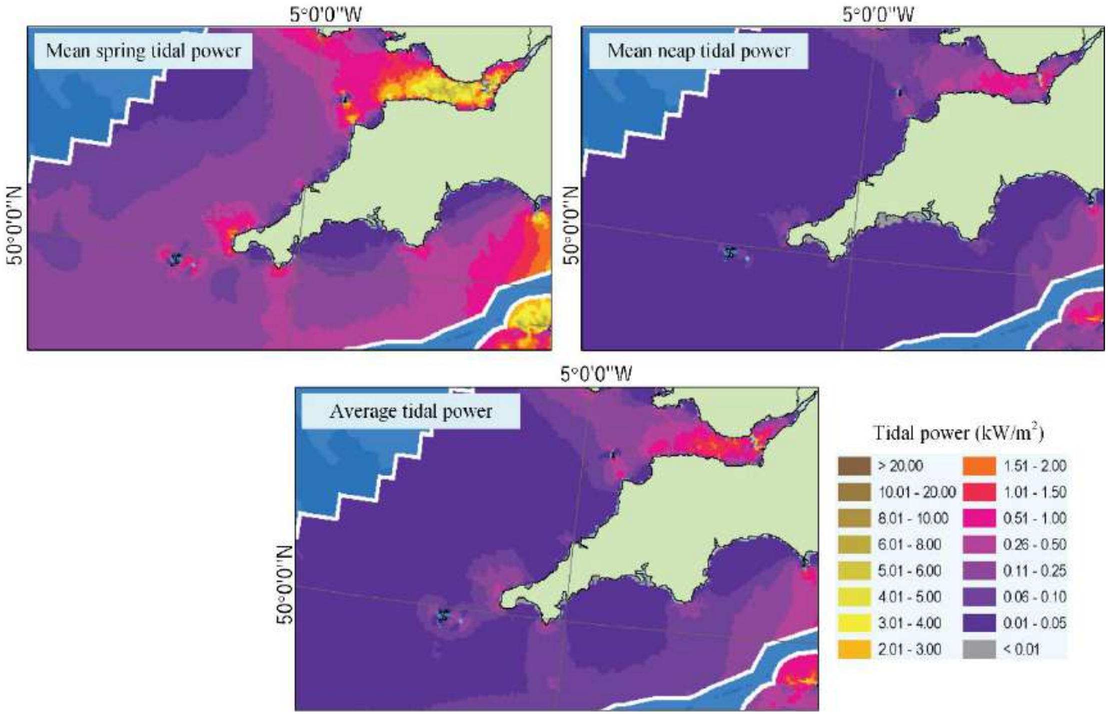


Figure 3-3: Mean spring/neap tidal power and average tidal power [36]

It can be seen from Figures 3-2 and 3-3 that there may not be a prime location for tidal stream around the IoS, but it should be noted that the IoS is composed by an array of small islands, hence there may be channels between the islands where the technology may work. Further modelling at fine scale, or measurements in the field would be needed to investigate the potential offered by the inter-island channels further.

Figure 3-4 presents the tidal stream diagrams for each hour of the tide at the IoS (unit: tenths of a knot) [38].

* Tidal power is calculated in kilowatts per square metres of vertical water column at mid depth in the water column.

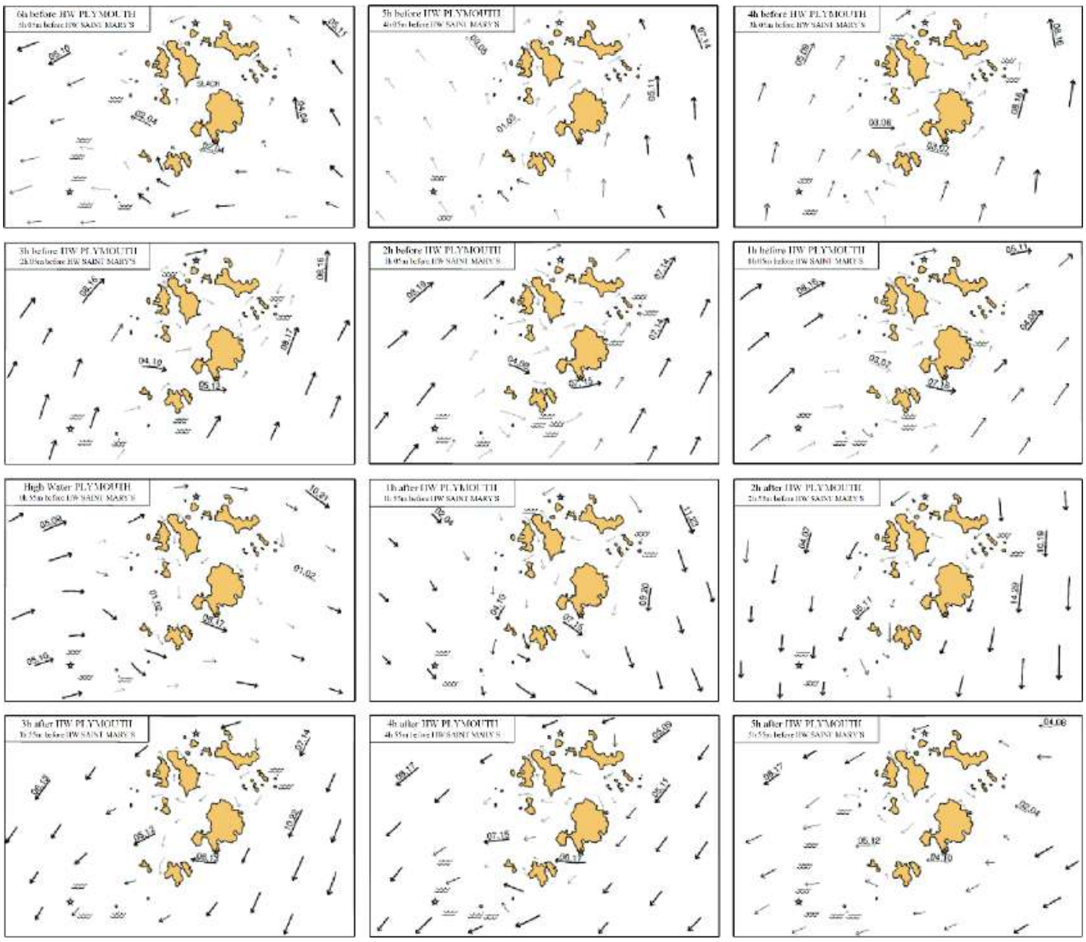


Figure 3-4: Tidal stream diagrams for each hour of the tide at the IoS (unit: tenths of a knot) [38]

Figure 3-5 shows five points, i.e., A~E, at the field of the IoS, the exact geographical positions and the corresponding tidal stream of which are given in Table 3-1.

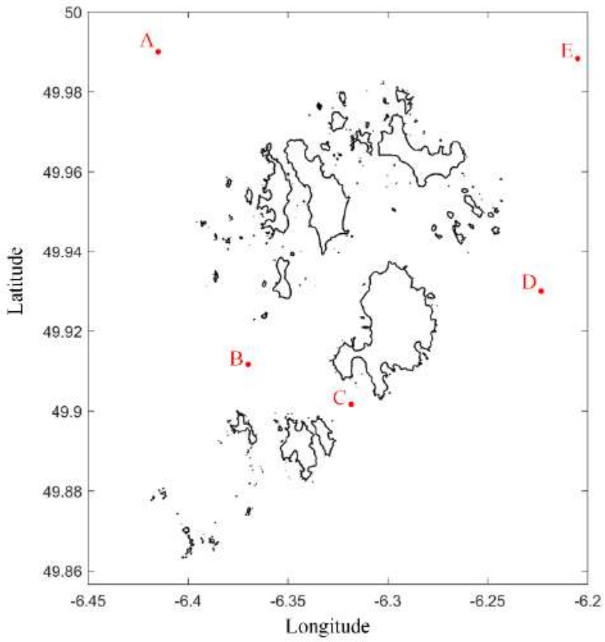


Figure 3-5: Five points (A-E) distributed at the IoS

Table 3-1: Tidal streams referred to HW at PLYMOUTH [38]

Hours		Geographical Positions
Before High Water	6, 5, 4, 3, 2, 1	Directions of streams (degrees)
High Water		Rates at spring tides (knots)
After High Water	1, 2, 3, 4, 5, 6	Rates at neap tides (knots)

	A	49°59′.4 N	6°24′.9 W	B	49°54′.7 N	6°22′.2 W	C	49°54′.1 N	6°19′.1 W	D	49°55′.8 N	6°13′.4 W	E	49°59′.3 N	6°12′.3 W
-6	252	1.0	0.5	320	0.4	0.2	300	0.4	0.2	007	0.9	0.4	322	1.1	0.5
-5	318	0.5	0.3	042	0.3	0.1	020	0.1	0.0	011	1.1	0.5	336	1.4	0.7
-4	034	0.9	0.5	097	0.6	0.3	109	0.7	0.3	017	1.6	0.8	348	1.6	0.8
-3	055	1.6	0.8	116	1.0	0.4	110	1.2	0.5	022	1.7	0.8	004	1.6	0.8
-2	062	1.9	0.9	121	0.8	0.4	111	1.5	0.7	027	1.4	0.7	024	1.4	0.7
-1	066	1.6	0.8	125	0.7	0.3	111	1.6	0.7	035	0.9	0.4	076	1.1	0.5
0	**072**	**0.9**	**0.5**	**161**	**0.2**	**0.1**	**111**	**1.7**	**0.8**	**110**	**0.2**	**0.1**	**134**	**2.1**	**1.0**
1	102	0.4	0.2	224	1.0	0.4	125	1.5	0.7	201	2.0	0.9	161	2.3	1.1
2	206	0.7	0.4	233	1.1	0.5	190	0.1	0.0	188	2.9	1.4	182	1.9	1.0
3	227	1.3	0.6	241	1.2	0.5	275	1.3	0.6	202	2.2	1.0	204	1.4	0.7
4	239	1.7	0.8	262	1.5	0.7	272	1.7	0.8	227	1.1	0.5	233	0.9	0.5
5	240	1.7	0.8	262	1.2	0.5	265	1.0	0.4	326	0.4	0.2	277	0.8	0.4
6	245	1.2	0.6	296	0.5	0.2	292	0.7	0.3	000	0.7	0.3	315	1.0	0.5

From the view of the peak tidal flow (i.e., D>E>A>C>B), there are more tidal power at D, E and A compared to the other two sites (i.e., C and B), which are located inside the island group. However, since D, E and A are outside the island group in deeper waters, installation of marine energy devices there would come with greater grid connection and cabling costs. What is worse, compared with C and B, the direction of the currents outside the array of islands at D, E and A show more rotation, and are therefore less concentrated around the main flood and ebb directions. They are therefore likely to be less useful for tidal current energy converters that have fixed rotor orientation (and therefore reduced capacity to extract energy from tides at oblique directions).

Water depth at sites C and B should be carefully considered. It is noted that these sites may be too shallow to install tidal stream devices.

Apart from the tidal current, distribution of the tidal range around Lundy and the IoS is also presented for reference (see Figure 3-6).

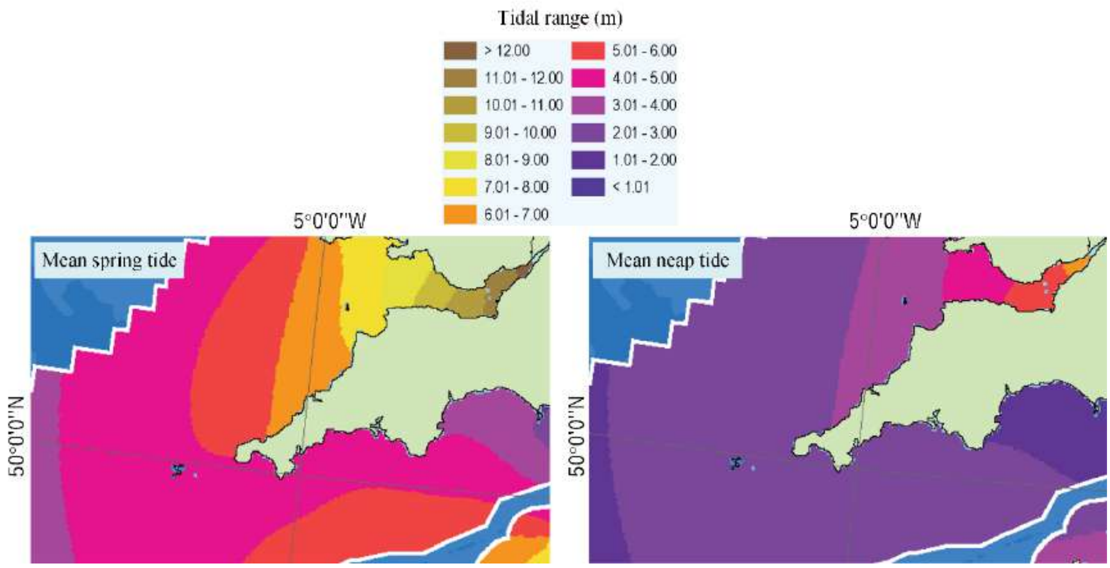


Figure 3-6: Mean spring/neap tidal range [36]

The peak flow of the 2D tidal stream around Chausey and Molène is plotted in Figure 3-7 [39]. The strongest tidal current around Chausey occurs at its south side, where the peak flow can be as large as 2.5-3.0 knots (1.29-1.54 m/s) and even 3.0-3.5 knots (1.54-1.80 m/s) at certain area. The corresponding peak tidal power can be approximately 1.10-1.87 kW/m^2 and 1.87-1.38 kW/m^2, respectively.

For Molène, the largest peak flow was observed at its north-west and south-east, where the 2D tidal stream can be as large as 3.5-4.0 knots (1.80-2.06 m/s) and even 4.0-4.5 knots (2.06-2.32 m/s), and the corresponding peak tidal power are approximately 2.99-4.48 kW/m^2 and 4.48-6.40 kW/m^2, respectively, which is greater than that at Chausey.

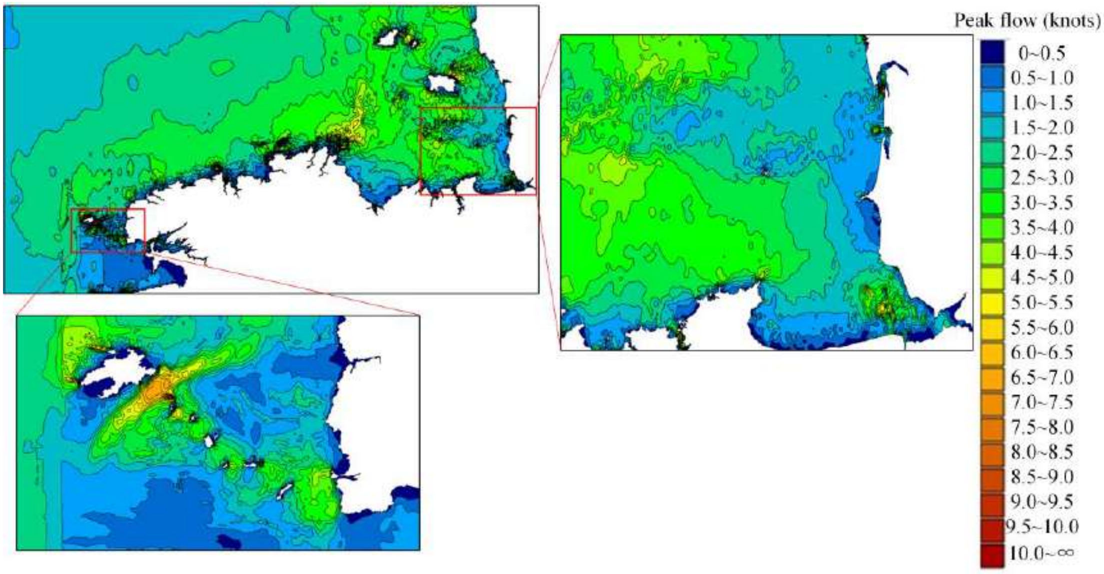
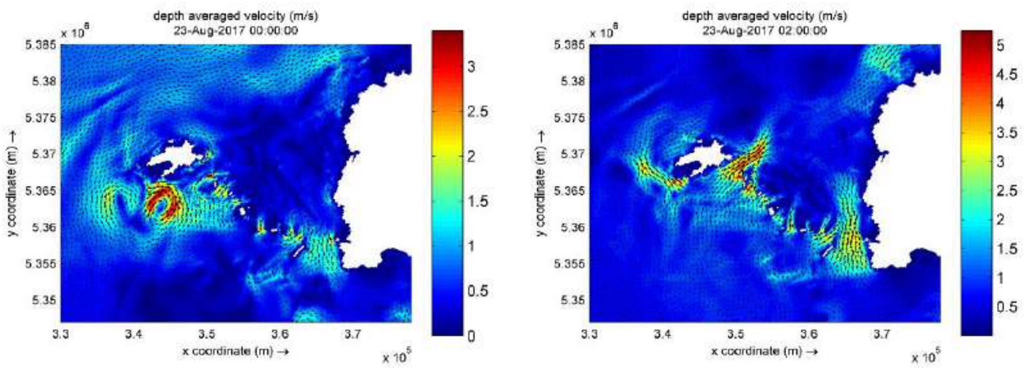


Figure 3-7: Peak flow of the 2D tidal stream [39]

Figure 3-8 shows depth-averaged currents around Molène at different times of a tidal cycle, i.e., 00:00:00-10:00:00, on Aug 23, 2017.

Note at 00:00:00, the tidal current at north-west of Molène is around 2.0 m/s with the direction coming from south-west, whereas the tidal current at south-east of Molène is only around 1.0 m/s. As time increases, the current at both sides of Molène first increases and then decreases, and as time keeps increasing from 04:00:00 to 06:00:00, the current directions change into the opposite directions. At 08:00:00, the tidal current at north-west of Molène reaches the largest around 3.5 m/s, and the corresponding tidal current at the other side of Molène is 2.5 m/s, approximately. As time increases to 10:00:00, both of the tidal currents at south-east and north-west decrease, while the latter one decreases more dramatically. Therefore, the north-west of Molène would be preferred for the installation of a tidal stream power device due to more tidal stream power there compared to the south-east.

It is shown that the tidal stream power at Fromveur Passage (south-east of the Ushant) is very promising, but it is far from Molène, resulting in great grid connection and cabling costs.



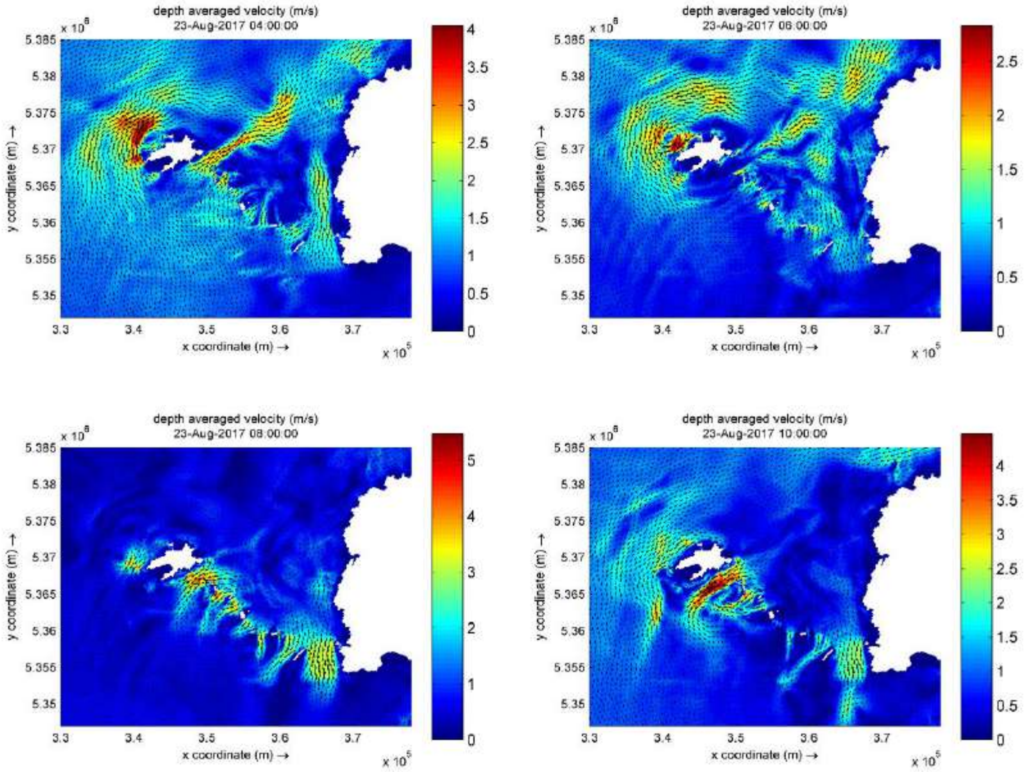


Figure 3-8: Depth averaged velocity around Molène at different time [40]

3.2 Wave power

Wave energy converters can be fixed or floating and capture power from the oscillation of waves at the surface or from movement of the water column.

Figure 3-9 below shows the areas with greatest wave power potential in the Celtic Seas and beyond, with potential at its greatest to the north and west of Scotland and the west of Ireland. The peninsula of South West England juts into the Atlantic and faces the prevailing westerly oceanic swell.

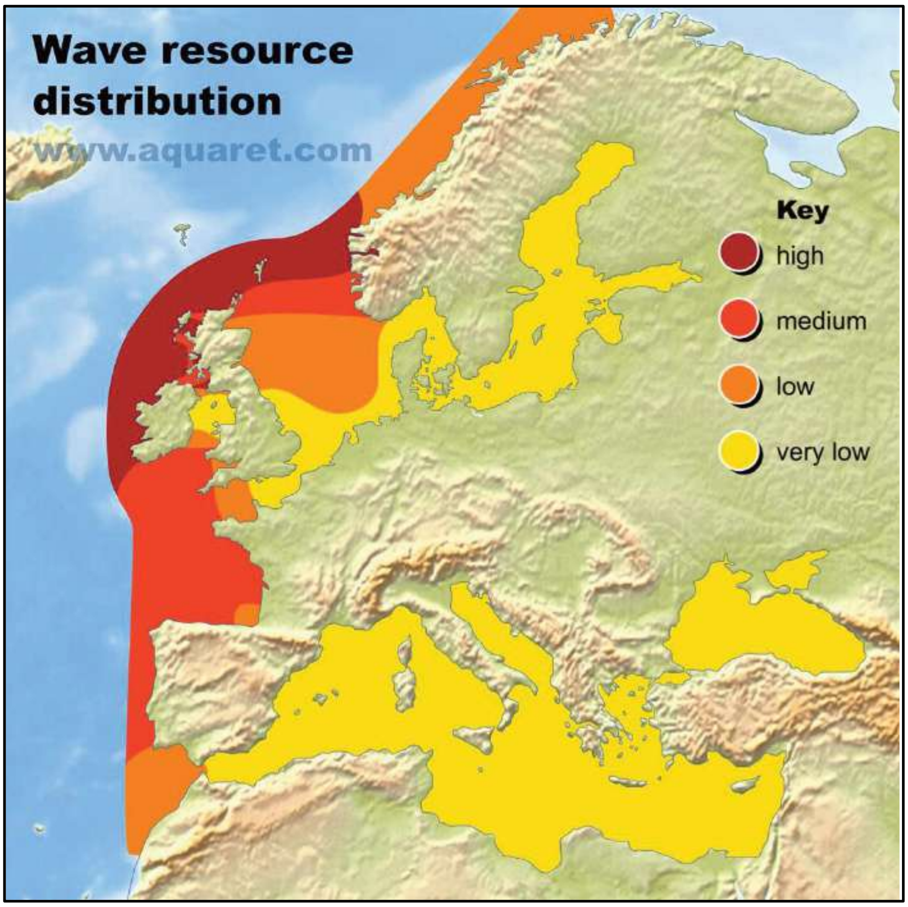


Figure 3-9: Wave resource distribution in Europe [10]

Figure 3-10 shows the distribution of seasonal/annual mean significant wave height around the peninsula of South West England. The corresponding seasonal/annual mean wave power can be found in Figure 3-11. The wave power presents a highly seasonal distribution, with output during winter months almost seven times higher than that experienced during summer. Despite the magnitude of this difference being large, the general patterns of monthly mean significant wave height and wave power distribution are as expected, given the role of wind in driving wave generation and the stronger wind experienced in the North Atlantic and UK coastal waters in winter.

This distribution could be seen as beneficial, since the average electricity demand levels are generally higher in winter than in summer, suggesting that the wave power resource will deliver more energy during periods of higher demand than at other times of the year [37].

Although the waves are powerful, South West England benefits from less extreme storm conditions that would challenge the “survivability” of the marine power devices. This is particularly important in the early stages of their development [41].

A typical average range of 15-25 kW/m (kilowatts per metre of wave crest) is observed in the area off the north Cornish coast, which increases to 35-40 kw/m in the area around the IoS, offering an opportunity for early stage developers with excellent wave resources and the potential to provide the islands with self-sufficient energy or even export back to the mainland [42]. The annual mean wave power at Lundy is 15.1-20 kW/s, much smaller than that at the IoS.

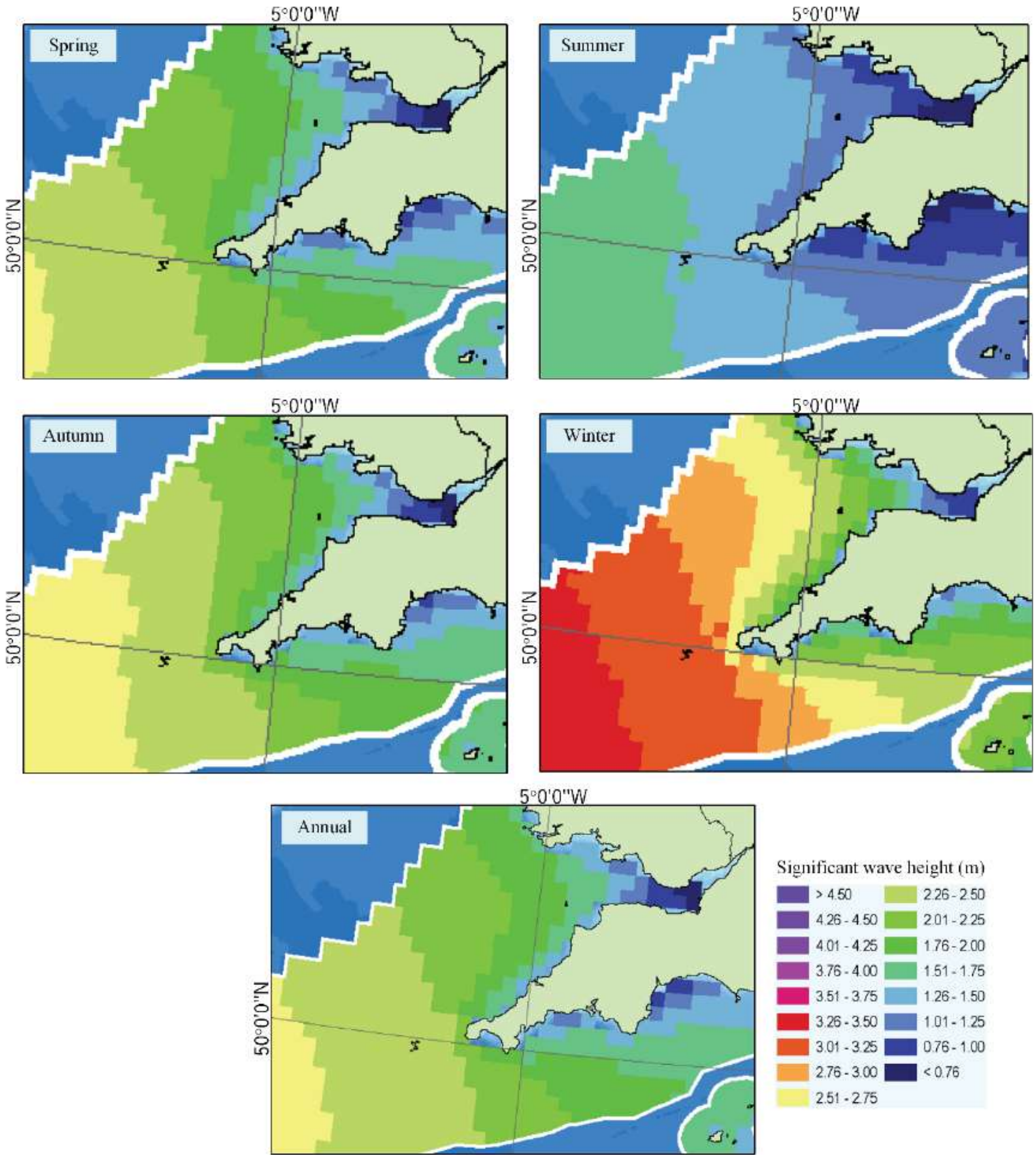


Figure 3-10: Seasonal/Annual mean significant wave height [36]

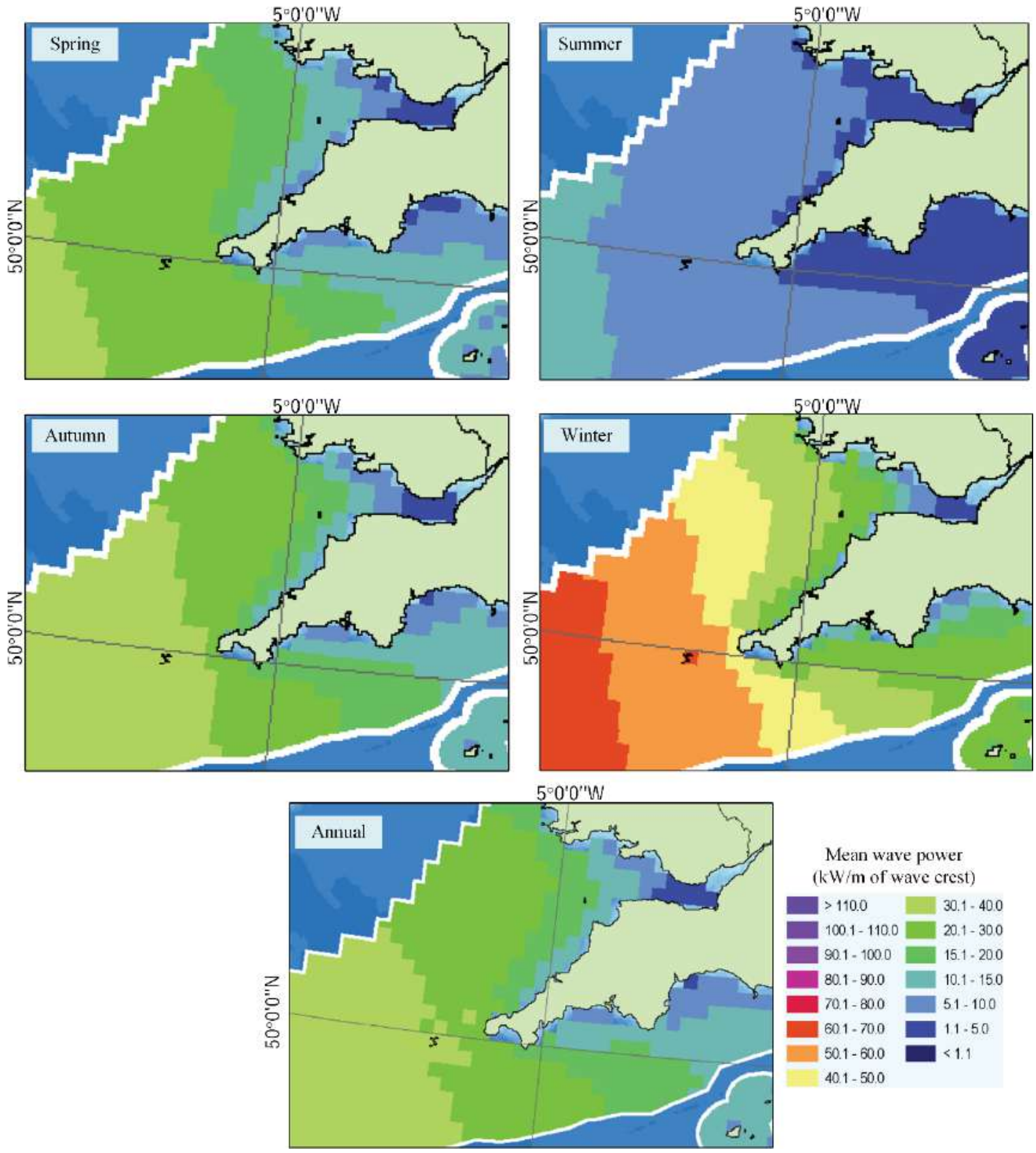


Figure 3-11: Seasonal/Annual mean wave power [36]

Figure 3-12 presents the normalized wave power fields and the transport vectors in the foreground for a high situation occurred in 2000/02/16 00 h (left), and the results for an average situation occurred in 2000/08/23 00 h (right) for the north part of the western French coast [43]. The maximum wave power values locations are also indicated. It should be pointed out that due to the fact that the significant wave height is a function of the energy spectrum while wave power depends on the group velocity, the maximum point in significant wave height field does not always correspond to the same location in wave power field.

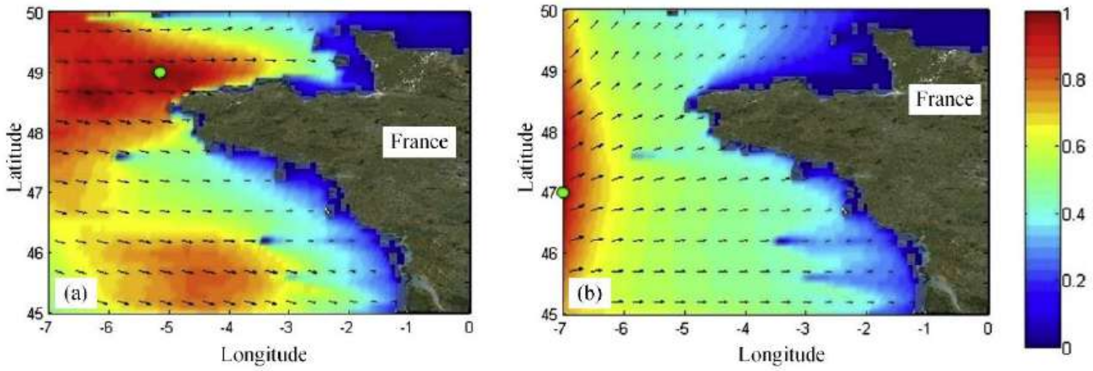


Figure 3-12: Computed wave power scalar fields, and energy transport vectors. (a) Energetic peak: 2000/02/16 00 h input parameters: H_s=4.05 m and T_p=16.9 s; (b) Average peak: 2000/09/23 00 h, input parameters: H_s=1.70 m and T_p=9.4 s [43]

Figure 3-13 illustrates the average annual wave power along the north part of the western French coast [43]. As can be observed, the Atlantic French coast presents an appealing wave energy resource where the implementation of wave energy converters might bring significant results. The average annual wave power around Molène can be as large as 30-35 kW/m, while it is only around 5 kW/m at Chausey.

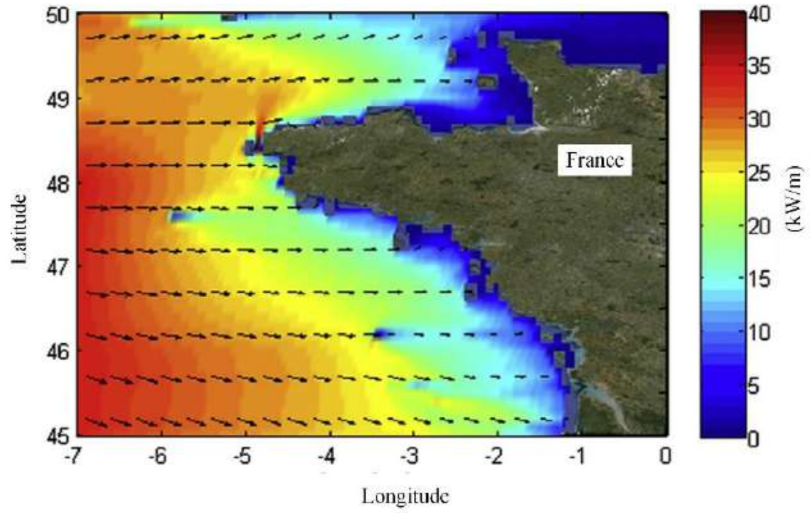


Figure 3-13: Average annual wave power yield by SWAN simulations [43]

The opportunity for wave power in the IoS and Molène is large in theory. The resource is substantial, but the technology is yet to be proven and is not yet commercial. Moreover, the marine impact of wave power is not fully understood, hence a considerable amount of work is needed to be done prior to the contemplation of any projects.

4. Conclusions

The present report presents the tidal/wave characteristics at the region around Lundy, the IoS, Chausey and Molène.

Constraints, such as environmental, technical, socio-economic and geology, are included, which can help identify the proper potential sites for marine renewable energy absorption.

The average annual tidal and wave power at the four sites are listed in Table 4-1.

Table 4-1: Estimates of average annual tidal and wave power at the four sites

	Tide Power	Wave Power
Lundy	0.5-1.0 kW/m^2	15.1-20 kW/m
IoS	0.26-0.5 kW/m^2	35-40 kW/m
Chausey	around 1.87 kW/m^2 (peak tidal power)	0-5 kW/m
Molène	around 4.48 kW/m^2 (peak tidal power)	30-35 kW/m

The largest tidal power around Lundy is found to be distributed at its north and south (average tidal power 0.51-1.00 kW/m^2), which is obviously larger than that (0.26-0.50 kW/m^2) at the east and the west sides of the IoS, where the largest tidal power is located for the IoS. While for the wave energy resources, the annual mean wave power at Lundy is 15.1-20 kW/s, much smaller than that at the IoS, which is 35-40 kw/m.

The strongest tidal current around Chausey occurs at its south side, while for Molène the strongest tidal current is observed at the north-west and south-east. Compared to Chausey, there are more tidal stream power around Molène, especially its north-west side. The average annual wave power around Molène can be as large as 30-35 kW/m, while it is only around 5 kW/m at Chausey due to the wave energy dissipation caused by the friction with the seabed.

It should be remembered that marine renewable energy devices are new technology and not fully commercial yet. To implement this option much more evaluation will be required.

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