# ORECCA European Offshore Renewable Energy Roadmap

## September 2011

# The ORECCA Project

The ORECCA (Offshore Renewable Energy Conversion Platform Coordination Action) Project is an EU FP7 funded collaborative project in the offshore renewable energy sector. The project's principal aim is to overcome the fragmentation of know how available in Europe and its transfer amongst research organisations, industry stakeholders and policy makers stimulating these communities to take the necessary steps to foster the development of the offshore renewable energy sector in an environmentally sustainable way. The project brings together a combination of world class experts from a wide variety of multinational companies, research institutions, consultancies, utilities and project developers. The project's focus is pan European and pan technology, with a specific focus on revealing the opportunities that exist across Europe when the three offshore renewable energy sectors within the project's scope are considered together. Within the ORECCA Project, the scope of the offshore renewable energy sector ("offshore renewables") was confined to:

- ***Offshore wind;***
- ***Wave energy; and***
- ***Tidal stream.***

These energy sectors have been identified as those that are currently expected to make significant contributions to the energy system in the medium to long term. As a result, other sectors, such as tidal barrage and ocean thermal energy conversion (OTEC) were not covered in the scope of the project.

Produced by the University of Edinburgh on behalf of the ORECCA Project.

*AUTHORS:* Henry Jeffrey & Jonathan Sedgwick

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ORECCA

# EXECUTIVE SUMMARY & RECOMMENDATIONS

This document represents for the first time a combined roadmap developed for the offshore wind, wave and tidal stream energy sectors, focussed on the synergies, opportunities and barriers to development that are revealed when the sectors are investigated together in pan-technology and pan-European context.

The principal target audiences of the recommendations set out are policy makers at the EU and Member State level. However, the recommendations and the way forwards set out are also of high importance for other stakeholders to the offshore renewable energy sector.

The roadmap's vision is to guide policy makers to support the accelerated development of the offshore renewable energy sector (offshore wind, wave and tidal energy) in Europe:

To identify synergies;

To overcome barriers to the development of the sector;

To realise the large opportunities presented by the sector;

To facilitate significant, cost effective commercial scale deployments by 2030;

To do all of this in an environmentally sustainable way.

The roadmap is structured around five key streams which are essential to the development of the offshore renewable energy sector. Each of these streams has a dedicated chapter in the main roadmap document:

- Resource;
- Finance;
- Technology;
- Infrastructure;
- Environment, Regulation & Legislation.

Europe has a large amount of natural resource across the three offshore renewable energy sectors. Technically offshore wind, wave and tidal together could supply 100% of Europe's future electricity demand. These resources present significant opportunities with respect to increased energy security, emissions reductions, and economic benefits including job creation.

Before looking forward to where the offshore renewable energy sectors are heading in the future, it is important to consider where the sectors are now. For the offshore wind sector, there is currently approximately 4GW installed capacity in Europe, and over 100GW in the planning pipeline for 2020. In comparison, for the ocean energy sector (wave and tidal stream), no commercial farm scale deployments currently exist, and the amount of capacity in the pipeline for Europe by 2020 is approximately 2GW. It is clear that the ocean energy sector is at an earlier stage of development than the offshore wind sector and a deployment timeline for the two sectors is shown in Figure A below.

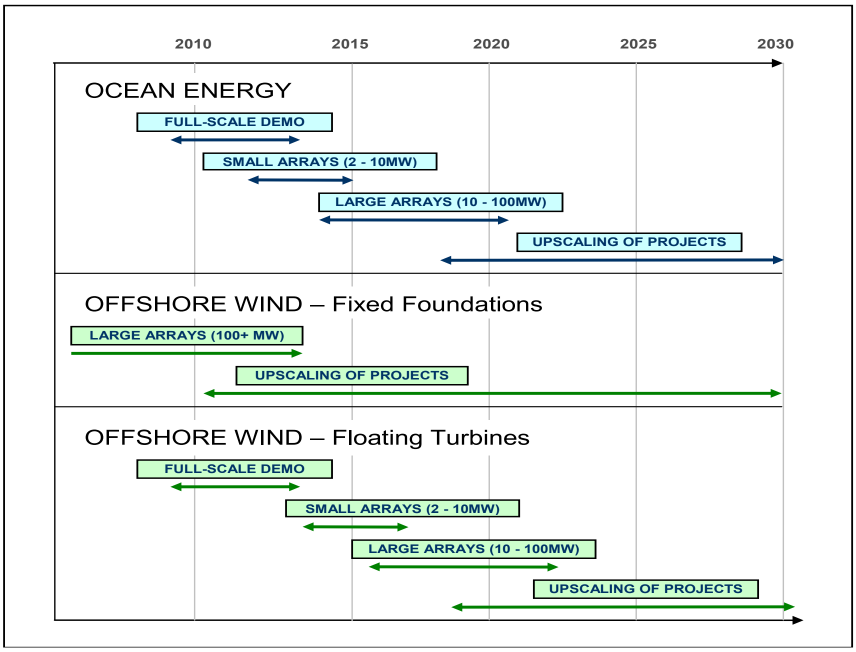



**Figure A:** Projected deployment timelines for the ocean energy (wave and tidal stream) and offshore wind sectors.
(Source: adapted from the DECC Marine Energy Action Plan 2010).

| | | 2050 Target |
|---|---|---|
| Offshore wind | European target [1] | 460 GW |
| | International target [2] | 1150 GW |
| Ocean energy | European target [3] | 188 GW |
| | International target [4] | 748 GW |

**Figure B:** Some deployment targets which have been set out in the offshore renewable energy sector. [[1]EWEA (European Wind Energy Association), [2]IEA (International Energy Agency), [3] EU-OEA (EU Ocean Energy Association), [4]Greenpeace Advanced Energy [R]evolution]

The ORECCA project does not set out deployment targets for the offshore renewable energy sectors, but aligns itself with existing targets and aims to facilitate their achievement by identifying synergies and addressing barriers to the development of the sectors. Both European and International targets exist for the sectors, as illustrated in Figure B. All of these targets present an opportunity for the realisation of large economic benefits in the European Union (EU). The EU OEA envisage that the realisation of the European target of 188GW installed capacity of ocean energy by 2050 alone could result in the creation of over 450,000 jobs.

The offshore wind targets are higher than the ocean energy targets at both the international and European level, due to the fact that the ocean energy sectors are currently at an earlier stage of development and it will take longer to achieve large scale commercial deployments. A large portion of the global targets will have to be met by deployments outside Europe. This represents an important market and opportunity for the sectors, which are currently heavily concentrated in Europe, to export technology and expertise worldwide.

## Combined Platforms & Co-location

In the short term, due to the relative immaturity of offshore renewable energy technologies (particularly wave and tidal technologies), it is generally seen as too early to deploy combined platforms. However, co-location of devices can realise large benefits with respect to infrastructure and represents an important opportunity over the short term with benefits from joint utilisation of electrical infrastructure and potentially of O&M teams, vessels and infrastructure. In the longer term, combined platforms should not be ignored (they present a large opportunity for the sector once significant further research and modelling is completed*), but the immediate opportunities for the sector remain focussed on co-location.

*Projects such as the European Commission funded MARINA Platform Project are already working in this regard.

# RESOURCE

The level of natural resource which exists in a particular country or region is of critical importance when considering the potential impact which a particular sector or technology can have.

- The roadmap reports where offshore wind, wave and tidal stream resources exist across Europe, but importantly, also reveals the potential for combined resources. To provide context, a high level breakdown of Europe's resource is shown in figure C below, before the combined resource 'hotspots' identified across Europe are illustrated in Figures D and E below.

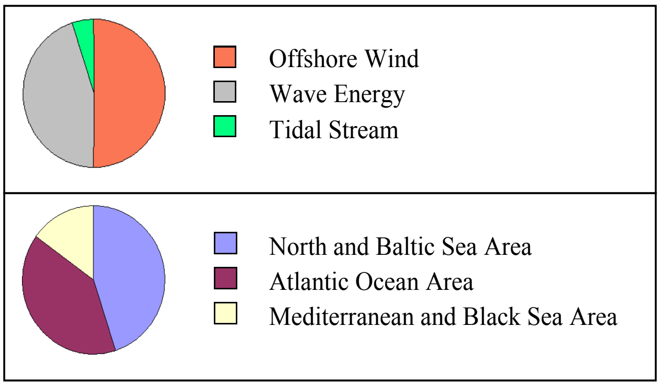



**Figure C:** Breakdown of Europe's offshore renewable energy resources across the three technologies and the three regions which the seas surrounding Europe were divided into.

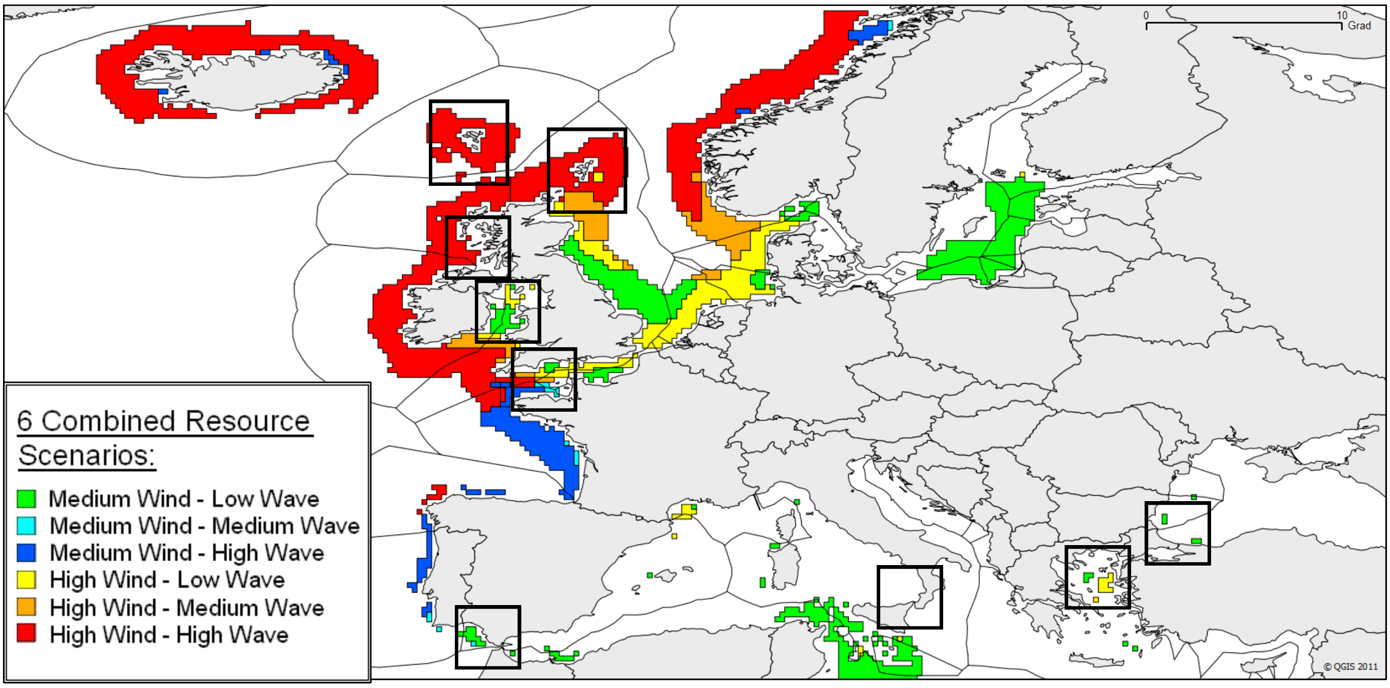
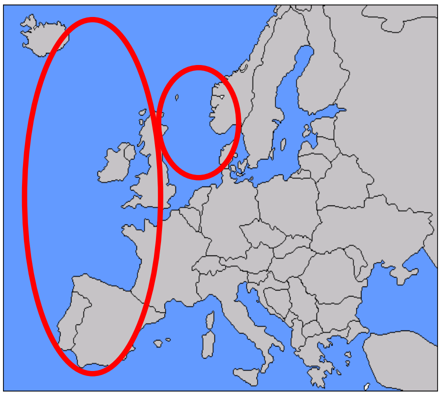



**Figure D:** Combined resource map showing the combined wind and wave resource across 6 scenarios with the tidal stream resources overlaid and highlighted with the black panes.



The roadmap identified two principal 'hotspots' where a large amount of high intensity combined resource (across offshore wind, wave and tidal energy) exists in Europe:

- The Western facing Atlantic coastline, off the coasts of Scotland, the UK, Ireland, Spain and Portugal.
- The Northern North Sea, off the coasts of Norway and the UK.

**Figure E**: Map of Europe showing the resource 'hotspots' identified.

In the short to medium term, all of the recommendations in the roadmap are focussed on these two principal 'hotspot' areas as they present the largest and most immediate opportunity. Whilst acknowledging that combined resource does exist in other areas, these areas are not an immediate priority. However, as the sectors develop, costs are reduced, and experiences gained, areas of less intense combined resource will form important secondary markets, and they should not be ignored over the longer term.

The areas where exploitable tidal resources exist are relatively limited in number but show high energy densities. Analysis revealed that tidal stream resources make the smallest contribution to the total offshore natural resource in Europe (as shown in figure C above).

Therefore, focussing on areas of wind and wave combined resource is the most important overlap between the three technologies in terms of exploiting combined resources. Exploiting combined wind and tidal resources is limited by the fact that 100% of the tidal sites identified are less than 20km from shore, a significant constraint for large wind turbines. However, this is not to say that there are not significant technology transfer and other synergies with the tidal stream sector. - It is also important to highlight that the data which underpins the tidal stream resource in the combined resource maps is different in nature to the data for the wind and wave resources. For the wind and wave resources, Europe wide grids of data are available. However, there is far less data available for tidal stream, and the data utilised is based upon measurements made at sites which have been identified as potential locations based on their geographic conditions.

## Water depth and distance from shore

The water depth and distance from shore of the areas where resources exist are an important consideration. Analysis revealed the information in Figure F below.

| | Distance from Shore | Water Depth |
|---|---|---|
| | % of combined resource further than 100km from shore | % of combined resource in water depths of greater than 60m |
| North and Baltic Sea Area | 40 % | 70 % |
| Atlantic Ocean Area | 60 % | 97 % |
| Mediterranean & Black Sea Area | 30 % | 94 % |

**Figure F:** Breakdown of the resource in the three areas by distance from shore and water depth.
**N.B.** Current constraints for fixed foundation wind turbines are limited to 60m water depth.
It is envisaged that floating devices will be required to exploit resources in water depths of greater than 60m.

**Across Europe approximately 80% of the combined resource is in water depths of greater than 60m and approximately 50% of the resource is further than 100km from shore.** It is therefore clear that, to exploit a large proportion of the available natural resource in Europe, it will be necessary to develop technologies to facilitate deployments in deeper water and further offshore. This is particularly applicable to the Atlantic Ocean and Mediterranean and Black Sea areas, where only a very small proportion of the combined resource lies in water depths where current constraints for fixed foundation offshore wind turbines facilitate exploitation.

# FINANCE

Without government support, the offshore renewable energy sectors are not currently cost competitive in terms of cost of energy alone. However, the sectors promise emissions reductions, increased energy security and economic benefits and there is therefore significant governmental interest in the sector and a large number of financial support mechanisms available across Europe.

Analysis revealed large variations in the financing landscape across Europe, with it being much more developed in some countries than in others. Figure H reveals gaps in terms of which countries have the funding and policies in place to make investment in the sector attractive.

**Figure G:** Photograph of Hywind floating wind turbine under testing (designed for use in water depths of 120–700m), an example of the type of innovative technology which will need to be developed to facilitate exploitation of the extensive combined resource in deep waters. (Photo: Trude Refsahl / Statoil)

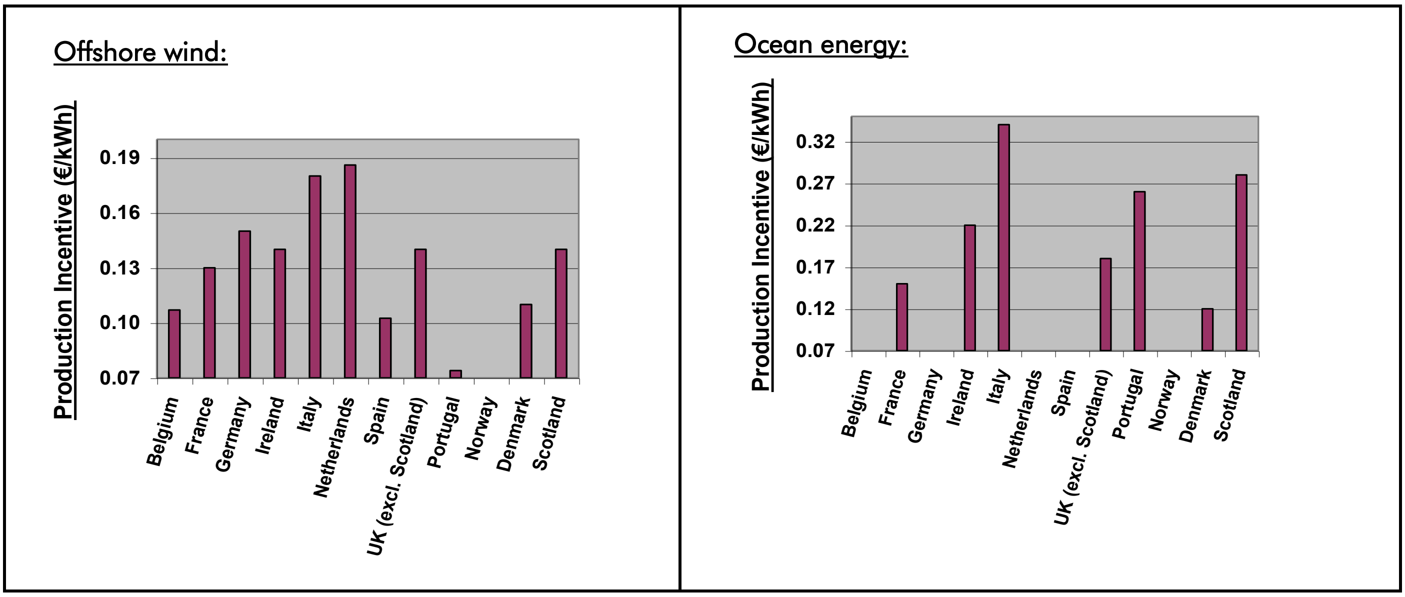



**Figure H:** Charts showing the Production Based Incentives (PBIs) in countries across Europe for both the offshore wind and ocean energy sectors respectively.

**N.B.** where appropriate, the data includes an assumed Europe wide wholesale electricity price of 0.07 €/kWh. Where there is no production incentive available above the wholesale price, the graphs report zero.

## *Offshore wind*

The analysis revealed that all countries with the exception of Norway have a PBI in place for offshore wind. However, within this, there is large variation from 0.07 to 0.19 €/kWh. Spain, Portugal and Denmark all have attractive natural resources, but have lower PBIs than other countries with comparable resources. However, the largest discrepancy illustrated in the graph is in Norway which has an attractive resource but no PBI in place to support the sector. This large, currently unexploited resource in Norway represents a large opportunity if the necessary finance policies and technologies can be developed.

## *Ocean energy*

Only 7 of the 12 countries analysed have a PBI in place for ocean energy. Of these seven, only four countries (Scotland, Italy, Portugal and Ireland) have a PBI in place which is significantly higher than the PBI for offshore wind in the same country, taking account of the high costs and emerging status of the ocean energy sector.
These four countries are setting a strong market signal for the sector which will help to attract investment and to accelerate development. The UK has one of the most attractive resources in Europe, but presently has only the 5th best PBI in place to support the sector, and Norway has no PBI for the ocean energy sector despite having a large ocean energy resource. The large amount of available resource across both the offshore wind and ocean energy sectors presents a major opportunity, particularly in the UK, Ireland, Norway, France, Portugal and Spain. However, the funding landscape will have to be advanced in all countries to increase the attractiveness of the sector as an investment target and to realize the opportunity presented.

Establishing the level the PBI should be set at in order to be effective is not something which can be done in this roadmap. The PBI needs to be high enough to give a positive return on investment for projects and to allow the correct technologies to be developed. Further research is required to determine the level of PBI required to be effective in each country, taking into account factors such as resource intensity, distance from shore and water depths.

Challenges to investment exist in the offshore renewable energy sector and a number of the finance recommendations are actions to address these. The most critical challenge to investment identified concerns difficulties associated with securing finance, especially to develop the first deployments of new technologies (when reliable data on investment returns and device performance is limited) and to complete the construction phases of projects (when investors are exposed to higher risks). Measures to mitigate this barrier are important and include soft loan programmes and government underwriting of project risk.

**Figure I:** Photograph of a tidal stream device currently being tested in Northern Ireland. (Source: Marine Current turbines)

## *Finance Recommendations*

### The ORECCA roadmap recommends that EU and member state administrations:

- **Maintain a careful balance between market-pull and technology push support measures for the sector** to ensure that both large scale deployments and research into technologies which could realise large cost reductions for the sector are supported.
- **Maintain technology-push capital support measures** to ensure step change cost reductions and performance improvements.
- **Ensure a long term market signal in relevant countries** to increase investor certainty.
- **Develop funding opportunities (particularly production incentives) in line with countries which are current leaders, in countries which have a less developed funding landscape, but where a large resource exists.**
- **Set up specific grant schemes for offshore renewable energy investments.**
- **Recognise within funding programmes the emerging stage of development that the wave and tidal stream energy sectors are at,** and provide targeted funding to accelerate their development.
- **Develop new risk sharing mechanisms to facilitate investment in the sector**, particularly in the construction phases, such as government underwritten guarantees and using public funds as a guarantee for private financial bodies.
- **Continue to encourage cross border collaboration on projects** in the sector to drive costs down and promote knowledge transfer.
- **Increase funding for demonstration projects** to accelerate the development of the sector by 'learning by experience'.
- **Provide targeted financing to support the development of the necessary technologies** (such as floating wind turbines and HVDC transmission) **to facilitate deployments in deeper waters and further from shore.**

**Figure J:** Photograph of Pelamis Wave Power device (Source: Pelamis Wave Power)

# TECHNOLOGY

Technology poses a number of challenges and opportunities for the offshore renewable energy sectors. Many factors such as the affordability and reliability of the technologies and devices will have a critical impact on its development.

The emerging status of offshore wind and ocean energy technologies creates considerable challenges for their development. There is a need to strike a balance between trials and deployments of advanced full scale devices whilst also developing emerging designs and sub components to ensure efficient and effective long term cost reduction as well as achieving high levels of reliability and survivability. This is true across offshore wind, wave and tidal technologies and across European member state countries.

## Summary of the technology challenges

- At present, offshore renewable energy development activity is spread over a wide variety of platform and foundation concepts and components, and at the highest level, offshore wind, wave and tidal current have distinctive development needs. Across the three sectors, there is a need to strike a balance between design variety and consensus, and the development of supply chain commonality.
- A number of generic technology areas and components – such as foundations, moorings, power take off (PTO), marine operations and resource assessment – offer important opportunities for collaborative development, although the transfer of generic knowledge and components within the developer community may be limited by commercial competition.
- There is a need for more performance data and operating experience to feed into the overall development cycle, particularly for the wave and tidal stream sectors which have relatively limited full scale experience in open sea operating conditions.
- There are significant opportunities for knowledge transfer from other sectors, such as offshore engineering. Enabling this transfer will involve a better understanding of the 'adaptation costs' of transferring components and methods to the marine environment, and identifying opportunities for collaboration with other industries and supply chain partners to ensure the availability of cost effective solutions.

At the highest level, offshore renewable energy technology development and deployment will require measures to address the underpinning generic technical challenges of predictability, manufacturability, install-ability, operability, survivability, reliability, and affordability.

**Figure K:** Photograph of the Oyster 1 wave energy device under testing at EMEC
(Source: Aquamarine Power)

**Figure L:** Artist's impression of an array of Hammerfest Strom tidal stream devices. (Source: Hammerfest Strom)

## Highest priority technology development activities:

The technology challenges and associated technology development activities within the offshore wind and ocean energy sectors were prioritised according to the assessed level of industry need. Nine technology development activities within the offshore wind sector and sixteen within the ocean energy sector were identified as the highest priority for the sectors, and these are outlined in Figure M below.

**Figure M:** Table outlining the technology development activities for the offshore wind and ocean energy sectors respectively that have been prioritised as the highest priority for the sectors.

| OFFSHORE WIND SECTOR: | OCEAN ENERGY SECTOR: |
|---|---|
| • Offshore dedicated turbine system demonstration;<br>• Ultra reliable turbine demonstration;<br>• Large blade rotors (>150m);<br>• Deep water jacket foundations;<br>• Deep water gravity foundations;<br>• Design standards (structural, mechanical, electrical, control etc);<br>• Testing and installation standards;<br>• Health and safety standards; and<br>• Advanced drive train research for lighter designs. | • 1st generation device and array trials;<br>• Performance data collection;<br>• Installation methods;<br>• Recovery methods;<br>• Cost effective O&M techniques;<br>• 2nd generation device development;<br>• Control systems;<br>• Energy conversion systems (PTO);<br>• Foundations and mooring systems;<br>• Wet HV connectors;<br>• Performance guidelines/specifications;<br>• Design of installation tools;<br>• Device modelling tools;<br>• Array design and modelling tools;<br>• Resource analysis tools; and<br>• Reliability modelling tools. |

### *Offshore wind*

These activities will ensure the development of highly reliable, large rotor, specifically dedicated offshore turbines with cost effective foundations suitable for deeper waters and are extremely important to facilitating large deployments in the coming years. The three sets of standards set out in Figure M (design, testing, health and safety) are important to build upon the existing IEC TC88 standards and will help to ensure that international best practice prevails. The advanced drive train research activity is also important and will facilitate step change improvements in turbine design and structure.

### *Ocean energy*

The first ten of the technology development activities identified in Figure M above reiterate the importance of testing devices, developing efficient and low cost installation, O&M and recovery techniques, and developing sub-components critical to these devices

The high priority of these activities is necessary due to the fact that no significant deployments beyond full scale prototype testing currently exist, and there is relatively little design consensus around the leading technologies to move the sector forwards. The development of performance specifications will allow international best practice to be established in terms of device performance in the sector. Designing tools to make installation of devices more efficient has the potential to have a large impact on installation and O&M costs. A number of the activities relate to developing tools for modelling devices, arrays, resource and reliability. Modelling these four aspects will be crucial to further increase the understanding of the complex interactions involved and then incorporate this knowledge into future device and system designs.

## Synergies and Commonalities

Five principal areas have been identified where immediate technical synergy opportunities exist between the offshore wind, wave and tidal energy sectors:

- **Foundations:** common foundation types to be used.
- **Array layout:** sharing of lessons learnt for effective array design.
- **Mooring/fixed connection points:** common mooring/fixed connection points to be used.
- **Grid connection and integration.**
- **Power take off:** common power take off technologies to be used.
- **O&M:** sharing of lessons learnt for effective design and technology development to reduce the need (and associated cost) for O&M (remote monitoring is a good example of this).

### *Technology Recommendations*

**The ORECCA roadmap recommends that EU and member state administrations:**

- **Create policies to develop design consensus within the ocean energy sector.**
- **Design policies which ensure that all possible subcomponent development activities are developed in a way so as to provide common solutions across the three offshore renewable energy sectors.**
- **Ensure that policies are in place to provide guidelines for funding bodies** to ensure that allocation of development funding is in line with the technical timelines and priorities set out in this roadmap.
- **Ensure that, for the offshore wind sector, policies and support are put in place to concentrate technology development activities on the nine high priority areas** in figure M above.
- **Ensure that, for the ocean energy sector, policies and support are put in place to concentrate technology development activities on the sixteen high priority areas** in figure M above.
- **Ensure that a mature, coherent and adaptive approach to policy is taken with regard to technology** developments internationally, to provide an appropriate combination of support mechanisms, and ensure effective distribution of investments as the sector matures.

# INFRASTRUCTURE

For the full commercialisation of the offshore renewable energy sector, a wide range of facilitating infrastructure is necessary.

This roadmap focuses on:

1. **Ports & Offshore Supply Chain** infrastructure;
2. **Vessels** infrastructure; and
3. **Grid** infrastructure.

There is an opportunity for infrastructure developments to be clustered in the 'hotspot' regions identified in the resource section where a large amount of high intensity combined resource exists. - Mobilising the necessary facilitating infrastructure surrounding these areas of intense resource presents an immediate opportunity for combined wind, wave and tidal infrastructure development and this should be acted on accordingly.

**Figure N:** Picture of an offshore wind construction port at Belfast, Harland and Wolff.
(Source: UK Offshore Wind Ports Prospectus).

## Ports

A number of ports, primarily in the Southern North Sea and the Irish Sea, have already been used for offshore wind and ocean energy. The port requirements (in terms of draft, length of quayside, gantry cranes, overhead clearance etc.) are highly dependent on factors such as the size and weight of the devices, and the type of foundations used. Despite the fact that it is too early to define some of the detailed port requirements (especially for the wave and tidal sectors where design consensus has not been fully achieved), the development of ports represents an immediate opportunity. These developments require further research to consider where ports need to be developed to support the exploitation of the 'hotspot' areas in the most efficient possible way. For example, the most cost effective development path for the Northern North Sea resource 'hotspot' is likely to be to further develop existing manufacturing facilities in the Southern North Sea, and to develop clusters of assembly and O&M port facilities around the Northern part of the North Sea, closer to the 'hotspot' natural resource.

Irrespective of whether combined platforms or co-location of devices, combined infrastructure represents an immediate opportunity. - This approach to thinking about port infrastructure in a coordinated way, aiming to develop clusters of port infrastructure to facilitate the exploitation of 'hotspots' of resource identified, is new. This is an important approach to ensure that the necessary infrastructure is developed in the most cost effective and efficient way possible.

The concept of offshore service hubs represents a significant opportunity as a large proportion of Europe's offshore renewable resource exists far from shore (50% > 100km from shore). To exploit this resource, cost reductions could be achieved if different functions such as O&M accommodation, housing of equipment and spare components, and even some elements of construction could be housed as part of an offshore service hub.

## Vessels

Important synergies between the offshore wind, wave and tidal sectors exist in the area of cable installation vessels, foundation installation vessels, and O&M vessels. Cable installation vessels represent an immediately exploitable synergy and similarly, synergies exist where similar foundation types are used across the three sectors (these synergies will increase as the sectors progress into deeper water and the mooring technologies become increasingly common). Depending on design, O&M vessels (typically very versatile and able to adapt to roles across a number of sectors) will also have significant synergies across the sectors.

A further synergy exists with regard to device transport and installation vessels. Multipurpose vessels continue to lead the market. Vessels such as jack up barges and heavy lift vessels are flexible and can be used by a number of sectors as well as having geographic flexibility to travel. Installation vessel synergies are specific to two distinct categories:

1. Shallow water installation vessels. Fixed structure offshore wind turbines, tidal devices, and shallow water wave deployments all have similar requirements, and can therefore utilise common installation vessels.

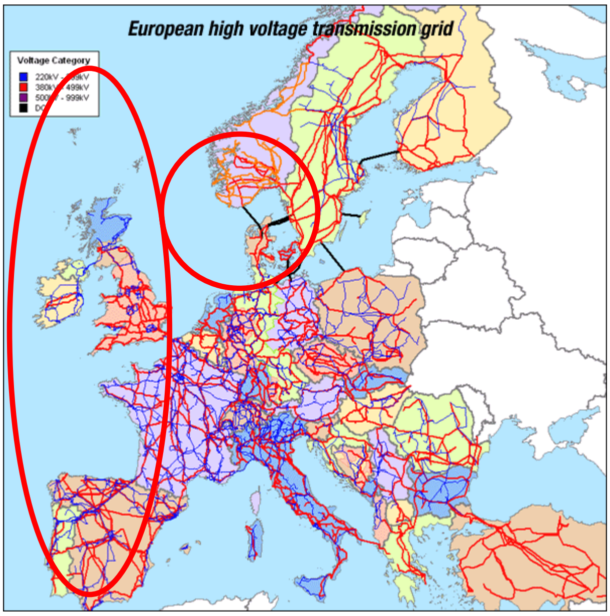
2. Deep water installation vessels. Floating offshore wind, deep water wave and floating tidal devices will have similar installation vessel requirements (dealing with anchors and mooring deployments etc.) and therefore can utilise common installation vessels.

It is important to highlight that, in contrast to the installation vessel synergies identified above, for a range of offshore wind and ocean energy technologies, specialised installation techniques and vessels are under development. Such solutions are very efficient for the designated purpose but cannot be used to install other technologies and consequently, there is a higher commercial and technological risk involved in using such specialised equipment.

Whilst the vessel synergies identified above mean that vessels can be shared across sectors and across countries, they also mean that there will be competition. It is important to ensure that useful synergies do not manifest themselves as detrimental competition. For example, the sectors will have to compete with the offshore oil and gas industry, not only for vessels, but also for the expert crew required to operate these vessels. This may have time and cost implications, and it requires careful consideration to ensure that it does not present a significant barrier to development. Factoring installation requirements into device designs is an important way to reduce the need for large installation vessels and therefore manage the competition (and associated cost implications).


**Figure O:** Photograph of a heavy lift barge installing an offshore wind turbine.
(Source: Saldis Salvage and Marine Contractors)

## Grid




Grid developments to facilitate the exploitation of the 'hotspot' areas where large amounts of resource have been identified are twofold:

1. **European level grid developments**, to develop a more advanced and interconnected grid between countries and European level planning to ensure that offshore grid developments are optimised to support the sector, particularly in areas such as the North Sea which is bordered by a large number of countries.

2. **Nation state level grid developments**, to increase the grid capacity in regions where 'hotspots' of resource have been identified, but the current grid infrastructure is inadequate. The four priority areas in this regard are located in **Ireland, Scotland, the UK, and Norway.**

**Figure P:** Map of Europe showing the high voltage transmission grid across Europe, with the Resource 'hotspots' highlighted.

## *Infrastructure Recommendations*

### The ORECCA roadmap recommends that EU and member state administrations

1. **Develop clustered** port and offshore supply chain infrastructure to facilitate the exploitation of the two key resource 'hotspots' identified.
2. **Prioritise further detailed studies to plan the finer details of how the clustering of ports and offshore supply chain infrastructure should be optimised**.
3. **Prioritise important National level grid reinforcements** (particularly in Norway, Ireland, Scotland and the UK) **to facilitate large scale deployments of offshore renewable energy in the 'hotspot' regions identified**.
4. **Prioritise important European level grid developments** to optimise the exploitation of the resource 'hotspots' identified. European level planning is required to ensure that offshore grid developments are optimised to support the sector.
5. **Take a coordinated approach, at the European level, when considering the development of grid, ports and offshore supply chain infrastructure.**
6. **Provide the necessary infrastructure to facilitate the progression to deployments further from centres of population, further offshore, and in deeper waters.** - This is vital to ensuring that a large portion of Europe's resource is potentially exploitable.
7. **Focus on co-location of technologies to exploit areas of combined resource in the most efficient way** (joint utilisation of grid and O&M infrastructure).
8. **Encourage the development of 'offshore service hubs'** to realise synergies from co-location and reduce the costs associated with deployments far from shore.
9. **Focus on** developing important infrastructure subcomponents common to all three offshore renewable energy sectors (such as offshore substations, submarine cables, technologies for electrical connections to floating platforms and HVDC systems).

# ENVIRONMENT, REGULATION & LEGISLATION

Legal and regulatory issues surrounding environmental protection will have a large impact on the rate of development and sustainability of offshore renewable energy.

Each Member State is responsible for transposing EU level legislation into their respective legal system, as well as implementing their own licensing processes for the consenting of projects. Therefore, the regulatory and legislative landscape varies largely across countries. The National legislative frameworks reflect the EU Directives which apply to offshore wind, wave and tidal energy, but often there is variation between how countries administer such legislative requirements and many associated policies are at different stages of development in different countries.

Three principal factors are identified in Figure Q next page which are illustrative of how developed the regulatory/legislative frameworks are in each country:

1. **Is a Strategic Environmental Assessment (SEA) in place (for wind, wave and tidal)?**
2. **Is a Maritime Spatial Plan (MSP) in place?**
3. **Does the country have a streamlined or one-stop-shop system for marine consenting?**

Some countries (such as Scotland and Ireland) are at further stages of putting an MSP in place, implementing a 'one stop shop' for marine consenting, and putting SEAs in place for each of the offshore wind, wave and tidal sectors. These are important factors for facilitating the development of the offshore renewable energy sector, and other countries, especially the UK, France, Norway, Portugal and Spain (which have been identified in the Resource chapter as having a large amount of combined resource) need to continue to progress in this regard to realise the large opportunities presented by the sector.

**Figure Q:** National policy landscape across Europe: matrix showing three important factors for supporting the development of the offshore renewable energy sector analysed across Europe.

| Country | Is there an SEA in place: | | | Is there an MSP in place? | Is there a 'one stop shop' marine consenting process? |
|---|---|---|---|---|---|
| | For offshore wind? | For wave? | For tidal? | | |
| **Belgium** | Yes | No | No | Yes | No |
| **France** | Yes | No | No | Partially | No |
| **Germany** | Yes | Partially | Partially | Yes | Yes |
| **Ireland** | Yes (provisionally) | Yes (provisionally) | Yes (provisionally) | Preparatory steps | Pending |
| **Italy** | No | No | No | No | No |
| **Netherlands** | Yes | No | No | Yes | No |
| **Spain** | Yes | No | No | Preparatory steps | No |
| **UK** | Partially, Pending | Pending | Pending | Partially and pending | Partially |
| **Portugal** | Under Development | Partial | No | Under Development | No |
| **Norway** | Yes | No | No | Partially | No |
| **Denmark** | Yes | No | No | Partially | Yes |
| **Scotland** | Yes | Yes | Yes | Partially | Yes |

[Green: Yes. Orange: Partially/pending. Red: No].

## Differences across countries and across offshore wind, wave and tidal

Some issues are entirely transferable across countries and across the three sectors, whilst others, such as public perception are very different across countries and sectors and experiences cannot be easily transferred. Some important differences between offshore wind, wave and tidal stream devices (which mean that many issues are not transferable between the sectors) are displayed in Figure R below:

| | Offshore Wind | Wave | Tidal stream |
|---|---|---|---|
| Rotating parts subsurface: | ✗ | ✗ | ✓ |
| Moving parts above surface: | ✓ | ✗ | ✗ |
| Remove hydrokinetic energy from the oceans: | ✗ | ✓ | ✓ |
| Remove kinetic energy from the atmosphere: | ✓ | ✗ | ✗ |

**Figure R:** Differences between the offshore wind, wave and tidal stream sectors which have a significant impact on their environmental impacts and the applicable legislation and regulation.

There is nevertheless transferable knowledge on environmental impacts. While species, devices and sites vary, it has been identified that issues surrounding piling, EMF effects of cables, the effects of flow alteration, and the way in which large organisms behave near devices, as well as surveying and monitoring techniques will be highly transferable across technologies and countries. Co-location of devices could also allow cost reductions, reducing the need for completing multiple EIAs for separate sites.

## Time Evolution of Priorities

It is important to prioritise issues according to how critical they are to the development of the industry. These issues will change as the industry develops, and are different across the offshore wind and the ocean energy sectors, largely due their different stages of development. The wave and tidal energy sectors are currently in the relatively early stages of development where the only deployments are prototypes undergoing testing, whereas the offshore wind sector is at a later stage of development, with some very large (> 100 MW) wind farms already in existence. As the sectors develop, changing technologies and methods, the move to new development sites (such as deeper waters and sites further from shore), and the increasing importance of cumulative effects will govern how the priority of environmental issues will evolve. In the initial stages of development, the environmental effects will be principally related to individual devices. However as the sectors reach the later stages of development (and the energy extracted becomes a significant fraction of the energy in the winds and the oceans), cumulative impacts will become progressively more significant, particularly for the wave and tidal stream sectors which will have significant cumulative impacts in terms of flow alteration, sedimentation etc.

## *Environment, Regulation & Legislation Recommendations*

**The ORECCA roadmap recommends that EU and member state administrations**

1. **Harmonise legislation and regulation across Europe, as far as practical.**
2. **Focus research into the environmental impacts of offshore renewable energy devices into seven priority areas** set out in this roadmap, including cumulative effects, EMF effects of sub-sea cables, flow alteration, sedimentation and habitat change near devices and mitigating actions for the effects of piling.
3. **Implement streamlined one-stop-shop marine consenting systems for countries which haven't already implemented these.**
4. **Develop Maritime spatial plans in countries where these are not already in place.**
5. **Conduct an SEA in each country, for each of the three technologies**, preceding commercial-scale development.
6. **Ensure that appropriate national authorities issue guidance necessary to ensure compliance with current legislation and regulation.** This includes ensuring that EIA requirements are clearly defined and communicated to developers.
7. **Encourage and facilitate developers and authorities to share experiences on EIAs** and develop mechanisms to avoid commercial issues over information sharing.
8. **Promote and encourage an "adaptive management" or "deploy and monitor" approach** and ensure that this is facilitated within legislation and regulation. This approach allows valuable learning by implementing.
9. **Ensure that legislation and regulation evolve and anticipate the growth and trends of the industry, such that the industry has foreknowledge of the requirements facing them.** This includes ensuring that there is recognition that scientific understanding is incomplete and therefore protocols may require alteration as understanding improves.
10. **Consider competing pressures** (such as climate change, fishing and marine transport) **when assessing environmental impacts of developments.** There should be recognition that the positive impacts of developments might outweigh some localised environmental impacts.
11. **Encourage the use of test sites for demonstration and development as an important opportunity to investigate potential environmental impacts** and further increase understanding of environmental issues. Test centres should have a comprehensive environmental baseline and EIA in place to allow them to become not only R&D centres for devices, but also for environmental effects.

# Contents

**Key to the ORECCA Roadmap:**

To aid visual clarity, a consistent colour scheme has been utilised throughout the roadmap, with three distinct types of coloured boxes:

**A purple colour scheme is used where important figures are included.**

**A red colour scheme is used where key points are highlighted.**

**A grey colour scheme is used where key policy recommendations are made.**

# 2 Introduction

## *2.1 Introduction to the ORECCA project and scope of the roadmap*

The ORECCA (Offshore Renewable Energy Conversion Platform Coordination Action) Project is an EU FP7 funded collaborative project in the offshore renewable energy sector. The project's principal aim is to overcome the fragmentation of know how available in Europe and its transfer amongst research organisations, industry stakeholders and policy makers stimulating these communities to take the necessary steps to foster the development of the offshore renewable energy sector in an environmentally sustainable way. The project's focus is pan-European and pan-technology, with a specific focus on revealing the opportunities that exist across Europe when the three offshore renewable energy sectors within the project's scope are considered together. Within the ORECCA Project, the scope of the offshore renewable energy sector ('offshore renewables') was confined to:

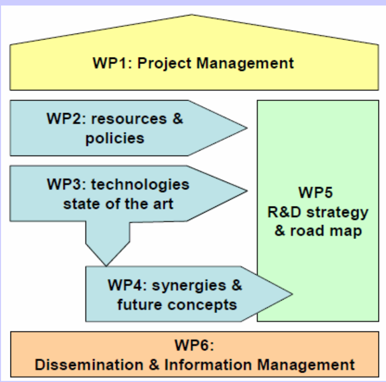
- **Offshore wind;**
- **Wave energy; and**
- **Tidal stream.**

- These energy sectors have been identified as those that are currently expected to make significant contributions to the energy system in the medium to long term. As a result, other sectors, such as tidal barrage and ocean thermal energy conversion (OTEC) were not covered in the scope of the project.

Whilst significant other research has been done in the offshore wind energy sector and in the ocean energy sector (defined as wave energy and tidal stream), the ORECCA project adds value to these by its unique focus on the opportunities and barriers to development that are revealed when the sectors are investigated together in a pan-technology and pan-European context. Whilst roadmaps have been developed for both the offshore wind sector, and for the ocean energy sector (as illustrated in Appendix 1), this roadmap represents the first time that a combined roadmap has been developed.

The ORECCA Project brings together a combination of world class experts from a wide variety of multinational companies, research institutions, consultancies, utilities and project developers. The project also draws upon interactions with other important offshore renewable energy programmes such as the EU funded MARINA project and the UK Supergen Marine programme. The project is divided into 6 principal work packages, as set out in figure 1 below.

**Six work packages (WPs) of the ORECCA project:**




| | |
|---|---|
| Work package 1: | **Project management;** |
| Work package 2: | **Resources and policies;** |
| Work package 3: | **Technologies state of the art;** |
| Work package 4: | **Synergies and future concepts;** |
| Work package 5: | **R&D strategy and roadmap;** |
| Work package 6: | **Knowledge management and dissemination.** |

**Figure 1:** Diagram showing the 6 work packages of the ORECCA project and how they are interlinked.

As illustrated in figure 1 above, each of the work packages (especially work packages 2,3 and 4) feed directly into this roadmap for the development of the sector. Each of the individual work packages produced comprehensive and detailed reports on their subject areas. The information in these reports provided the foundation for the production of this roadmap. The work package reports are referenced throughout, but can all be found (along with other information on the project) on the ORECCA website: www.orecca.eu.

The roadmap will provide a high level route forward for the offshore renewable energy sector, and it will be a useful tool to identify opportunities and synergies and help make strategic decisions. The Roadmap is written by the offshore renewable sector for all relevant stakeholders. As the principal decision makers for many of the actions identified to progress the sector, the principal target audience of the recommendations and actions are policy makers at the EU and Member State level. However, the recommendations and the way forwards for the sector are also of high importance for other stakeholders to the offshore renewable energy sector, including researchers, consultants, utilities, project developers, technology developers, investors, and the supply chain.

## What will the roadmap cover?

The roadmap is divided into 10 sections. The first 4 chapters serve an introductory capacity. The vision of the roadmap will be set out, followed by an introduction to the offshore renewable energy sector to set the roadmap in context. The current state of the sector in 2011 in terms of installed capacity and capacity in the pipeline will be presented, followed by the targets that have been set out for 2050 at a European and International level. This introduction will be concluded by presenting a deployment timeline for both ocean energy and offshore wind, to illustrate the stage of development of each sector and which stages they need to move through to reach their targets.

These preliminary sections lay a firm foundation for the core of the roadmap (chapters 5-9) where the opportunities and barriers for the sectors are identified and key recommendations are made. The opportunities and the barriers to development are clustered around five principal themes which are illustrated in figure 2 below and each have a dedicated chapter.

**Five principal streams of the ORECCA roadmap:**

1. **Resource**
2. **Finance**
3. **Technology**
4. **Infrastructure**
5. **Environment, Regulation and Legislation**

**Figure 2:** The roadmap's 5 principal streams.

Each of the roadmap's core chapters, each focussed on one of the principal streams in figure 2, sets out key recommendations and actions needed to assist the strategic development of an integrated EU offshore renewable energy sector. These actions and recommendations are brought together in the final chapter of the roadmap (chapter 10) which forms the conclusion to the roadmap.

## 2.2 *Vision and Opportunity*

**The vision of the ORECCA Roadmap is to** guide policy makers to support the accelerated development of the offshore renewable energy sector (offshore wind, wave and tidal energy) in Europe:

- to identify synergies;
- to overcome barriers to development;
- to realise the large opportunities presented (important benefits include increased energy security, carbon savings, and economic benefits such as job creation);
- to facilitate significant, cost effective commercial scale deployments by 2030; and
- to do all of this in an environmentally sustainable way.

**Figure 3:** Vision statement of the ORECCA Roadmap.

# 3 Introduction to Offshore Renewable Energy Sector

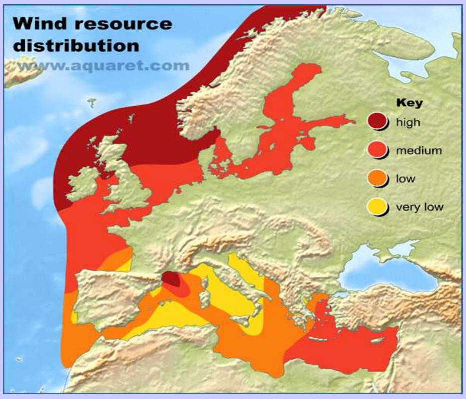
The offshore renewable energy sector as discussed in this roadmap includes offshore wind, wave energy and tidal stream. These technologies are at various stages of maturity with offshore wind more advanced than wave or tidal energy. There are commercial developments of offshore wind in many European locations with increasing levels of installed capacity each year. Ocean energy is at an earlier stage of development with prototypes being tested and demonstration projects underway across Europe.

EU member states play critical international roles in the development and deployment of these offshore renewable energy technologies. With high levels of offshore resources, strong research and development capabilities as well as industry and investment opportunities, the EU is well placed to continue its strategic involvement and importance in the offshore renewable energy sector.

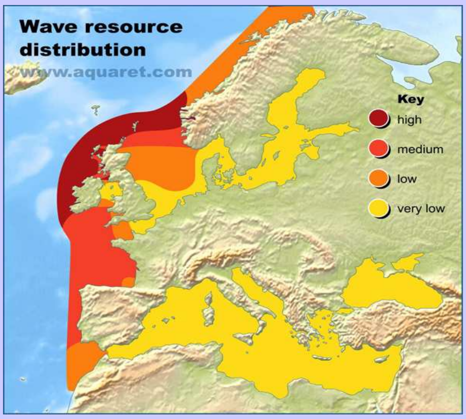
## *3.1 European resource in the offshore renewable energy sector*

Europe is blessed with a large amount of natural resource across the offshore wind, wave and tidal stream sectors. This will be considered in detail later in the roadmap, but it is important to consider how much resource exists in the sector in order to provide context for why the roadmap, and ultimately accelerating the development of the sectors, is important. The large amount of resource which exists is displayed in figure 4 below, and these graphs are illustrative of the large opportunity which the sectors present in Europe.

**European offshore renewable energy resources:**




Map showing the offshore wind resource which exists across Europe.




Map showing the wave energy resource which exists across Europe.

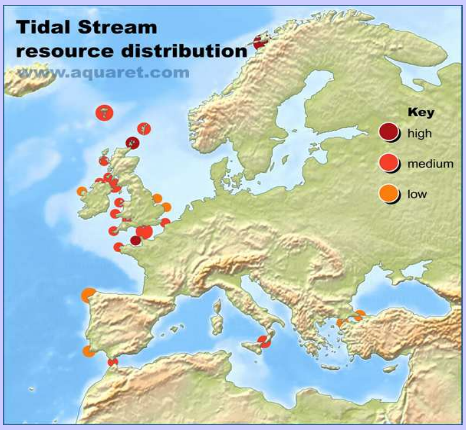
| | |
|---|---|
|  | Map showing the tidal stream energy resource which exists across Europe. |

**Figure 4:** Resource maps showing the offshore wind, wave and tidal stream resources which exist across Europe. Source: AQUARET Project; Available at: www.aquaret.com

From figure 4 above, it is clear that a large amount of offshore renewable energy resources exist in the seas surrounding Europe. The distribution of resource across offshore wind, wave and tidal energy is however, very different. For example, off the West coasts of Scotland and Ireland, both the offshore wind resource and the wave resource are high, but in the Mediterranean Sea, there is a very low wave resource despite the fact that some areas have medium and even high wind resources.

These intricate differences between the distribution of offshore wind, wave and tidal stream resources across Europe are the fundamental reason behind the approach taken in this Roadmap, which is principally focussed on assessing the three sectors together to reveal where opportunities exist.

## *3.2 Technologies in the offshore renewable energy sector*

For all three of the sectors considered in this roadmap, there are a number of different designs and devices which currently exist or are being developed:

- In the **offshore wind** sector, there is a large amount of design consensus around large horizontal axis turbines with fixed foundations. However, devices with fixed foundations are not suitable for the deep water deployments where a large amount of Europe’s offshore resource exists, and therefore designs such as floating wind turbines will have to be further developed over the coming years.
- For the **tidal stream** energy sector a reasonable amount of design consensus exists around horizontal axis turbines. However, there are still a large number of different devices under various stages of development within the sector and these have a variety of different blade types, foundations etc.
- Finally, the **wave energy** sector exhibits the least design consensus. There are a large number of different devices at various stages of development, based around a number of different principles. Types of device include, amongst others, those based on overtopping, point absorbers, attenuators, and oscillating water columns.

Despite the large number of different devices and types of devices which currently exist in the offshore renewable energy sectors, in the following section, the roadmap will present one example device from each of the three sectors. These three example technologies are presented in figures 5, 6 and 7 below.

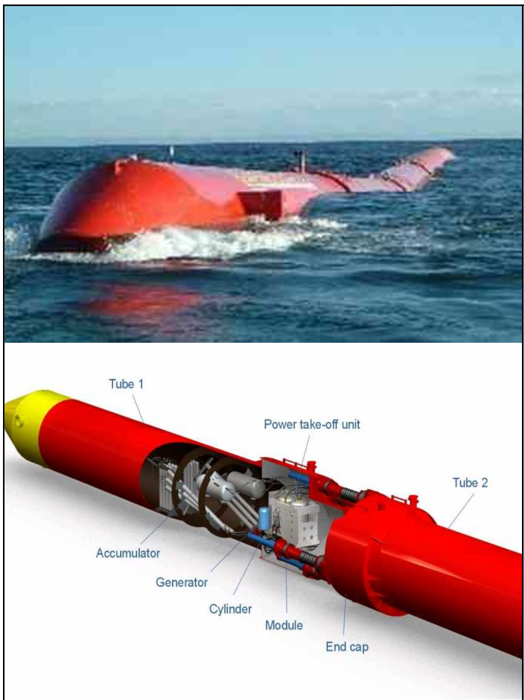
## Offshore wind energy sector:

- **Company:** Statoil
- **Technology:** Floating wind turbine.
- **Nameplate Capacity:** 2.3 MW
- **Stage of Development:** Full scale prototype under testing.

The device extracts energy from moving airflows in the same way as a fixed foundation onshore or offshore wind turbine. However, the wind turbine is based on a floating platform. The floating structure consists of a steel cylinder filled with a ballast of water and rocks. It extends 100 metres beneath the sea's surface and is attached to the seabed by a three-point mooring spread. The device is 65m high with a rotor diameter of 82m, and is designed for use in water depths of between 120 and 700m.

**Figure 5:** Example of an offshore wind energy device; the Hywind device, developed by Statoil (Photo: Trude Refsahl / Statoil; Illustration: Still shot from animation: Hywind assembly) www.statoil.com

## Wave energy sector:




- **Company:** Pelamis Wave Power Ltd.
- **Technology:** Attenuating wave energy converter.
- **Nameplate Capacity:** 0.75 MW (Pelamis P2 device).
- **Stage of Development:** Multiple full scale devices under testing.

The device sits on the surface of the water, comprising a number of cylindrical sections joined together by hinged joints. As waves pass down the length of the machine these sections flex relative to one another and hydraulic cylinders at each joint convert this energy into electricity. The device is designed to operate in water depths greater than 50m, usually 2-10km from the coast.

**Figure 6:** Example of a wave energy conversion device; the Pelamis device, developed by Pelamis Wave Power Ltd. (Photo & Diagran: Pelamis Wave Power Ltd.). www.pelamiswave.com

**Tidal stream energy sector:**

- **Company:** Marine Current Turbines.
- **Technology:** Horizontal axis tidal turbine.
- **Nameplate Capacity:** 1.2 MW (Strangford Lough device)
- **Stage of Development:** Commercial scale, grid connected 2nd generation device.

The turbines are deployed in areas with a high intensity tidal stream resource. The device has two submerged horizontal axis turbines which extract energy from the water which flows past it. The rotor blades can be pitched through 180 degrees so that the rotor can run efficiently in a bi-directional flow (on both the ebb and the flood tides) The device is designed for open ocean deployment in the harshest environments.

**Figure 7:** Example of a tidal stream energy conversion device; the Marine Current Turbines SeaGen device. (Source: Marine Current Turbines). www.marineturbines.com

**Combined Platforms:**

In the short term, due to the relative immaturity of offshore renewable energy technologies (particularly wave and tidal technologies), it is generally seen as too early to deploy combined platforms, with a single structure exploiting natural resource from multiple sources (eg. a wind-wave device). However, combined platforms present a large opportunity for the sector in the medium term, once significant amounts of research and modelling to understand the complex interactions for combined platforms is completed. Despite the current immaturity of combined platforms, co-location of devices could realise significant benefits, particularly with respect to infrastructure, and contribute to reducing costs in the sector. Therefore, throughout the roadmap, when investigating the synergies which exist between the offshore wind, wave and tidal stream sectors, and when investigating the areas where combined natural resource exists, the focus of the roadmap will be on the benefits of co-location. In the longer term, combined platforms should not be ignored, but the immediate opportunities for the sector, for example synergies with respect to shared infrastructure, remain focussed on co-location. Co-location, particularly with respect to the benefits of shared infrastructure, is discussed further in the Infrastructure chapter.

## *3.3 Timescales for accelerating the deployment of the offshore renewable energy sector*

When considering the timeline over which it is possible to accelerate the deployment of the offshore renewable energy sectors, it is important to consider two principal aspects:

1. Where is the sector now? - The current level of installed capacity and the amount of capacity currently in the pipeline (planned or under construction but not currently operational); and

2. Where is the sector going? - Existing deployment targets for the sector, set out by different stakeholders;

These aspects are considered in the following sections and are then used to construct a deployment timeline for the sectors to illustrate what stage of development the sector is currently at, and which stages it needs to move through as its deployment is accelerated.

### *Current installed and pipeline capacity in Europe:*

It is important to note that the installed capacity of Ocean energy in Europe is negligible. The sector is currently at an early stage of development, and no commercial farm scale deployments currently exist. The amount of capacity in the pipeline for the ocean energy sector is also small. There is approximately 1800 MW capacity in the pipeline by 2020 in the UK, but for the rest of Europe combined, the capacity in the pipeline is less than 50 MW. However, it is possible and useful to consider the current and pipeline installed capacity for the offshore wind sector, and this is illustrated in figure 8 below.

**Current and pipeline offshore wind installed capacity in Europe:**

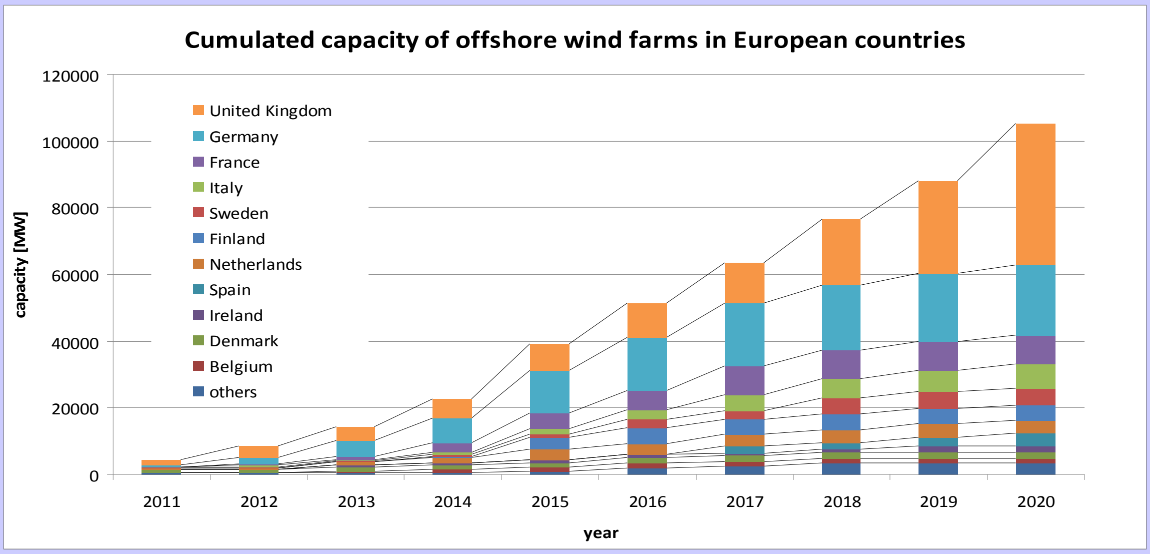



**Figure 8:** Cumulated capacity of all current and pipeline offshore wind installed capacity in Europe. (Source: Fraunhofer IWES).

### *Current deployment targets/aspirations:*

The ORECCA project doesn't set out deployment targets for the offshore renewable energy sector *per se*, rather, it works within the forecasted targets in terms of future installed capacity that have been developed by other organisations. Many organisations have set out deployment targets for the sectors at national, regional, and international levels. The ORECCA roadmap aims to align itself with existing targets and address barriers to achieving these targets.

## Deployment targets at the European level:

The European Wind Energy Association (EWEA) has set out targets for the offshore wind sector to achieve an installed capacity in Europe of 40 GW by 2020 and 460 GW by 2050 [1]. Similarly, the European Ocean Energy Association (EU OEA) have set targets for the ocean energy sector to achieve 3.6 GW in Europe by 2020 and 188 GW by 2050 [2].

It is estimated that these targets could result in the creation of 450,000 jobs by 2050 to meet the ocean energy targets[2] and approximately 300,000 jobs to meet the offshore wind targets[1].

## Deployment targets at the Global level:

The IEA have set out targets for the offshore wind sector to reach a global installed capacity of approximately 1150 GW by 2050[3]. The IEA have also set out targets for the ocean energy sector to achieve an installed capacity internationally of 180 GW by 2030 and 748 GW by 2050[4]. IEA also estimate that, internationally, to meet the 180 GW 2030 target alone will require the creation of 160,000 jobs.

The international and European level 2050 targets for both the offshore wind and the ocean energy sectors are illustrated in figure 9 below. NB. For the ocean energy targets, the EU OEA and the IEA define the scope of the ocean energy sector differently. However, the principal contributors to these targets are wave and tidal stream, therefore it is justified to compare them.

**2050 Targets for the offshore wind and ocean energy sectors:**

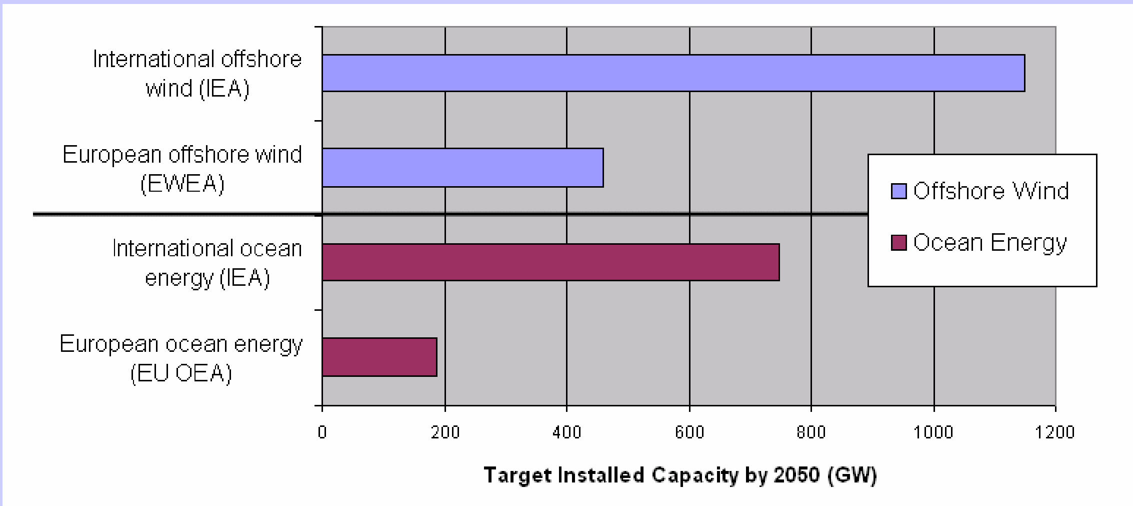



**Figure 9:** Graph showing the different European and International level targets set out for the offshore wind and ocean energy sectors, by the IEA, EWEA and the EU OEA.

There are two important points to highlight from figure 9 above, which presents the International and European level 2050 targets for the offshore wind and ocean energy sectors:

- The offshore wind targets are higher than the ocean energy targets at both the international and European level. This is due to the fact that the ocean energy sectors

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[1] EWEA (2011) Pure Power III: Wind Energy Targets for 2020 and 2030
[2] EU OEA (2010) Oceans of Energy: European Ocean Energy Roadmap 2010-2050.
[3] BLUE Map high scenario in IEA (2010) World Energy Outlook.
[4] Greenpeace Advanced Energy [R]evolution scenario, as referenced by the IEA.

are currently at an earlier stage of development than the offshore wind sector, and it will take longer to achieve large scale commercial deployments.

- A large portion of the global targets will have to be met by deployments outside of Europe. This represents an important market and opportunity for the sectors, which are currently heavily concentrated in Europe, to export technology and expertise worldwide.

### *Deployment timeline for the offshore renewable energy sector*

It is important to consider a deployment timeline for the two sectors (offshore wind and ocean energy), based on the current state of the industry and the deployment targets outlined above. Graphically, the projected deployment timeline for the offshore wind and ocean energy sectors is displayed in figure 10 below. It is clear from the figure that the ocean energy sector (wave and tidal) is at a lower level of maturity than the more mature offshore wind sector.

**<u>Projected offshore renewable energy deployment timeline:</u>**

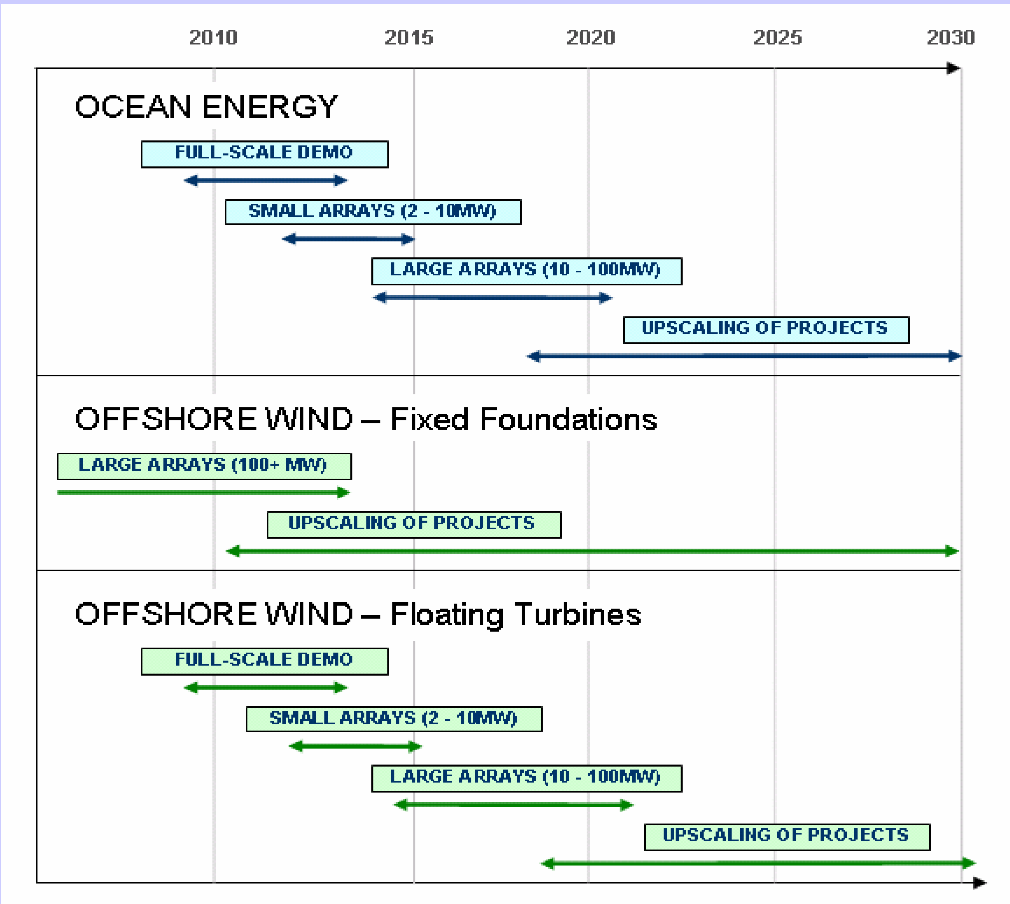



**Figure 10:** Projected deployment timelines for the ocean energy (wave and tidal stream) and offshore wind sectors. (Source: adapted from the UK Department for Energy and Climate Change (DECC) Marine Energy Action Plan 2010 [5]).

[5] http://www.decc.gov.uk/assets/decc/What%20we%20do/UK%20energy%20supply/Energy%20mix/Renewable%20energy/explained/wave_tidal/1_20100317102353_e_@@_MarineActionPlan.pdf

# 4 Roadmap Structure & Methodology

This roadmap was developed through three sector workshops and a comprehensive review process to ensure that input was obtained from a wide range of European stakeholders to the sector. The stakeholders included in the development of the roadmap encompass a wide range of experts in fields which span all of the roadmap's five key themes, illustrated in Figure 11 below. A broad investigation of the future potential and current status of implementation of offshore renewable energy solutions and their associated policy and regulatory frameworks was undertaken in the other work packages and the roadmap integrates these together.

The roadmap is structured around five key elements – illustrated in figure 11 below – which are essential to the development of the offshore renewable energy sector. The main challenges faced by the sector are clustered around these key themes, each of which is briefly described in the following section.

**Five principal aspects of the roadmap:**

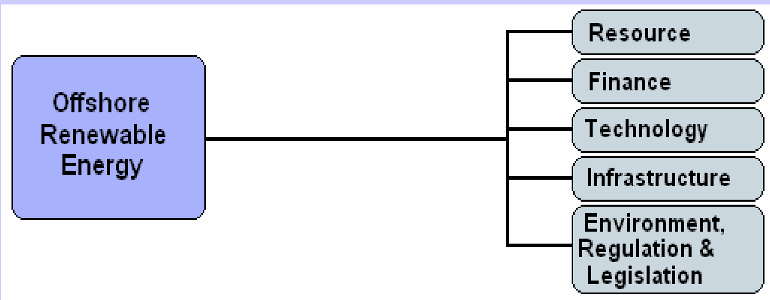



**Figure 11:** Diagram showing the structure of the ORECCA roadmap, with five principal streams.

It is useful to briefly outline what will be included in each of the roadmap's five key chapters:

- **Resource:** this section of the roadmap contains an illustration of where the natural resources exist in Europe across offshore wind, wave and tidal, and where the areas of combined resource exist. Identifying areas where resource exists and areas where synergies exist between offshore wind, wave and tidal resources is important to reveal where the opportunities for the sector lie. This section firmly underpins all the other sections of the roadmap.

- **Finance:** this analysis is focussed on revealing where gaps in the current funding landscape for the offshore renewable energy sector exist, and therefore where opportunities for the sector lie. The section concludes with key actions required to move development plans into action by reducing financial risk to investors to support the successful commercialisation and deployment of the sectors.

- **Technology:** the current state of the art for offshore wind, wave and tidal energy technologies is identified. Exploring not only established technologies but also innovative concepts and synergies, such as combined platforms, this section will also prioritise the sector needs in order to identify the critical actions required.

- **Infrastructure:** this section of the roadmap focuses on identifying synergies in the infrastructure requirements of offshore wind, wave and tidal. The section presents key actions required for the sector to capitalise on the 'hotspots' of offshore resource identified in the resource section.

- **Environment, Regulation and Legislation:** this section presents the current situation with regards to environmental impact assessments, consents and licensing processes across Europe. Key gaps, needs and required actions for the development of these areas are identified and presented.

Inter-linkages between the different key sections of the roadmap are important and are highlighted throughout the roadmap. It is essential to reiterate the importance of examining each of the roadmap's five key streams whilst maintaining the context provided by the other four, ensuring a whole system approach, addressing barriers to the sector across all five key streams. For example, when analysing the funding opportunities or the infrastructure in a given country, it is important to maintain the context provided by considering how much natural resource is available in the same country. If there are countries or regions with a large amount of natural resource, but without the necessary funding, legal or regulatory policies in place to facilitate its development and extraction, then clearly this presents a large opportunity for the sector.

This highlights how the resource chapter is pivotal to much of the rest of the roadmap. However, there are also important inter-linkages between the other sections of the roadmap. For example, any developments in technology which are required are also likely to require targeted funding and financing.

# 5 Resource

An important driver of any renewable energy developments is the underpinning natural resource availability. The level of resource which exists in a particular country or region is critical when considering the potential impact which a particular sector or technology can have. In this vein, this section of the roadmap will report where offshore wind, wave and tidal stream resources exist across Europe. An important facet of the ORECCA Project is that it will reveal not only the potential for individual resources in the target areas, but also the potential for combined resources, and key areas to explore for combined/co-located resources.

A high level understanding of the available resources across Europe has allowed the roadmap to highlight where opportunities for the offshore renewable energy sector exist. In line with the focus of the roadmap, these opportunities are identified across countries and across offshore wind, wave and tidal energy technologies. It is important to highlight that, as identified in the previous section, the resource analysis underpins many of the recommendations made and opportunities highlighted throughout the other sections of the roadmap. It is important to analyse the other aspects of the sector (finance, infrastructure, environmental concerns, legislation, and regulation) in the context of how the available resource is distributed across Europe and across the three technologies.

How much resource exists? Where does this resource exist? How far from shore is the resource? What water depth is the resource in? All of these questions are considered and reported in this section of the roadmap.

### *Europe's available resources divided between the offshore wind, wave and tidal sectors*

The breakdown of Europe's offshore resources across the three offshore renewable energy sectors is illustrated in figure 12 below.

**Europe's available resource divided across the three offshore renewable energy sectors:**

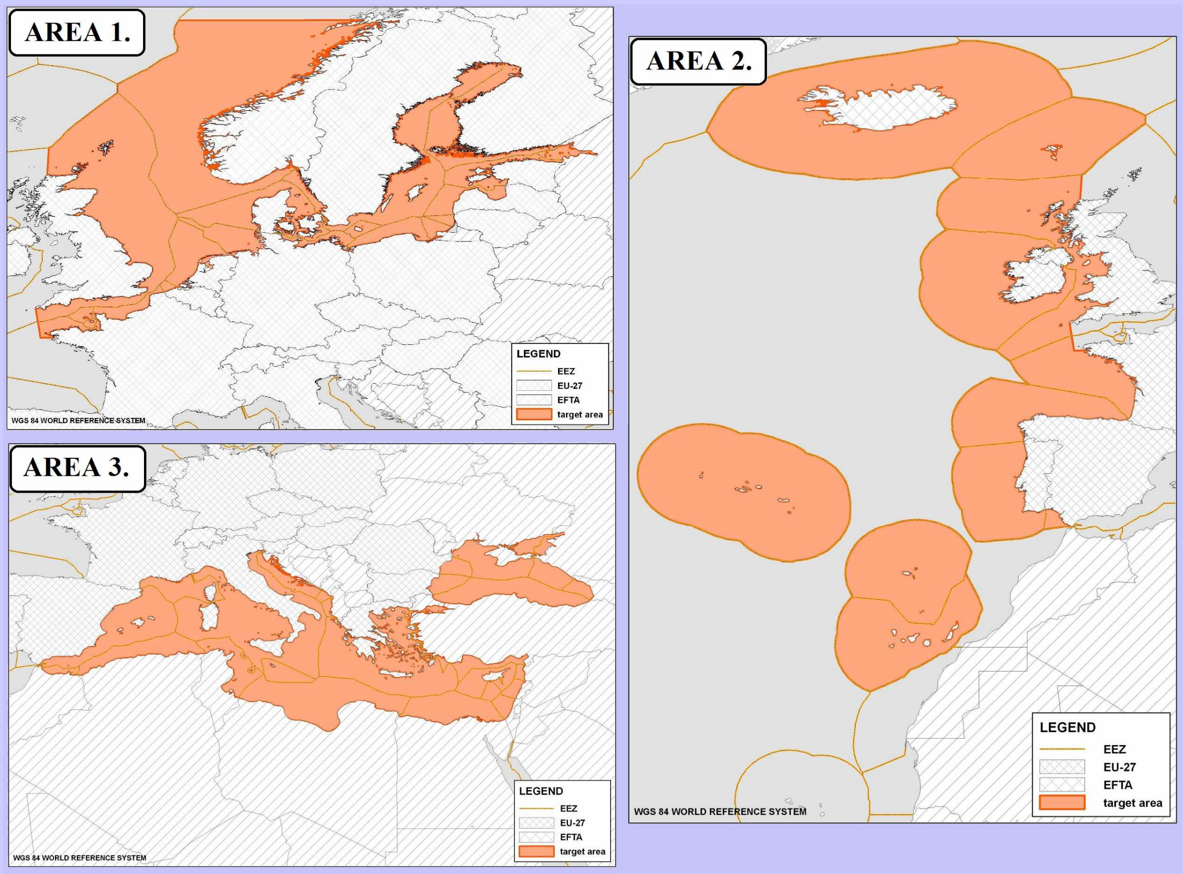

[Data from ORECCA WP2 Report: 'Investment and Grant Opportunities for Offshore Renewable Energy Projects in Europe'.]

**Figure 12:** Breakdown of the estimated available resource in Europe across offshore wind, wave and tidal.

For the analysis of the offshore renewable resource across Europe, the seas surrounding Europe were broken down into three broad regions, which are displayed in Figure 13 below:

- **AREA 1: North and Baltic Sea;**
- **AREA 2: Atlantic Ocean; and**
- **AREA 3: Mediterranean and Black Sea.**

**<u>Three broad regions the seas around Europe were divided into:</u>**



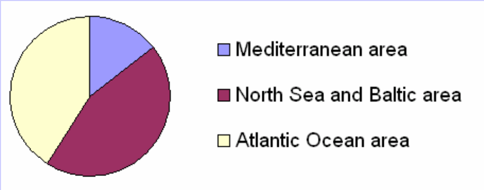

[Source: ORECCA WP2 Report: 'GIS Project & Calculations']

**Figure 13:** Maps showing the three areas which the seas around Europe were divided into.

### *Europe's available resources divided between the three geographical regions*

To maintain context before investigating each of the three geographical regions in turn, it is important to understand how the resource available across Europe is split across the three regions, and this is illustrated in Figure 14 below. This information is based on a large number of assumptions, but it is nevertheless important, and reveals that a large proportion of the available resource exists in the North Sea and Baltic and Atlantic Ocean regions, with only a limited amount of resource available in the Mediterranean and Black Sea area.

**How is Europe's available natural resource divided across the 3 regions?**




[Data calculated from the ORECCA GIS data presented in ORECCA WP2 Report: 'GIS Project & Calculations']

NB. For the purposes of this high level breakdown across the three geographic areas, a number of assumptions have been made. Tidal resource was excluded from the analysis which is solely calculated on wind and wave resource. It was assumed that 2.5% of the marine area suitable for resource exploitation could be occupied, and that a density of 15 MW installed capacity/$km^2$ could be achieved. These assumptions were then applied to all sea areas which satisfied the following criteria:

- Greater than 6m/s mean annual wind speed at 10m above sea level;
- Greater than 5 kW/m mean annual wave power.
- Between 25km and 200km from shore.
- Water depth of less than 500m.

**Figure 14:** Breakdown of the estimated available natural resource in Europe across the three defined regions.

### *Structure of this Resource section of the roadmap*

Each of the three geographical regions is analysed in turn. For each region, this analysis is structured around four principal aspects:

1. A combined resource map for the region, showing the areas where wind wave and tidal stream resources exist;
2. Analysis of the combined resource map, identifying areas where 'hotspots' of high intensity combined resource exist;
3. A bathymetry map of the geographical area showing how the sea depth varies over the regions where the resource exists;
4. Analysis of the resource identified by sea depth and distance from shore[6]. These two important factors are not displayed visually on the combined resource maps but have an extremely important impact and a clear inter-linkage with the other chapters of the roadmap.

### *Construction of the combined resource maps*

The combined resource maps for each of the three regions (Figures 16, 18 and 20 below) show the tidal stream resources overlaid on combined wind and wave resource maps which are constructed using the six scenarios outlined in figure 15 below[7]. **It is important to note that the resource maps show the resources that exist across Europe constrained by 500m maximum water depth and between 25km and 200km from shore.** These resource maps do not therefore represent the available resource for each country, which would include resources within 25km of shore as well as much further from shore and in greater water depths than

[6] The sea depth and distance from shore analysis is based on the outputs of the ORECCA GIS tool.
[7] It is important to highlight that there are many important factors (such as ports, offshore renewable plants currently operating or under construction, shipping lanes, marine protected areas, and centres of population) that have been omitted from the three combined offshore wind, wave and tidal stream resource graphs displayed in Figures 16,18, and 20 below. This is necessary to obtain a clear and informative visualisation of where combined resource exists.

500m. However, these constraints have been chosen[8] and are consistent across all regions and countries analysed. The data underpinning the combined resource maps is also consistent across Europe and therefore the resource data produced and displayed in the resource maps is consistent and directly comparable across regions and countries.

**Six scenarios used to construct the combined wind and wave resource maps:**

| | | Mean annual wind speed 10m above sea level (m/s) | Annual mean wave power (kW/m) |
|---|---|---|---|
| **Scenario 1** [Medium wind – low wave] | | 6 - 8 | 5 – 15 |
| **Scenario 2** [Medium wind – medium wave] | | 6 – 8 | 15 - 25 |
| **Scenario 3** [Medium wind – high wave] | | 6 - 8 | Greater than 25 |
| **Scenario 4** [High wind – low wave] | | Greater than 8 | 5 – 15 |
| **Scenario 5** [High wind – medium wave] | | Greater than 8 | 15 - 25 |
| **Scenario 6** [High wind – high wave] | | Greater than 8 | Greater than 25 |

**Figure 15:** The six scenarios used to construct the combined wind and wave resource maps upon which the tidal resources are overlaid to produce Figures 16, 18, and 20 below.

The areas where exploitable tidal resources exist are relatively limited in number but show high energy densities. Analysis revealed that tidal stream resources make the smallest contribution to the total offshore natural resource in Europe (as shown in figure 12 above). Therefore, focussing on areas of wind and wave combined resource is the most important overlap between the three technologies in terms of exploiting combined resources.

Exploiting combined wind and tidal resources is limited by the fact that 100% of the tidal sites identified are less than 20km from shore, a significant constraint for large wind turbines. Similarly, exploiting combined wave and tidal resources is limited by the fact that the geographic conditions necessary to produce sites with high intensity tidal stream resources are not conducive to wave developments. – However, this is not to say that there are not significant technology transfer and other synergies with the tidal stream sector.

**N.B. Tidal data in the combined resource maps:**

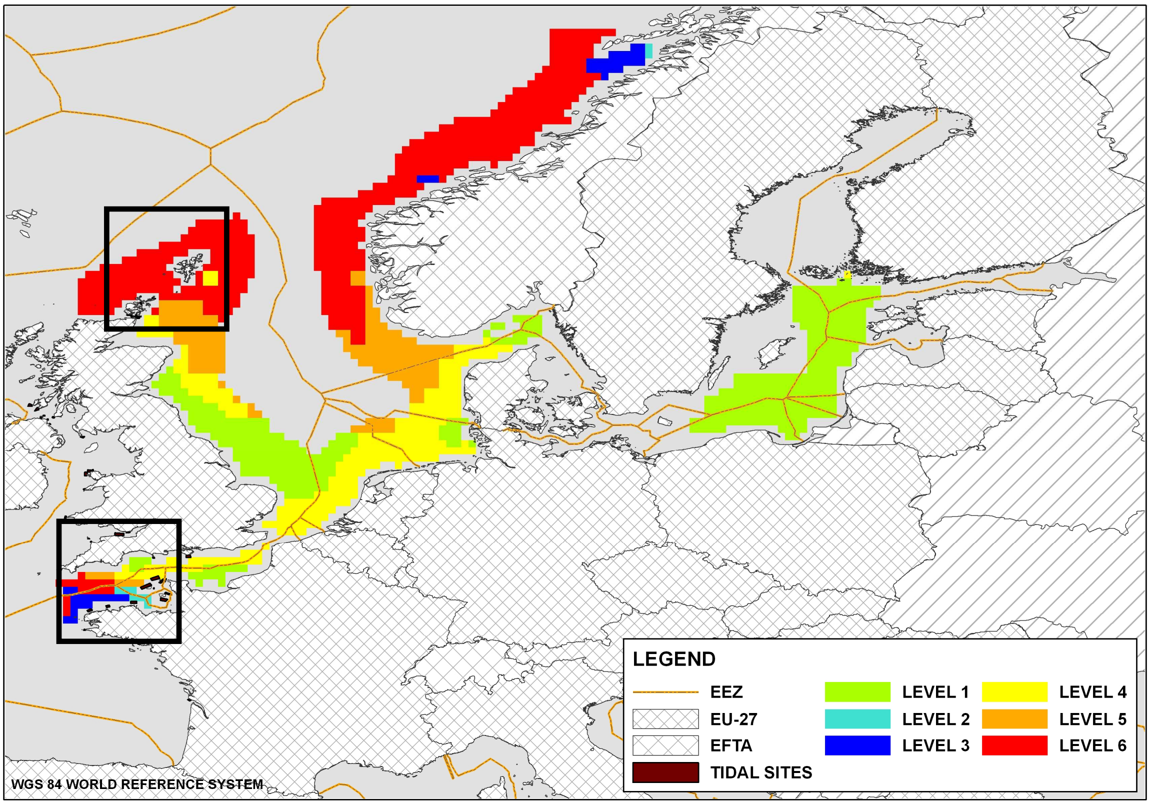
It is important to highlight that the data which underpins the tidal stream resource in the combined resource maps is different in nature to the data for the wind and wave resources. For the wind and wave resources, Europe wide grids of data are available. However, there is far less data available for tidal stream, and the data utilised is based upon measurements made at sites which have been identified as potential locations based on their geographic conditions.

[8] The 500m water depth and 200km from shore have been chosen as sensible limits to the resource which is potentially extractable in the medium to long term, and 25km from shore minimum constraint was chosen due to the resolution of the underpinning data.

## 5.1 AREA 1: North and Baltic Sea

The North and Baltic Sea area is bound by the coast of the Baltic Sea in the East, and by the Eastern and Southern coasts of the UK in the West, extending to the West end of the English Channel. The combined wind, wave and tidal resource map for the region is displayed in Figure 16 below.

**Combined wind, wave and tidal resource map for the North and Baltic Sea area:**



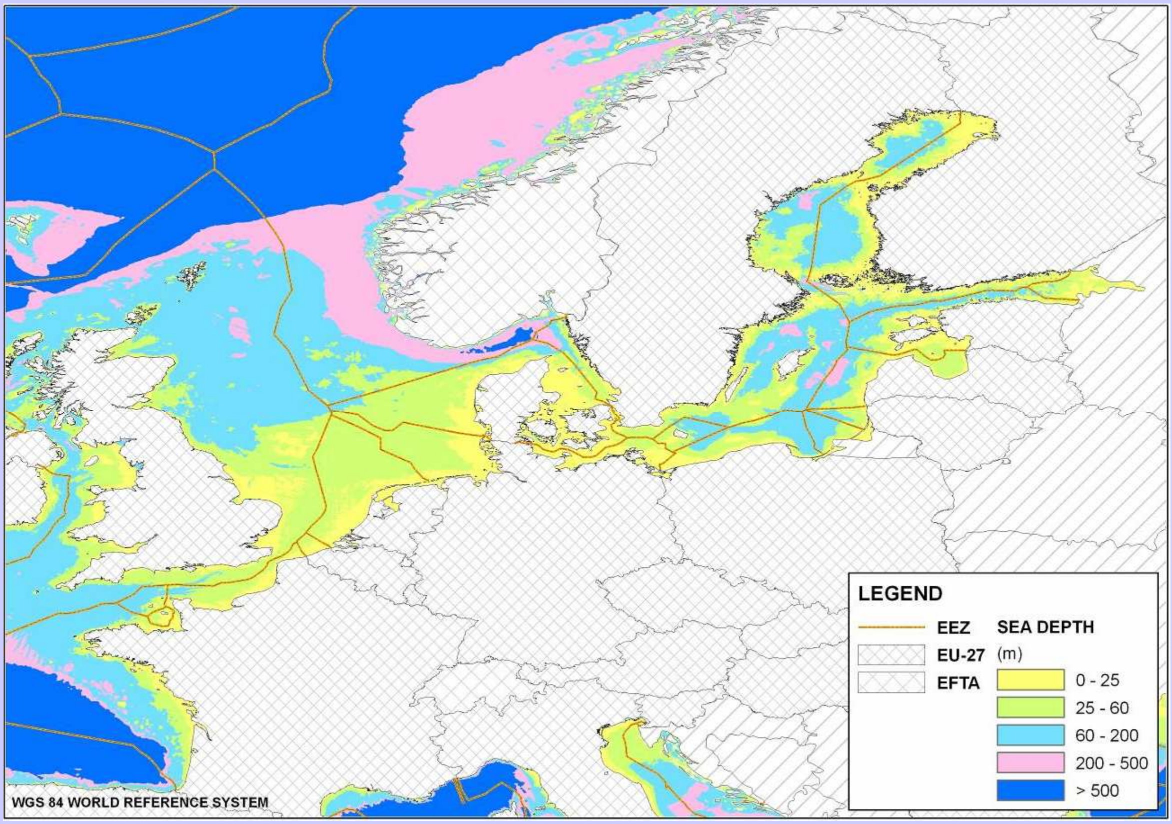

[Source: ORECCA WP2 Report: 'GIS Project & Calculations']

**Figure 16:** Resource map showing the combination of wind and wave resource, overlaid with the tidal resource, for the North and Baltic Sea area. NB. The black panes highlight where the tidal stream sites are located, as it is difficult to see them at this scale.

It is clear from figure 16 above that there is a high resource in the North Sea and Baltic area. The region has a large amount of tidal stream resource, almost entirely located in the Orkney and Pentland Firth regions in the North of Scotland. As well as this large tidal resource, it is evident from the figure that a large amount of combined wind and wave resource exists in the region. The combined wind and wave resource is the most intense in the Northern part of the region, as can be seen from the large concentration of scenario 5 and 6 classified areas, around the North East coast of the UK (particularly Scotland) and the North West coast of Norway. A large amount of less intense resource exists in the Southern part of the region. Overall, the area is extremely well endowed with combined wind and wave resource, and this presents a significant opportunity to the sector. The North Sea is already home to a large number of offshore wind farms, in various stages of development, and a large opportunity exists for further exploitation of the offshore wind resource, as well as high wave resources in the region.

The sea depth varies greatly within the North and Baltic Sea area. As can be seen in Figure 17 below, a large part of the Southern North Sea is in predominantly shallow water (less than 50m) due to the existence of a continental shelf. However, this is stark contrast to areas such as the North East part of the North Sea, off the coast of Norway, where there is no continental shelf, and the water is very deep, even within relatively close distances from shore.

**Sea depth in the North and Baltic Sea area:**




[Source: ORECCA WP2 Report: 'GIS Project & Calculations']

**Figure 17:** Bathymetry map showing sea depth throughout the North Sea and Baltic area.

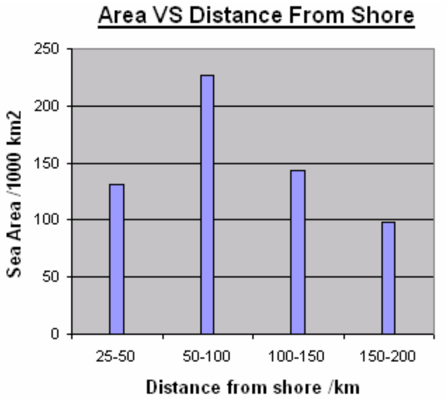
The combined wind and wave resource (illustrated in figure 16 above) which has been identified in the North and Baltic Sea region is analysed with respect to distance from shore and sea depth in the table on the following page.

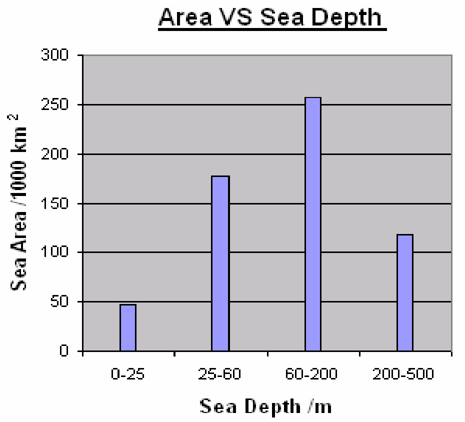
**SEA DEPTH AND DISTANCE FROM SHORE ANALYSIS – NORTH SEA AND BALTIC AREA**

In the North and Baltic Sea area, there is nearly 600,000 $km^2$ of sea surface area which was classified as one of the six scenarios developed by the project. To become classified as one of the six scenarios, an area must satisfy the following thresholds:

- Greater than 6m/s mean annual wind speed at 10m above sea level;
- Greater than 5 kW/m mean annual wave power.
- Between 25km and 200km from shore.
- Water depth of less than 500m.

The nearly 600,000$km^2$ of area in the North and Baltic Sea area which met these thresholds is analysed by distance from shore and sea depth in the two figures below.




As illustrated in the two figures above, approximately **40%** of the resource area is further than **100km** from shore, and over **60%** is in water depths of greater than **60m**

In the North Sea and Baltic area, it is therefore possible to extract energy from a proportion of the resources in the area utilising current technologies in terms of the feasible distances from shore and water depths. However, to exploit the large amounts of combined resource which exists in the area, it is clear that it will be necessary to develop technologies to facilitate deeper water and further offshore. Developing technologies to facilitate deployment in water depths of over 60m will increase the resource area which is potentially extractable by more than three-fold.

[Source: ORECCA WP2 Report: 'GIS Project & Calculations']

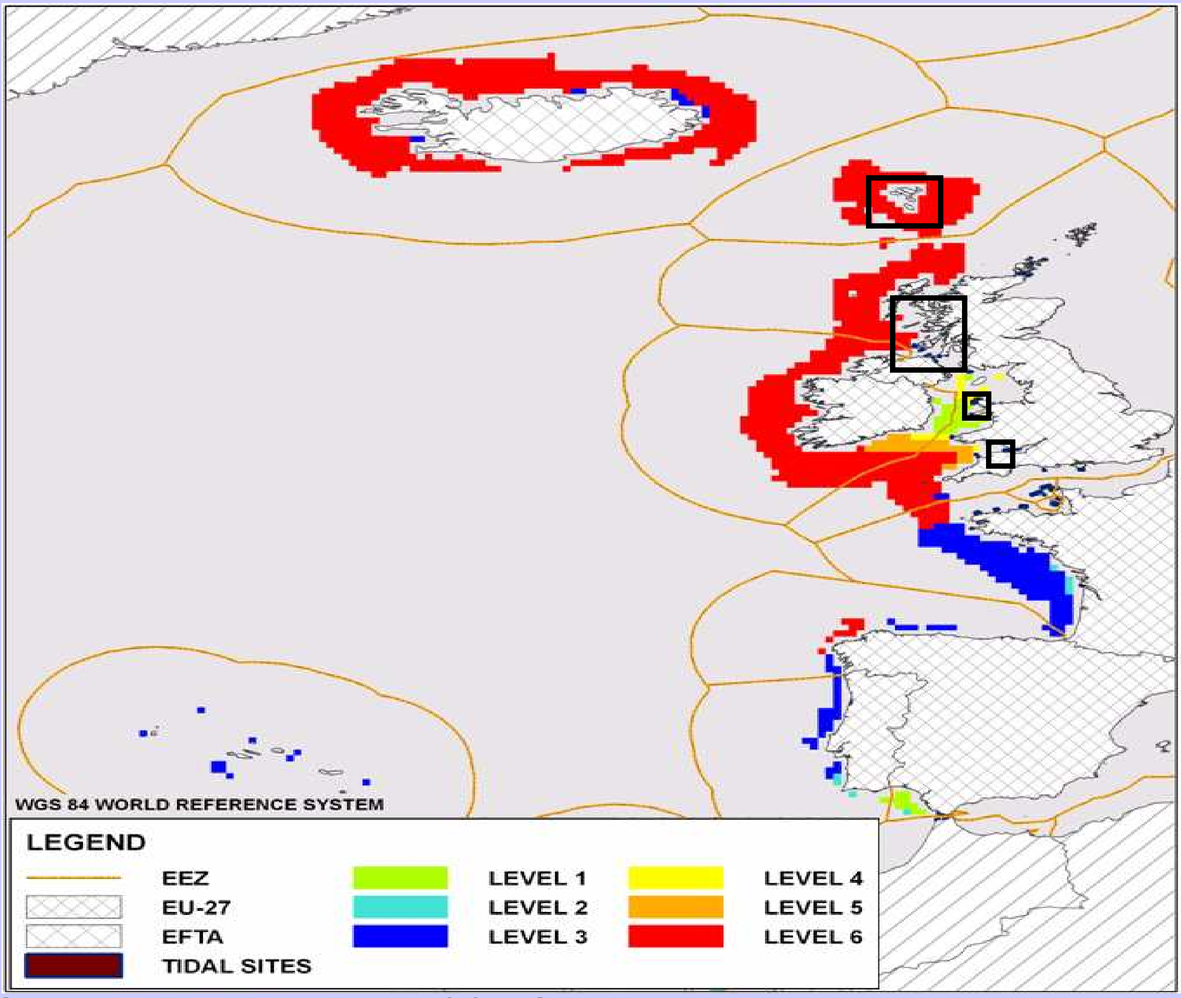
**<u>Important points to highlight for the North and Baltic Sea resource:</u>**

- Large amount of resource across offshore wind, wave and tidal, particularly concentrated in the Northern part of the North Sea, off the coasts of the UK and Norway.
- Approximately 40% of the resource area in the region is further than 100km from shore and approximately 60% lies in water depths of greater than 60m.

## 5.2 AREA 2: Atlantic Ocean

The Atlantic region extends from Iceland in the North and includes the Azores and Canary Islands in the South. The Irish Sea is also included in the region, but the English Channel (East of the Western tips of Southern England and Northern France) is not.

**Combined wind, wave and tidal resource map for the Atlantic Ocean area:**




[Source: ORECCA WP2 Report: 'GIS Project & Calculations']

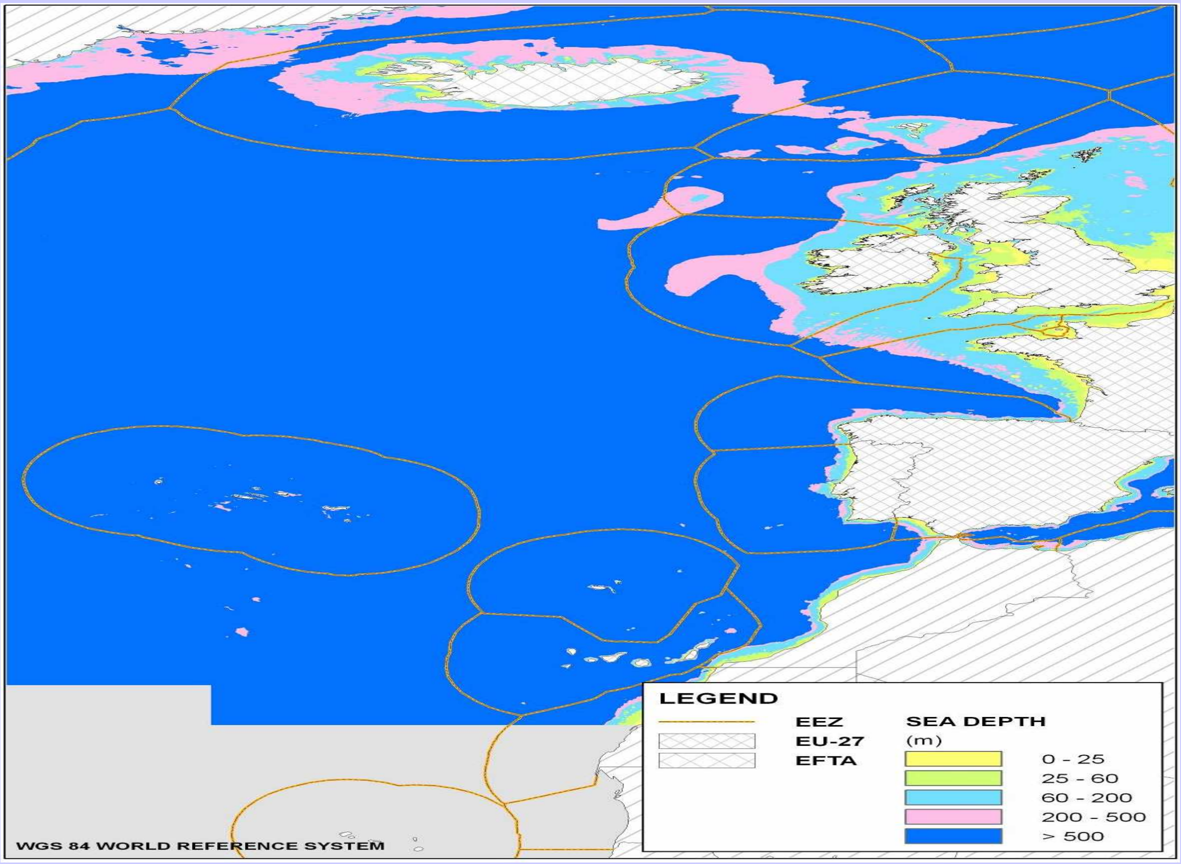
**Figure 18:** Resource map showing the combination of wind and wave resource, overlaid with the tidal resource, for the Atlantic area. NB. The black panes highlight where the tidal stream sites are located, as it is difficult to see them at this scale.

It is clear from figure 18 above that there is a high resource in the Atlantic Ocean area. The region has a large amount of tidal stream resource (concentrated off the coasts of Ireland, the UK and in particular, Scotland), as well as a large amount of combined wind and wave resource. The areas of the most intense combined wind and wave resource are in the North West of the region, as illustrated on the map by the high concentration of scenario 6 classified areas off the North and West coasts of Ireland and Scotland. A large amount of less intense resource exists in the Southern part of the region, off the West coasts of Southern UK, France, Spain and Portugal. Overall, a large amount of offshore wind, wave and tidal stream resource exists in the area and this presents a significant opportunity to the sector. There are multiple existing and planned test sites in wave (notably in Scotland, Ireland, Portugal, Spain, France, and England) and tidal energy (notably in Scotland and Northern Ireland) all along the Atlantic

Coast reflecting the resource in this region. However despite the high wind resource there are few offshore wind farms, with the exception of the Irish Sea, due in part to the extreme wave climate in the Atlantic and water depth greater than the fixed structures design depths. A large opportunity for further exploitation of all three resources exists in the region, particularly in the Northern part of the area.

Figure 19 below illustrates the sea depth across the Atlantic Ocean region.

**Sea depth in the Atlantic Ocean region:**




[Source: ORECCA WP2 Report: 'GIS Project & Calculations']

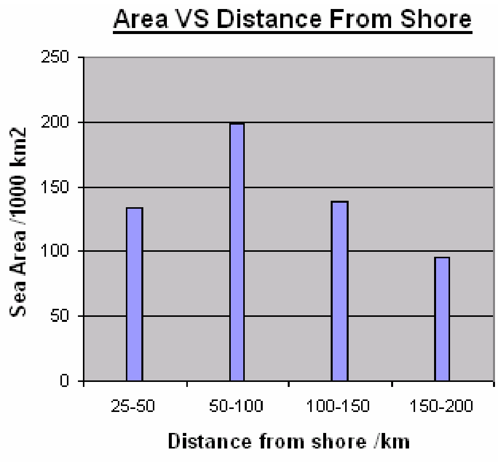
**Figure 19:** Bathymetry map showing the sea depth throughout the Atlantic Ocean area.

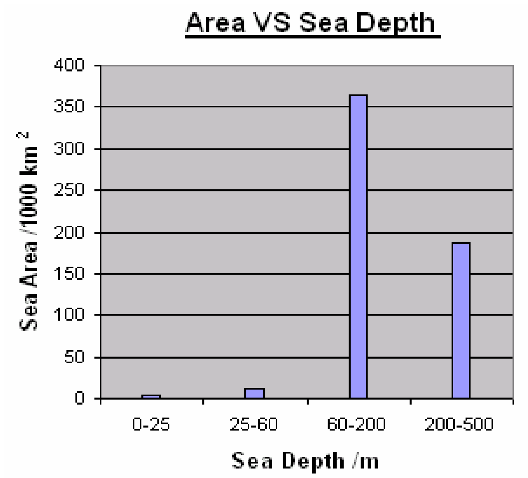
As can be seen in Figure 19 above, most of the Atlantic Ocean region is in relatively deep water. There is only a small amount of the region which is in water depths of less than 60m. In the Northern part of the region, off the coasts of Ireland, the UK and France, there is a continental shelf and therefore a reasonably constant water depth with the majority of the sea area in medium water depths of between 60m and 200m. However, as illustrated by the graph, the majority of the sea area in the South Atlantic, off the coasts of Spain and Portugal is in deep water of greater than 500m water depth, even within relatively close distances from shore. The areas with water depth suitable for fixed offshore structures i.e. less than 60m, is limited in this region with the exception of the French coast and the Irish Sea.

- The combined wind and wave resource (illustrated in figure 18 above) which has been identified in the Atlantic Ocean region is analysed with respect to distance from shore and sea depth in the table on the following page.

**SEA DEPTH AND DISTANCE FROM SHORE ANALYSIS – ATLANTIC OCEAN AREA**

In the Atlantic Ocean area, there is nearly 600,000 $km^2$ (similar to the amount in the North and Baltic Sea area) of sea surface area which was classified as one of the six scenarios developed by the project. This nearly 600,000$km^2$ of area which met the previously defined thresholds is analysed by distance from shore and sea depth in the two figures below.




Approximately **60%** of the resource area is further than **100km** from shore. Therefore deploying technologies to increase the possible distance from shore from 100km to 200km will more than double the area of resource which is potentially exploitable.

Approximately **97%** of resource area lies in water depths of greater than **60m**. Therefore to exploit the vast majority of the resources in the Atlantic region, technologies to facilitate deeper water deployments will be required. Increasing the maximum sea depth for which it is possible to deploy devices so that it is possible to deploy devices in any water depths will increase the resource area which is potentially exploitable by more than thirty-fold.

[Source: ORECCA WP2 Report: 'GIS Project & Calculations']

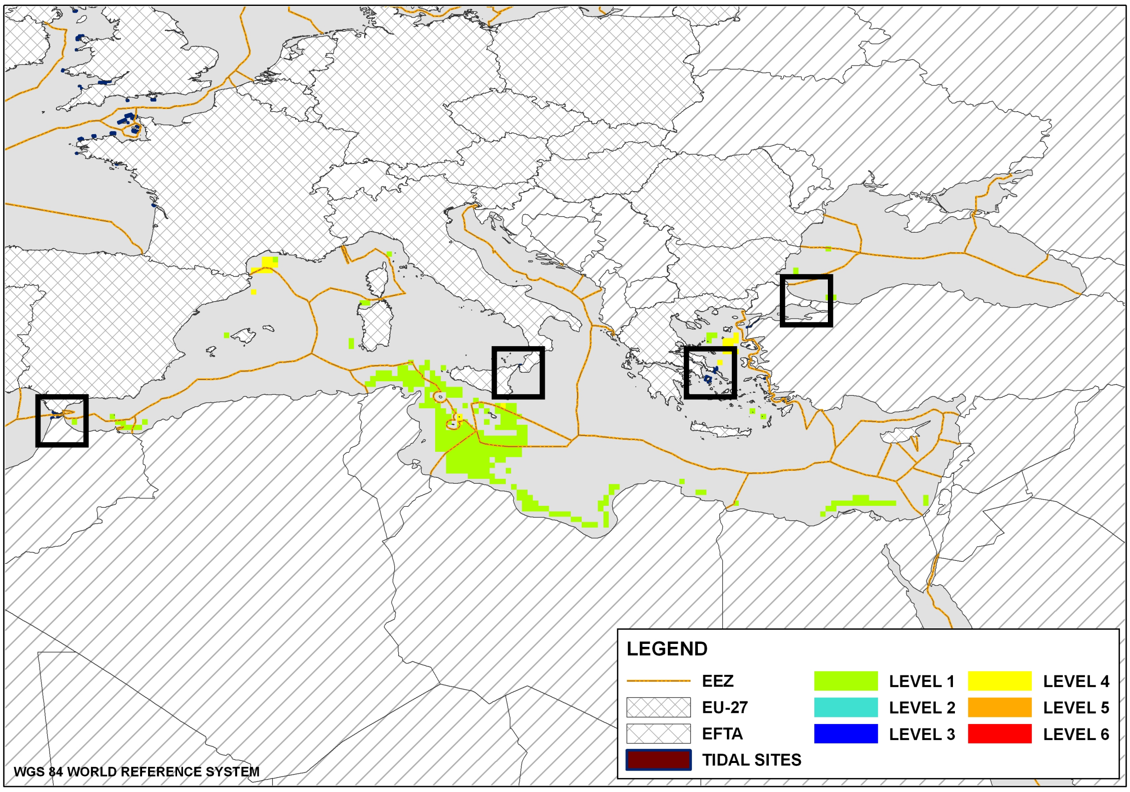
**Important points to highlight for the Atlantic Ocean resource:**

- Large amount of high intensity resource, across offshore wind, wave and tidal, particularly concentrated in the Northern part of the Atlantic region, off the coasts of Ireland, Scotland, the UK and France.
- Approximately 60% of the resource area in the region is further than 100km from shore and approximately 97% lies in water depths of greater than 60m. Therefore developing devices which can be deployed in water depths of greater than 60m will increase the potentially exploitable resource area by more than thirty-fold.

## 5.3 *AREA 3: Mediterranean and Black Sea*

The Mediterranean and Black Sea region extends from the Straits of Gibraltar in the East, to the Eastern edges of the Black Sea and Mediterranean basins in the East.

**Combined wind, wave and tidal resource map for the Mediterranean and Black Sea area:**




[Source: ORECCA WP2 Report: 'GIS Project & Calculations']

**Figure 20:** Resource map showing the combination of wind and wave resource, overlaid with the tidal resource, for the Mediterranean area. NB. The black panes highlight where the tidal stream sites are located, as it is difficult to see them at this scale.

As can be seen from figure 20 above, the amount of resource in the Mediterranean and Black Sea area is lower than for the other two regions investigated. Unlike the other two regions, the Mediterranean and Black Sea region has seen a very limited amount of development across the three sectors, and there is virtually zero current deployment of offshore wind, wave or tidal stream devices. The area has a very low wave energy resource with the highest average wave power in the region of approximately 6kW/m. Despite a moderate wind resource there is relatively little measured data for offshore wind in the Mediterranean and Black Seas, especially in the south of the Mediterranean.

Tidal stream resources exist in the area, but are limited primarily to the Straits of Messina, Bosphorous and Gibraltar. The combined wind and wave resources in the area are of a lower intensity than for the Atlantic and North Sea regions. There is no resource classified as the two highest intensity scenarios, 5 and 6. However, there is a reasonable amount of lower intensity combined wind and wave resource concentrated in a limited number of areas shown in Figure 20 above. Opportunities still exist for the development of the sector in the Mediterranean and

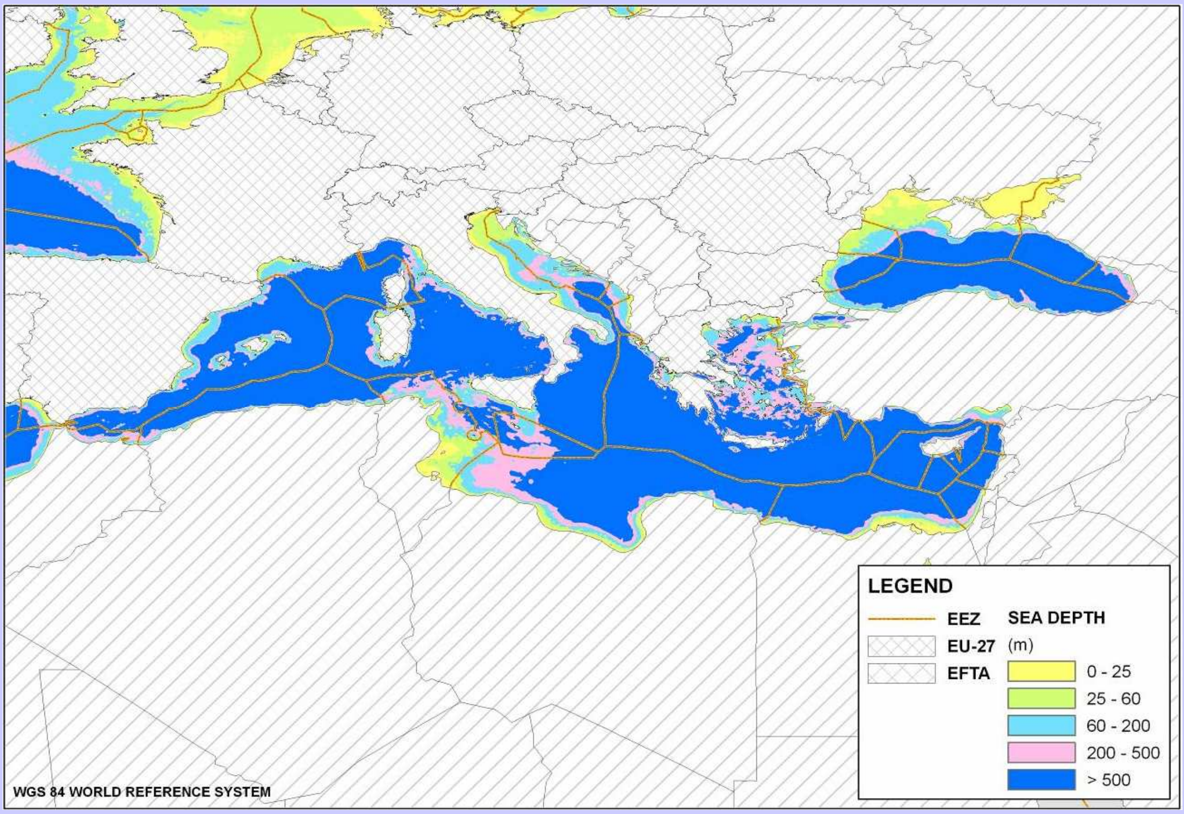
Black Sea area, however, it is important to note that the levels of resource (whilst still potentially exploitable) are not as high as in the other regions investigated.

There are however, two potential factors in the Mediterranean and Black Sea area which should not be ignored:

1. A moderate wind resource exists in the region, despite the fact that the wave resource is very low. Therefore, despite the fact that opportunities for combined resource are limited, the wave loading in the area will be much lower than for other areas analysed and this might mean that the area is well suited for test sites for developing new offshore wind technologies.
2. Although the resource in the area is of lower intensity, this is coupled with the fact that the environment is correspondingly less harsh and extreme. Therefore, devices (specifically designed for the characteristics of the area) could be designed to be smaller and lighter, and therefore cheaper.

Figure 21 below illustrates the water depths across the Mediterranean and Black Sea region.

**Sea depth in the Mediterranean and Black Sea area:**




[Source: ORECCA WP2 Report: 'GIS Project & Calculations']

**Figure 21:** Bathymetry map showing sea depth throughout the Mediterranean and Black Sea area.

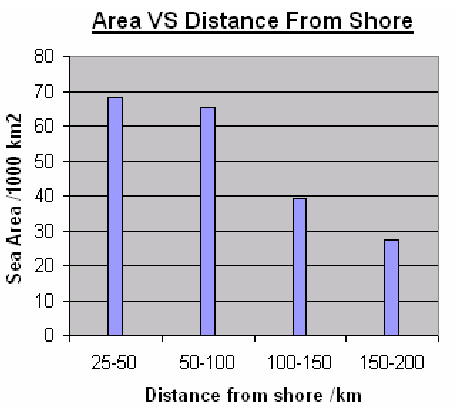
As can be seen in Figure 21 above, a large part of the Mediterranean and Black Sea area is in very deep water of greater than 500m water depth, even within relatively close distances from shore. Both Seas have very deep water with limited shallow water regions close to shore. There are notable areas of shallower water, particularly in the Adriatic Sea, in the Northern part of the Black Sea, and off the coasts of Algeria and Western Libya. However, there is only a very limited amount of the region with sea depths of less than 60m. This creates issues with visibility of offshore structures from shore (any fixed offshore structures would have to be deployed very close to shore to obtain feasible water depths). Visibility is an issue in every region, but is prominent in the Mediterranean and Black Sea region due to the fact that any fixed structures are limited to areas very close to shore. The region also has a protected sea-grass which inhabits water depths of less than 20m, further limiting locations available for fixed offshore structures.

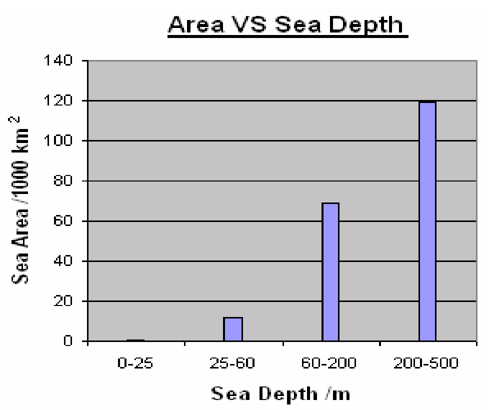
- The combined wind and wave resource (illustrated in figure 20 above) which has been identified in the Mediterranean and Black Sea region is analysed with respect to distance from shore and sea depth in the following table.

**SEA DEPTH AND DISTANCE FROM SHORE ANALYSIS – MEDITERRANEAN AREA**

In the Mediterranean and Black Sea area, there is approximately 200,000 km$^2$ (this is approximately one third of the amount which exists in each of the other two regions investigated) of sea surface area which was classified as one of the six scenarios developed by the project. It is important to highlight that this 200,000 km$^2$ only has the lowest level of wave energy, (there are no areas with wave resource with greater than 15 kW/m of wave resource). Therefore, the opportunities for combined resource in the region are limited.

The 200,000km$^2$ of area in the region which met the previously defined thresholds is analysed by distance from shore and sea depth in the two figures below.




Approximately **33%** of the resource area classified is further than **100km** from shore. Therefore, a large portion of the resources in the region are potentially extractable with current technologies in terms of possible distance from shore, and deploying technologies to increase the possible distance from shore from 100km to 200km will only increase the area of resource which is potentially extractable by approximately 50%.

Approximately **94%** of resource area lies in water depths of greater than **60m**. Therefore to exploit the vast majority of the resources in the Mediterranean, technologies to facilitate deeper water deployments will be required. Increasing the maximum sea depth for which it is possible to deploy devices so that it is possible to deploy devices in any water depths will increase the area classified as one of the six scenarios which is potentially exploitable by more than twenty-fold.

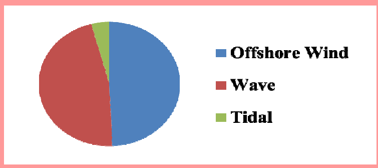
[Source: ORECCA WP2 Report: 'GIS Project & Calculations']

**Important points to highlight for the Mediterranean and Black Sea resource:**

- Relatively small amount of resource compared to the other two geographical areas. Tidal resource exists in the region, but concentrated in a small number of specific areas. Wind resources exist but wave resources in the region are low intensity.
- Approximately 30% of the resource area in the region is further than 100km from shore and approximately 94% lies in water depths of greater than 60m.

**Important points to highlight from the Resource Chapter:**

- Approximately 50% of the available offshore renewable resource in Europe is wind, 46% wave, and 4% tidal stream.




- There are 2 principal 'hotspots' where a large amount of combined wind and wave resource exists: I the Northern North Sea; and II the Western facing Atlantic coastline.

- From a project developer's perspective, these 'hotspot' areas may not be the most attractive for development in the short term. Despite the high intensity resources in these areas, in many parts the grid and port infrastructure are not sufficiently developed, the water depths are high and the conditions (eg. wave loading) are extreme. However, in the longer term, and from a policy maker's perspective, there are large benefits to facilitating the exploitation of these 'hotspot' areas, and this is the major focus of this roadmap.
- Combined resource exists in other areas, such as the Southern North Sea and Baltic Sea, but the resource in this area is less intense than in the other regions identified.
- Most of Europe's resource across the three technologies is clustered in six countries: Ireland, the UK, France, Norway, Portugal and Spain.
- As a result of the relatively limited number of sites where tidal stream resources exist and the relatively low percentage of the total European resource which tidal stream is responsible for, focussing on areas of wind and wave combined resource is the most important overlap between the three technologies. – However, it is also important to highlight that the data which underpins the tidal stream resource in the combined resource maps is different in nature to the data for the wind and wave resources for which Europe wide grids of data are available. There is far less data available for tidal stream, and the data utilised is based upon measurements made at sites which have been identified as potential locations based on their geographic conditions.
- A large proportion of the resources in Europe are in deep water and far from shore. Whilst the amount of resource which is far from shore and in deep water varies across the three regions analysed, across Europe approximately 80% of the resource area classified as one of the six scenarios is in water depths of greater than 60m and approximately 50% of the resource area is further than 100km from shore.

# 6 Finance

Finance is a critical consideration, especially for a developing industry such as the offshore wind, wave and tidal energy sectors. Without governmental support systems in place, offshore renewables are not currently competitive in terms of cost of energy. However, they promise large benefits in terms of carbon savings, energy security concerns, and economic benefits in terms of jobs and supply chain creation. This means that there is large governmental interest across Europe in developing the sector. Therefore, a large number of finance opportunities are available, broadly divided into two distinct types:

1. Capital support/technology-push funding opportunities - such as grants or loans to support activities within the sector.
2. Revenue support/market-pull funding opportunities - such as production based incentives (PBIs) for electricity generated from offshore renewable energy sources.

It is important to maintain a careful balance between these two types of financial support. Whilst market-pull support is important to incentivise large scale deployment and achieve the benefits derived from economies of scale, technology-push support is equally important to ensure the research and development of new technologies which could realise large cost reductions and performance improvements for the sector.

This finance chapter of the roadmap is split into three key sections:

1. Analysis of the current development funding landscape for offshore renewables across Europe;
2. Analysis of the current challenges to attracting investment in the sector;
3. Analysis of the funding landscape in different countries across Europe to identify funding gaps and opportunities.

## *6.1 Analysis of the current development funding landscape and challenges to attracting investment in the sector*

When analysed across countries, the large variations across Europe are evident, and this is illustrated in figure 22 below. In Figure 22, the funding opportunities in each country were analysed against three criteria which were identified by industry as the most important factors for any development funding programme:

1. **High contribution of R&D and investment grants as a percentage of costs;**
2. **Grants specific to offshore renewable energy projects;** and
3. **Agreements with banks and private financial institutions to facilitate increased access to finance.**

**Funding opportunities for the offshore renewable energy sector across Europe:**

| | Total No. of funding schemes | Average RD&D grant contribution (% of project costs) | No. of offshore specific funding schemes | No. of agreements with banks |
|---|---|---|---|---|
| Belgium | 4 | 41.50 | 1 | 0 |
| France | 7 | 28.75 | 0 | 0 |
| Germany | 5 | 50.00 | 2 | 0 |
| Ireland | 5 | 36.25 | 4 | 0 |
| Italy | 8 | 36.28 | 0 | 0 |
| Netherlands | 7 | 40.63 | 0 | 1 |
| Poland | 4 | 43.75 | 0 | 0 |
| Romania | 5 | 50.37 | 0 | 0 |
| Spain | 12 | 80.00 | 2 | 0 |
| UK | 11 | 58.75 | 7 | 1 |

[Data from ORECCA WP2 Report: 'Investment and Grant Opportunities for Offshore Renewable Energy Projects in Europe'.]

**Figure 22:** Analysis of funding opportunities for the offshore renewable energy sector across Europe.

It is clear that the funding landscape for research in offshore renewable energy in some countries is more developed than in other countries. Different countries emerged as leaders in different factors. For example, the UK had the highest number of funding opportunities specific to offshore technologies, but Spain emerged with the most favourable average grant contribution, as a percentage of the project costs.

This analysis is important to establish which countries have the funding opportunities in place which best fit with the industry needs to invest in this sector. Identifying the gaps in the funding landscape will reveal opportunities in the sector.

**Key Messages on development funding in Europe:**

Some countries – such as the UK - already have an attractive funding landscape for R&D in the offshore renewable energy sectors. However, all countries have areas which can be improved on. Very few countries have funding opportunities specific to the offshore renewable energy sector and even fewer countries have agreements in place with banks and private financial institutions to facilitate increased access to finance, two measures which have been identified as important to incentivising investment in the sector.

### *6.2 Challenges to attracting investment in the sector*

A number of challenges to investment exist in the offshore renewable energy sector and it is important that these barriers are both understood and addressed. Currently, high risk profiles, high costs and lack of reliable data on investment returns and timescales inhibit risk averse investors from investing in the sector, and therefore obtaining private sector financing is difficult. To date, only offshore wind projects have been financed through project finance. Because wave and tidal are still at project phases pre-commercialisation, they are mainly forced to finance through the developer's balance sheet. This presents a significant challenge and endangers the sector's development. Actions which can be taken to reduce both risks and costs and make financing easier to obtain, will be necessary to facilitate the large investments which are required. Three high priority actions to facilitate the required levels of investment are outlined in figure 23 below.

**Three high priority actions to facilitate the required levels of investment in the sector:**

1. **Ensure a long term market signal to increase investor confidence in investing in the sector.** Many policy actions can contribute to ensuring this long term confidence in investing in the sector. For example, increasing the amount of specific funding allocated for offshore renewable energy projects (this will also avoid competition with other investments and allow policy makers to steer the sector in a specific direction);
2. **Reducing costs in the sector to increase attractiveness to investors.** Prioritising finance to reduce costs in the sector is important, and the technology priorities for the sector are set out in the Technology chapter (cost reduction potential was an important criteria in this analysis). For example, wave and tidal technology improvements have been identified as an area with high potential for cost reductions in the sector;
3. **Increasing access to capital.** Difficulties associated with securing finance are especially prominent for developing the first deployments of new technologies (when reliable data on investment returns and device performance is limited) and for completing the construction phases of projects (when investors are exposed to higher risks). Securing finance, especially for these higher risk stages of development, remains challenging, and currently many developers are forced to utilise primarily balance sheet financing, leaving large companies with solid balance sheets, or high risk investors as the main developers in the sector. There is a large need to create the financial conditions to attract financial investors; willing to support the developers all the way from project start-up, through to production. This could be supported by measures such as soft loan programmes and government underwriting of project risk. Considering that the majority of governmental support schemes are targeting R&D, this represents a gap between the funding available and the actual need in the market.

**Figure 23:** Three high priority actions that have been identified to facilitate the required levels of investment in the sector.

**Important messages on challenges to investment:**

Removing barriers to investment in the sector is crucial to facilitate the development of the sector. Lack of access to capital, especially during high risk stages of development has been identified as a critical financing gap for the sector; a gap between the funding available and the actual need in the market. Measures to mitigate this barrier to the development of the sector are important and include government underwriting of project risk to de-risk these high-risk development stages and attract financial investors in to support the sector.

## 6.3 *Analysis of the funding landscape which exists in each country to identify funding gaps and opportunities for the sector across Europe*

Figure 24 reveals existing financing gaps, needs and opportunities across Europe. The table presents the production based incentives (PBIs) for which offshore wind and ocean energy technologies are eligible for in different countries, a very important factor when investigating the opportunities for the sector which exist in a given country.

**Analysis of the funding opportunities across Europe and across offshore wind, wave and tidal:**

| Country | Maximum Production Based Incentives (€/kWh) - available for next 10 years | |
|---|---|---|
| | *Offshore wind* | *Ocean Energy (wave/tidal)* |
| **Belgium** | **0.11** | ***NI*** |
| **France** | **0.13** | **0.15** |
| **Germany** | **0.15** | ***NI*** |
| **Ireland** | **0.14** | **0.22** |
| **Italy** | **0.18** | **0.34** |
| **The Netherlands** | **0.19** | ***NI*** |
| **Spain** | **0.10** | ***NI*** |
| **UK (excluding Scotland)** | **0.14** | **0.18** |
| **Portugal** | **0.07** | **0.26** |
| **Norway** | ***NI*** | ***NI*** |
| **Denmark** | **0.11** | **0.12** |
| **Scotland** | **0.14** | **0.28** |

NI: No Incentive available above the wholesale electricity price.

It is important to highlight that, where appropriate, the data includes an assumed Europe wide wholesale electricity price of 0.07 €/kWh.

[Data from ORECCA WP2 Report: 'Investment and Grant Opportunities for Offshore Renewable Energy Projects in Europe'.]

**Figure 24:** Analysis of the funding opportunities across Europe, and across the 3 technologies.

It is important to consider the funding opportunities presented in figure 24 in the context of the results provided by the resource chapter, and this will be done in the following analysis. To decide where attention should be focussed, it is important to answer the question: where is there resource availability but poor funding systems in place?

The table in Figure 24 reveals that all countries with the exception of Norway have a PBI in place for offshore wind. However, having a PBI in place is not sufficient in itself; the incentive must be at a high enough level to promote investment in the sector. Across the countries in the figure, the level of the PBI applicable for offshore wind varies from 0.07 €/kWh in Portugal up to 0.19 €/kWh in the Netherlands.

For ocean energy, only 7 of the 12 countries in the table have a production incentive in place. The level of these incentives is also variable: from 0.12 €/kWh in Denmark up to 0.34 €/kWh in Italy. It is important to note that, of the seven countries with a PBI in place for ocean energy; for Denmark, the UK and France, the ocean energy PBI is comparable in magnitude to the offshore wind PBI in the same country. However, this is not the case in the Scotland, Italy, Portugal and Ireland which have a PBI in place for ocean energy which is significantly higher than the PBI for offshore wind in the same country, taking account of the high costs and emerging status of the ocean energy sector. This higher level of PBI for the ocean energy sector in the countries identified is the result of a conscious decision by the respective governments to support and encourage the development of the sector.

Establishing the level the PBI should be set at for the offshore wind and ocean energy sectors in order to be effective is not something which can be done in this roadmap. The PBI needs to be high enough to give a positive return on investment for projects and needs to be high enough to allow the correct technologies to be developed. Further research is required to determine the level of PBI required to be effective in each country, taking into account factors such as resource intensity, distance from shore and water depth.

As described in the Resource chapter of the roadmap, there are two broad principal 'hotspots' where a large amount of combined natural resource exists in Europe. The resource chapter identified France, Ireland, the UK, Norway, Portugal and Spain as the countries with the largest available natural resource. However, the funding landscape will have to be in place to ensure that the large opportunities presented by the offshore resources in these countries are realized. In Norway in particular, despite having an attractive resource, there are no PBIs in place to provide revenue support to the sector. In the other countries identified, this may mean that, the PBI needs to be increased, based on further research to identify the level required to be effective in each country.

The influence of water depths and distance from shore on the exploitation of available resources represents an important inter-linkage with both the Technology and Resource chapters of the roadmap. As identified in the Resource chapter, a large amount of the available natural resource is at high distances from shore and in deep water, particularly for countries such as Norway which has a large resource, with the majority lying in deep water. Therefore, to facilitate the exploitation of these large resources far from shore and/or in deep water, not only will the necessary funding incentives have to be in place to incentivise the required investments, but funding will also have to be focused to develop new technologies (such as floating wind turbines or HVDC transmission) that are capable of operating in the deeper water or far from shore conditions.

The production based incentives in each country are an important determinant of how attractive the sector is in each country to investment. The PBI is a useful proxy for the finance landscape and attractiveness of the sector in each country to investors. This analysis is highly interlinked with the Resource chapter of the roadmap and it is important to ask the question:

> **Where is there a high concentration of natural resource, but without the funding and policies in place to make investment in the sector attractive?**

Figures 25 and 26 below present the PBIs in each country to reveal where any important gaps exist.

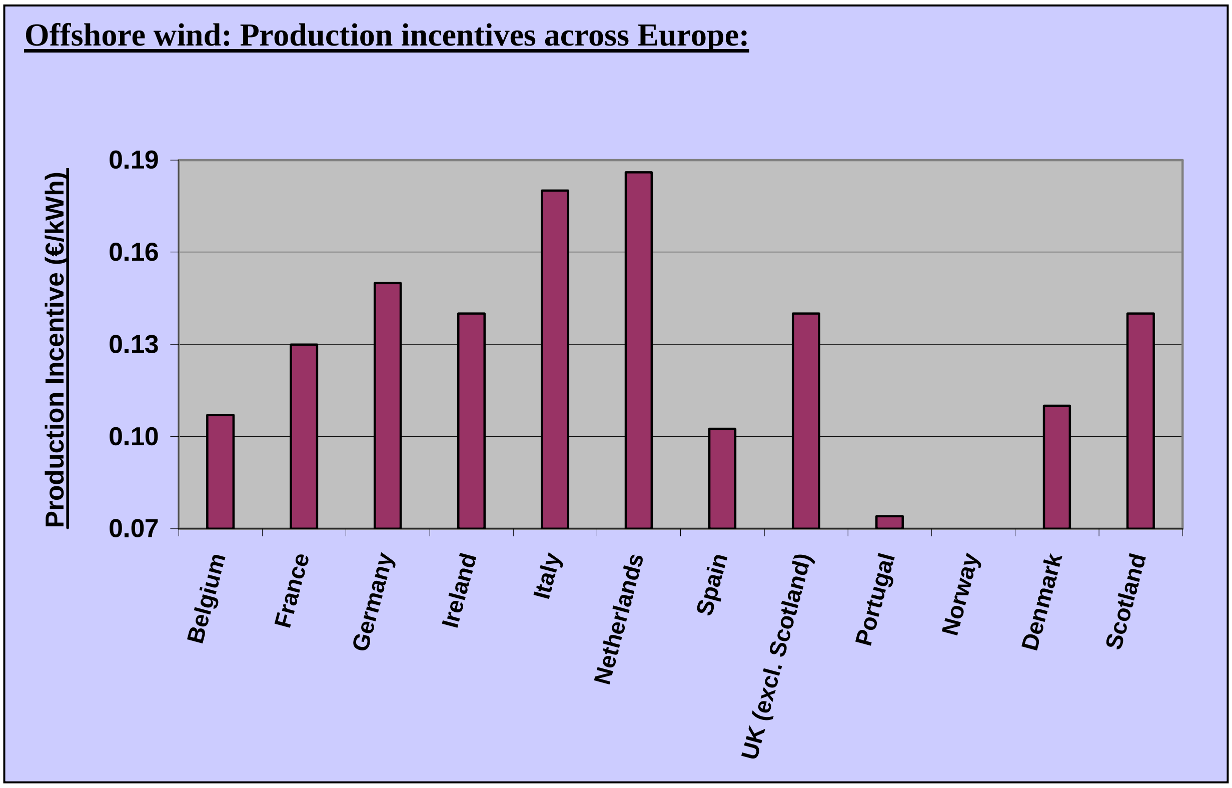



**Figure 25:** Offshore wind available production based incentives (PBIs) across Europe.

N.B. where appropriate, the data includes an assumed Europe wide wholesale electricity price of 0.07 €/kWh. Where there is no production incentive available, above the wholesale price, there is no bar visible on the graph.

Figure 25 highlights the PBIs of each country for offshore wind in further detail than the table in Figure 24 above. Spain, Portugal and Denmark all have attractive natural resources but have lower applicable production incentives. However, the largest discrepancy illustrated in the graph is for Norway which has an attractive resource (as identified in the Resource chapter) but has no PBI in place to support the sector. The large, currently unexploited natural resource off the coasts of Norway represents a large opportunity if the necessary finance policies and technologies can be developed. As discussed in the Resource chapter, as well as putting the necessary finance policies in place to support the sector, the exploitation of the large offshore wind resource in Norway and other regions will require the development of new technologies to facilitate deployments in very deep waters and far from shore. This therefore represents an important linkage with the Resource and Technology chapters of the roadmap.

**Offshore wind - production incentives - Key Messages:**

Spain, Portugal, Denmark, and especially Norway have low production incentives in place compared to other European countries despite having attractive (or in the case of Norway, very large) amounts of estimated available resource.

**Ocean energy: Production incentives across Europe:**

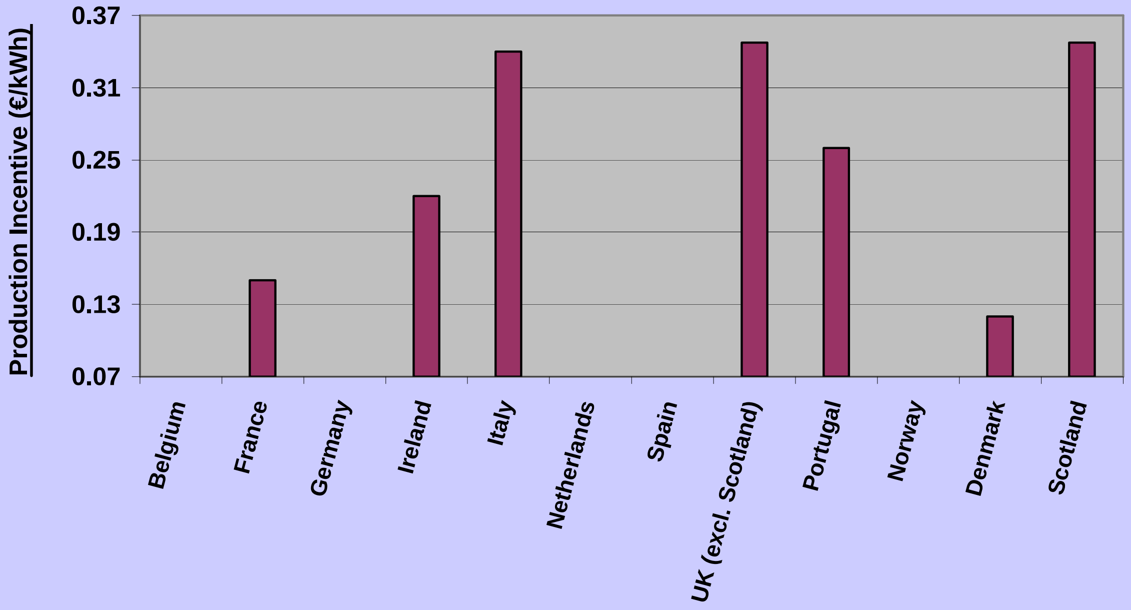



**Figure 26:** Ocean energy available production based incentives (PBIs) across Europe.

N.B. where appropriate, the data includes an assumed Europe wide wholesale electricity price of 0.07 €/kWh. Where there is no production incentive available, above the wholesale price, there is no bar visible on the graph.

Figure 26 above highlights in greater detail than figure 24 the PBIs in place for ocean energy across Europe. It is clear that Ireland, Italy, Portugal and Scotland have the strongest PBIs in place for the sector. This sets a strong market signal for the sector in these countries and will help to attract investment in the sector and to accelerate development. The figure highlights two important discrepancies. The UK has one of the most attractive natural resources for ocean energy (as identified in the resource chapter), but has only the 5$^{th}$ best PBI in place to support the sector. Similarly to offshore wind, as highlighted in Figure 24, there is no PBI in place for the ocean energy sector in Norway. Norway has a large ocean energy resource (as identified in the Resource chapter), and addressing the finance policies necessary to incentivise its exploitation represents a large opportunity for the sector.

**Ocean Energy – production incentives - Key Messages:**

Many countries have little or no estimated available ocean energy resource (wave and tidal) and therefore have a low or no production incentive in place for the sector. However, several countries, particularly the UK, France and Denmark have an attractive resource but a low PBI in place to encourage the realisation of the opportunity presented.

## 6.4 Key recommendations from this Finance chapter

**The ORECCA roadmap recommends that EU and member state administrations:**

**Maintain a careful balance between market-pull and technology push support for the sector** to ensure that both large scale deployments and research into technologies which could realise large cost reductions for the sector are supported.

**Maintain technology-push capital support measures** to ensure step change cost reductions and performance improvements.

**Ensure a long term market signal in all countries to increase investor certainty in the sector.**

**Develop funding opportunities (particularly production incentives) in line with countries which are current leaders, in countries which have a less developed funding landscape, but where a large resource exists.**

**Set up specific grant schemes for offshore RES investments**
- Clearly allocates funds to the sector and allows government to steer investments.

**Specifically recognise within funding programmes the emerging stage of development that the wave and tidal stream energy sectors are at.** If significant benefits from synergies between the sectors are to be realised in the medium term, the development of the wave and tidal sectors will need to be accelerated, and this will require targeted funding.

**Develop new risk sharing mechanisms to facilitate investment in the sector**
- Government underwritten guarantees and utilisation of public funds as a form of guarantee for private financial bodies can help to mitigate risks, particularly in the construction phases, and attract investors into the sector.

**Continue to encourage cross border collaboration on RTD projects** in the sector to drive costs down and promote knowledge transfer.

**Increase funding for demonstration projects** to accelerate the development of the sector by 'learning by experience'.

**Provide targeted financing to support the development of the necessary technologies to facilitate deeper water and far from shore deployments** to realise the large potential resource in these conditions identified in the Resource section.

# 7 Technology

Technology poses a number of challenges and opportunities for the offshore renewable energy sectors. Many factors such as the affordability and reliability of the technologies and devices utilised by the sectors, will have a critical impact on its development.

The emerging status of offshore wind and ocean energy technologies creates considerable challenges for its development. There is a need to strike a balance between trials and deployments of advanced full scale devices whilst also developing emerging designs and sub components to ensure efficient and effective long term cost reduction as well as achieving high levels of reliability and survivability. This is true across offshore wind, wave and tidal technologies and across European member state countries.

This technology chapter of the roadmap will serve three functions:

1. It will present a summary of the technology challenges for the sector;
2. It will present technology development timelines for both the offshore wind sector and the ocean energy sector. These technology development timelines will be focussed around: device and system demonstrators; sub-components; guidelines and standards; and research and tool development.
3. It will provide technology recommendations to facilitate solutions to technical barriers and ensure the successful development and deployment of the sector in the future.

A representative, but by no means exhaustive, summary of the generic, cross technology challenges for the sector is provided in figure 27 below.

**Summary of the technology challenges for the sector:**

- At present offshore renewable energy development activity is spread over a wide variety of concepts and components, and at the highest level, offshore wind, wave and tidal current have distinctive development needs. Although this variety of device design and experimentation is important, it may create problems in terms of focussing development and deployment investment and, hence the speed of commercialisation. Across the sector as a whole, there is a need to strike a balance between design variety and consensus, and the development of supply chain commonality.
- A number of generic technology areas and components – such as foundations, moorings, power take off (PTO), marine operations and resource assessment – offer important opportunities for collaborative development, although the transfer of knowledge and components within the developer community may be limited due to commercial competition.
- There is a need for more performance data and operating experience to feed back into the overall development cycle, particularly for the wave and tidal stream sectors which have relatively limited full scale experience in open sea operating conditions.
- There are significant opportunities for knowledge transfer from other sectors, such as offshore engineering. Enabling this transfer will involve a better understanding of the 'adaptation costs' of transferring components and methods to the marine environment, and identifying opportunities for collaboration with other industries and supply chain partners to ensure the availability of cost effective solutions.

**Figure 27:** Summary of challenges to the development of the offshore renewable energy sectors.

At the highest level, offshore renewable energy technology development and deployment will require measures to address the underpinning generic technical challenges as highlighted in the figure 28 below.

**Underpinning technical challenges the offshore renewable energy sectors need to address:**

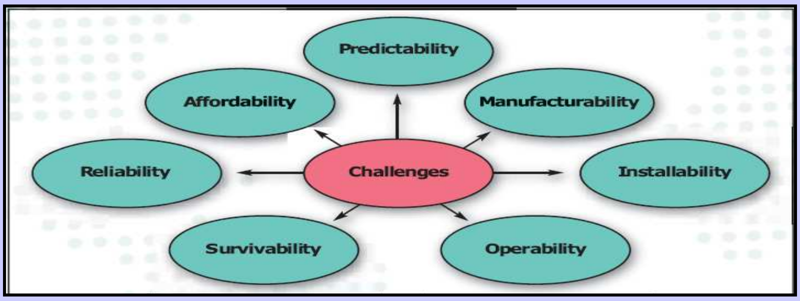



**Figure 28:** Diagram showing generic challenges involved in the development of the offshore renewable energy sectors. (Source: UK Energy Research Centre)

## *7.1 Deployment timeline*

Every section of the roadmap is interconnected to the deployment timeline presented in figure 29. However, this technology section is particularly closely linked and these inter-linkages will be set out and investigated further in the following sections. The projected deployment timeline for the ocean energy and offshore wind sectors is reiterated in Figure 29 below, which illustrates a pathway to achieve significant targets of offshore renewable energy installed capacity by 2030. In the following sections the technical priorities for the sector map directly onto this deployment timeline presented.

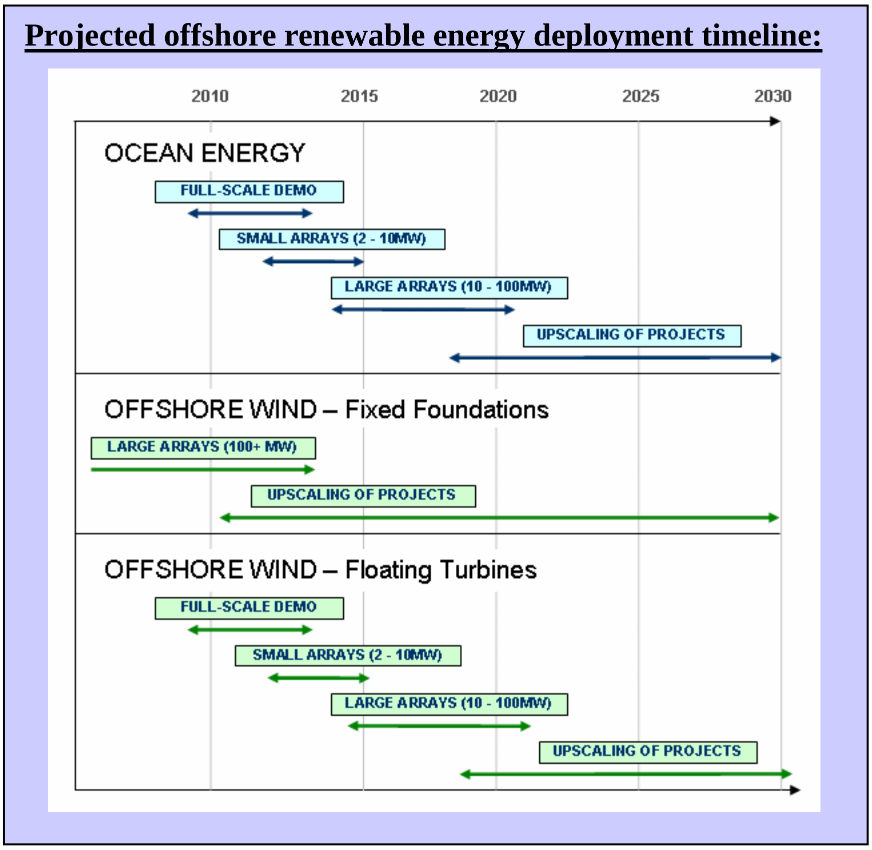



**Figure 29:** Projected deployment timelines for the ocean energy (wave and tidal stream) and offshore wind sectors. (Source: adapted from the UK Department for Energy and Climate Change (DECC) Marine Energy Action Plan 2010).

It must be highlighted that the offshore renewable energy targets set out in section 3.3 above will only be achieved through structured device deployment, as illustrated in figure 29 above, culminating in the deployment of significant device arrays. In order to ensure effective development, deployment must be a progressive process, which is reflected in the Plan’s timeline. It must be emphasised that these deployments are based upon favourable and continuous economic and political climates being in place for marine energy throughout the deployment period, as well as the addressing of technical challenges highlighted in the remainder of this chapter.

## *7.2 Technology Development Priorities*

Although influenced by the resource, finance, infrastructure and environmental elements within this roadmap, the underpinning technology requirements are the main focus of this chapter. This technology chapter of the roadmap is divided into 4 main themes, which represent the main technology development areas for Ocean Energy and Offshore Wind:

- Device and system demonstrators;
- Sub-components;
- Guidelines and standards; and
- Research and tool development.

The activities within these four broad technology development areas are presented in figures 32, 33, 34, and 35 below; two technology development timelines for the offshore wind sector and two for the ocean energy sector. The four technology development timelines build and expand upon two ETI (Energy Technologies Institute) roadmaps which are focussed specifically on the UK. However the prioritisations and the timelines have been adapted and adjusted (based on review by the ORECCA partners) in order to add a European context and a cross technology focus. This approach is justified by the fact that in general, technology challenges cross borders well. For example, a reliability challenge for offshore wind turbines in Denmark will be identical to the same reliability challenge faced in the UK or elsewhere.

In each of the four timelines, the technology development activities are illustrated, having been prioritised into three different priority categories depending on the assessed level of industry need. This prioritisation was done with respect to the six criteria outlined in figure 30 below.

**Prioritisation criteria:**

| | **Level of priority** |
|---|---|
| **Sector urgency** | Will failure to fund the activity stop immediate deployments in the sector? |
| **CAPEX cost reduction potential** | What is the CAPEX cost reduction potential of the activity? |
| **OPEX cost reduction potential** | What is the OPEX cost reduction potential of the activity? |
| **Uniqueness to the sector** | Is the technology unique to the sector or generic across a number of sectors? |
| **Existing funding level** | To what degree is funding already available for the activity? |
| **Impact on technical risk and survivability** | How much would development contribute to overall system risk reduction and survivability? |

**Figure 30:** prioritisation criteria utilised to categorise the activities in figures 32, 33, 34, and 35 below according to their level of priority.

The three resulting prioritisation categories are displayed in figure 31 below. If an activity is classified as Priority 3, this doesn't necessarily mean it is not an important industry issue, just that it is not an immediate priority based on the efficient utilisation of limited financial resources to facilitate the development of the sector in the most efficient way.

**Underpinning technical challenges the offshore renewable energy sectors need to address:**

- Priority 1: High priority based on the assessment criteria.
- Priority 2: Medium priority.
- Priority 3: Low priority.

**Figure 31:** Key for figures 32, 33, 34, and 35 below, showing the three prioritisation categories used to prioritise the activities according to the assessment criteria outlined.

In the following two sections, the technology priorities are presented and then analysed; first for the offshore wind sector, and then for the ocean energy sector. It is important to highlight that, for the subcomponents sections, the timelines will only represent the subcomponent developments for the 1st generation of devices. Some of these subcomponent related activities will have to be repeated for further generations of devices.

## *7.3 Offshore wind*

Individual activities within the offshore wind sector are mapped and prioritised against the overall deployment plan whilst still grouped into the overall themes, and this is displayed in figures 32 and 33 below.

**Device & system demonstrators and sub-components timeline for the offshore wind sector:**

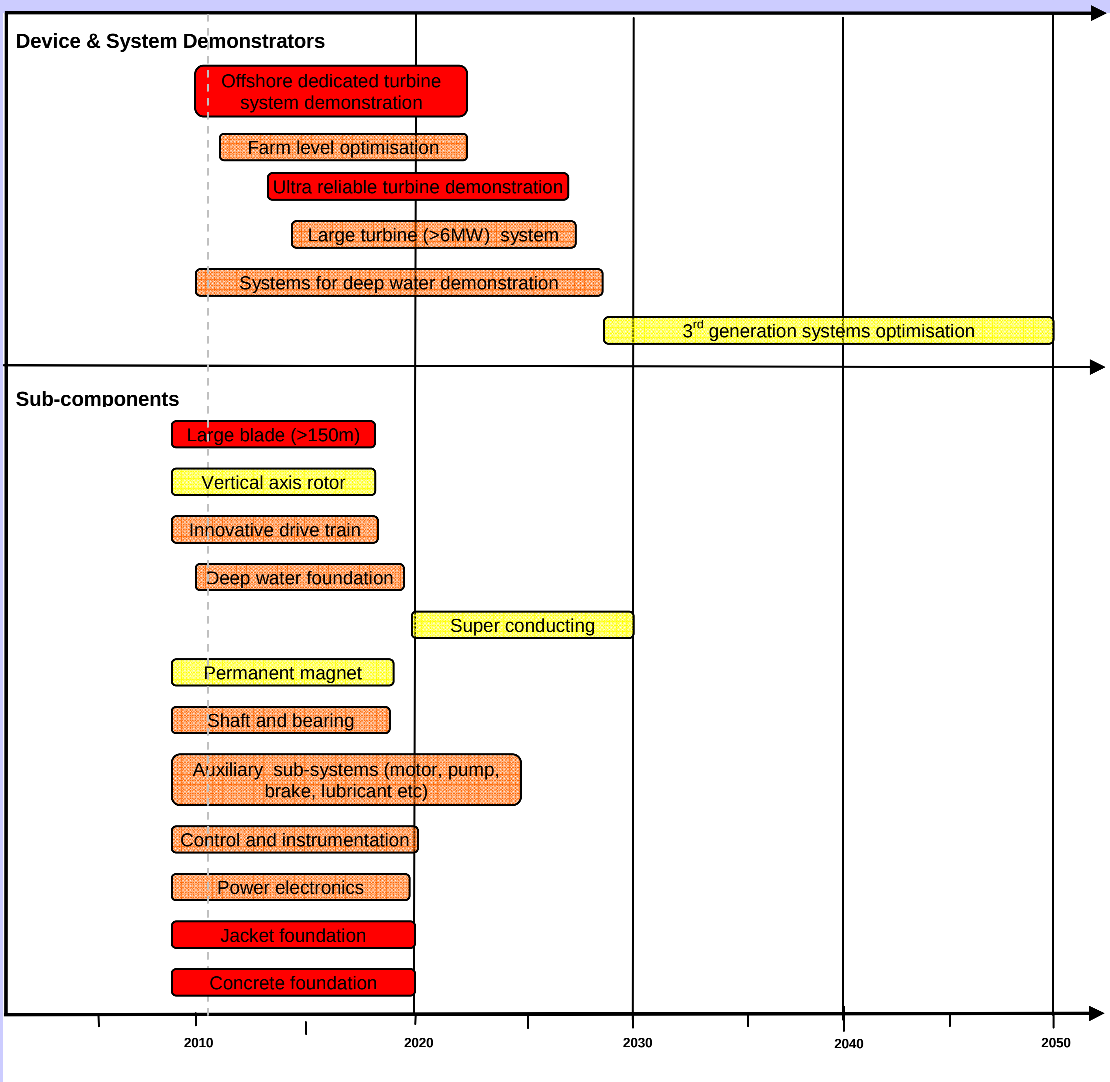



**Figure 32:** Device & system demonstrators and sub-components timeline for the offshore wind sector. (Source: adapted from ETI Offshore Wind Technology Roadmap)

**Offshore Wind – device & system demonstrators and subcomponents - Key points:**

It is clear from the figure above that five activities have been selected as priority 1, the highest priority for the sector, based on the metrics outlined earlier:

- Offshore dedicated turbine system demonstration;
- Ultra reliable turbine demonstration;
- Large blade rotors (>150m);
- Jacket foundations; and
- Concrete foundations.

These activities will, between them ensure the development of highly reliable, large rotor, specifically dedicated offshore turbines with cost effective foundations suitable for deeper waters. These developments are extremely important to facilitating large deployments in the immediate to medium term.

**Guidelines & standards, research and tool development timeline for the offshore wind sector:**

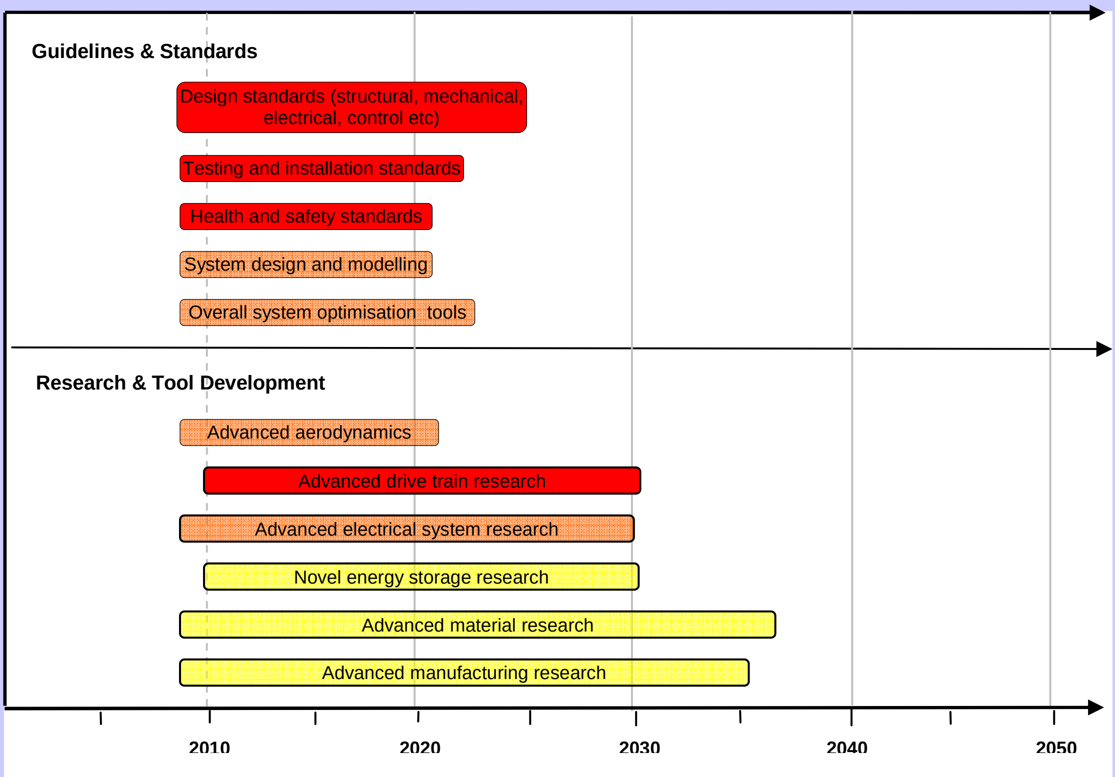



**Figure 33:** Guidelines and standards and research & tool development timeline for the offshore wind sector. (Source: adapted from ETI Offshore Wind Technology Roadmap)

**Offshore Wind – guidelines & standards and research & tool development - Key points:**

Four key activities have been selected as priority 1, the highest priority for the sector, based on the metrics outlined earlier:

- Design standards (structural, mechanical, electrical, control etc);
- Testing and installation standards;
- Health and safety standards; and
- Advanced drive train research.

The three sets of standards are important for the sector, to build upon the existing IEC TC88 standards and move the sector forwards. Standards in these areas will help to ensure that international best practice prevails. The advanced drive train research activity is important and will facilitate step change improvements in turbine design and structure.

## 7.4 Ocean Energy

Similarly to the analysis above for the offshore wind sector, individual activities within the ocean energy sector are mapped and prioritised against the overall deployment plan whilst still grouped into the overall themes, and this is displayed in figures 34 and 35 below.

**Device & system demonstrators and sub-components timeline for the ocean energy sector:**

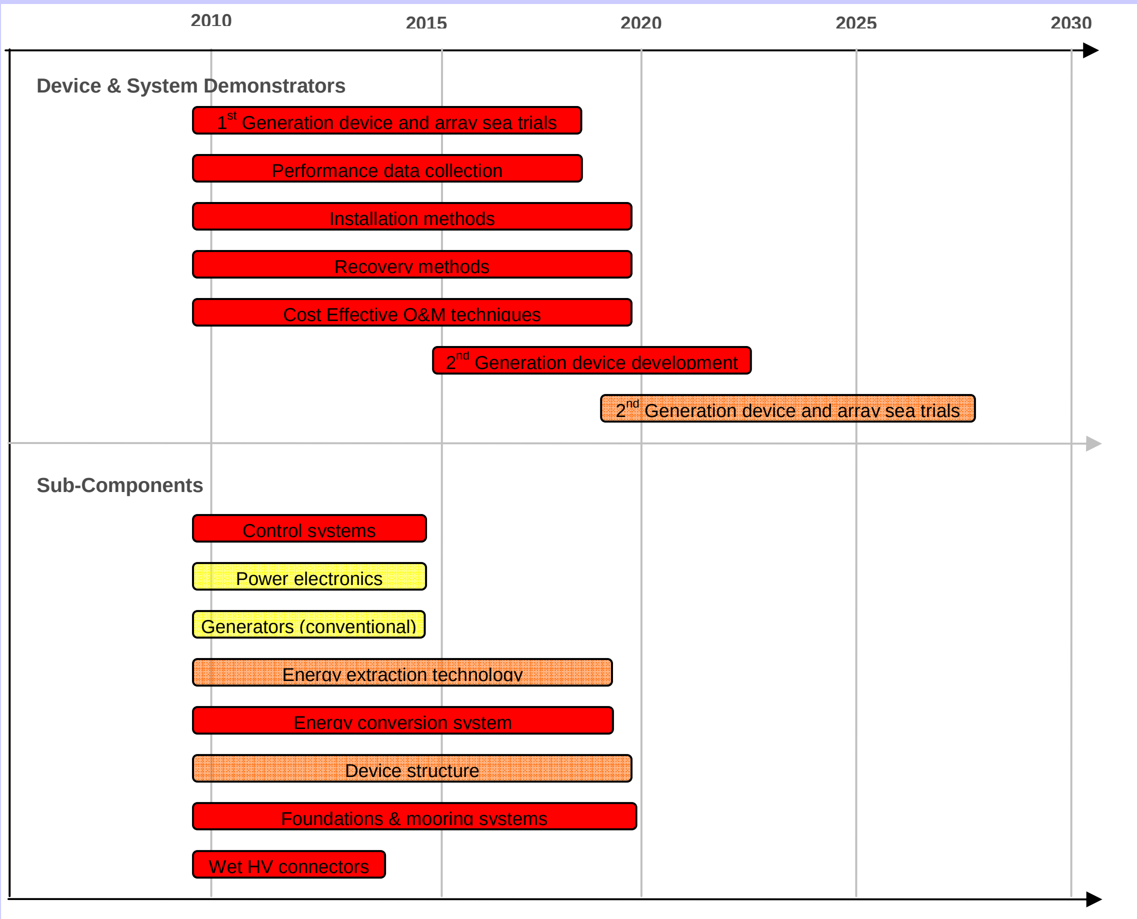



**Figure 34:** Device & system demonstrators and sub-components timeline for the ocean energy sector.

(Source: adapted from ETI & UKERC (2010) Marine Energy Technology Roadmap). www.energytechnologies.co.uk/Libraries/Related_Documents/ETI_UKERC_Roadmap.sflb.ashx)

**Ocean Energy – device & system demonstrators and subcomponents - Key points:**

Ten key activities have been selected as priority 1, the highest priority for the sector, based on the metrics outlined earlier:

- 1st generation device and array trials;
- Performance data collection;
- Installation methods;
- Recovery methods;
- Cost effective O&M techniques;
- 2nd generation device development;
- Control systems;
- Energy conversion systems;
- Foundations and mooring systems; and
- Wet HV connectors.

It is clear that a large number of activities from both the 'device and system demonstrator' and 'subcomponent' categories for the ocean energy sector have been identified as the highest priority. This reiterates the importance of testing devices, developing efficient and low cost installation, O&M and recovery techniques, and developing sub-components critical to these devices. The high priority of so many technology related activities is illustrative of the fact that the sector is at an earlier stage of maturity than the offshore wind sector, no significant deployments beyond full scale prototype testing currently exist, and there is relatively little design consensus around the best technologies to move the sector forwards.

**Guidelines & standards, research and tool development timeline for the ocean energy sector (wave and tidal energy):**

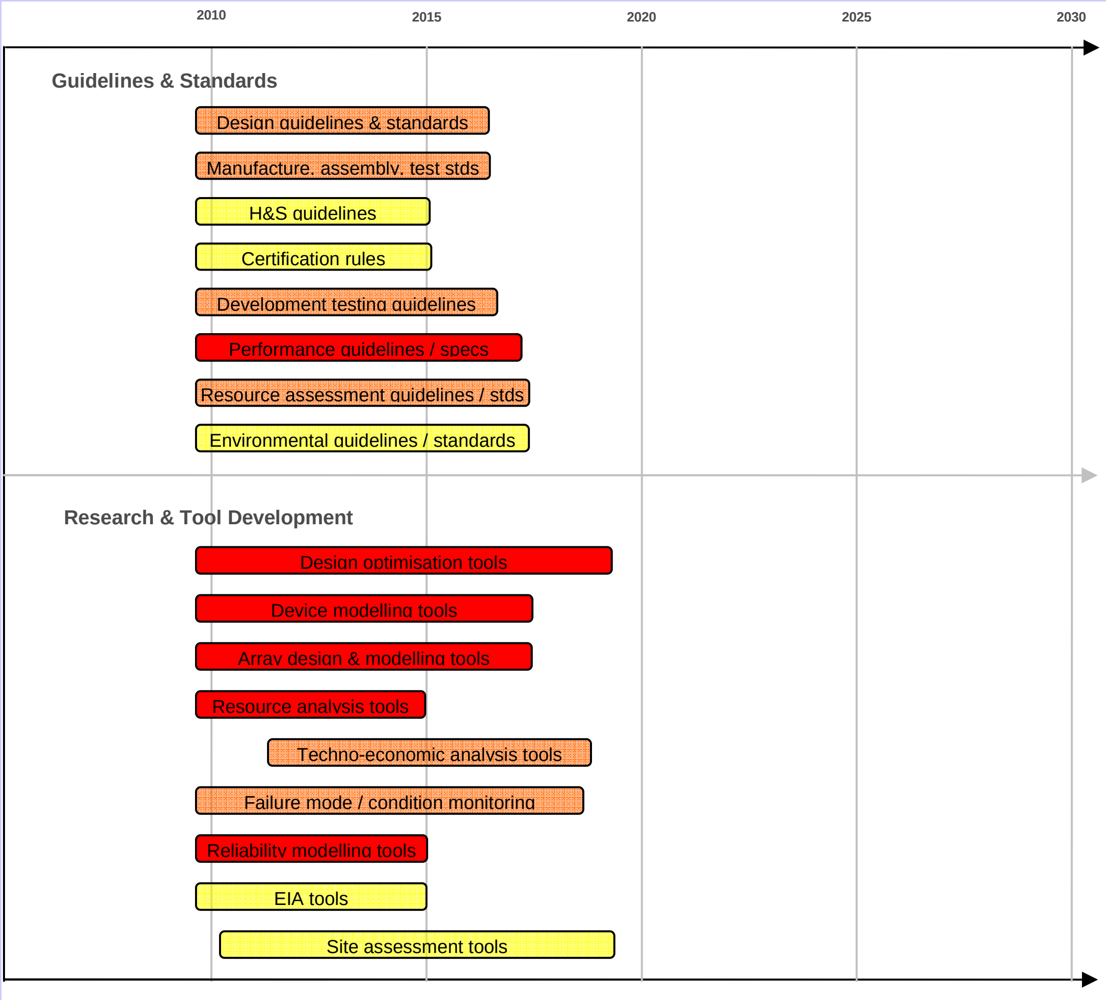



**Figure 35:** Guidelines & standards and research & tool development timeline for the ocean energy sector (wave and tidal energy). (Source: Adapted from ETI & UKERC (2010) Marine Energy Technology Roadmap). www.energytechnologies.co.uk/Libraries/Related_Documents/ETI_UKERC_Roadmap.sflb.ashx)

**Ocean Energy – guidelines & standards and research & tool development - Key points:**

Six activities have been selected as priority 1, the highest priority for the sector, based on the metrics outlined earlier:

- Performance guidelines/specifications;
- Design of installation tools;
- Device modelling tools;
- Array design and modelling tools;
- Resource analysis tools; and
- Reliability modelling tools.

The development of performance specifications will allow international best practice to be established in terms of device performance in the sector. Designing tools to make installation of devices more efficient has the potential to have a large impact on installation and O&M costs. The remaining four activities relate to developing tools for modelling devices, arrays, resource and reliability. Modelling these four aspects will be crucial to further increase the understanding of the complex interactions involved and then incorporate this knowledge into future device and system designs.

## 7.5 *Synergies and Commonalities*

Important technical synergies exist where technology development activities can benefit all three sectors. These areas of commonality are important and could realise cost reductions and accelerated development of the sectors. Some key synergies across the offshore wind, wave and tidal sectors are outlined in Figure 36 below.

**Technical synergies and commonalities in the offshore renewable energy sectors:**

**Foundations:** Wind and tidal stream energy use the same offshore foundation structures, namely monopile and concrete caisson. All floating devices for offshore renewable energy propose the use of the same standard mooring technologies for offshore structures developed by the maritime and oil and gas industries.

**Array layout:** The spacing of wind turbines in a wind farm may be conducive to wave clusters located at each wind turbine in the farm. Likewise the large spacing between wind turbines may allow for the installation of a wave energy array between the wind turbine towers.

**Mooring/Fixed Connection Point:** Two renewable energy technologies could potentially share a connection point and a fixed device e.g. wind turbine, could be used as a mooring or connection point for a floating technology such as a wave energy device.

**Access:** A wave energy device may provide increased access to the wind turbine either by reducing the wave climate at the offshore wind turbine or by providing a physical structure around the turbine through which safer access could be achieved.

**Reduced wave loading:** A wave energy device may reduce the wave climate at the offshore wind turbine which can provide increased weather windows for access if placed in front of the wind turbine structure and could also reduce wave loading on the structure.

**Figure 36:** Technical synergies and commonalities which exist between the offshore wind, wave and tidal sectors.

**Key points to highlight from this Technology Chapter:**

- The major high-level technical challenges facing the offshore renewable energy sectors relate directly to the deployment plan and can be summarized as: predictability, manufacturability, installability, operability, survivability, reliability and affordability.
- This technology chapter of the roadmap is based on ETI technology roadmaps then expanded by evidence gathered from ORECCA technology sub groups to give a European context.
- Technical timelines have been developed for the offshore wind and ocean energy sectors, and activities have been prioritised within these to meet the deployment plan set out.

## 7.6 Key Recommendations from this Technology chapter

**The ORECCA roadmap recommends that:**

- Policies should be created to develop design consensus within the ocean energy sector.
- Policies should be designed which ensure that all possible subcomponent development activities are developed in a way so as to provide common solutions across the three offshore renewable energy sectors.
- Policies should be put in place to provide guidelines for funding bodies to ensure that allocation of development funding is in line with the technical timelines and priorities set out in the technology chapter of this roadmap.
- For the offshore wind sector, policies and support should be put in place to concentrate technology development activities on 9 high priority areas:
  - Offshore dedicated turbine system demonstration;
  - Ultra reliable turbine demonstration;
  - Large blade rotors (>150m);
  - Jacket foundations;
  - Concrete foundations;
  - Design standards (structural, mechanical, electrical, control etc);
  - Testing and installation standards;
  - Health and safety standards; and
  - Advanced drive train research.
- For the ocean energy sector, policies and support should be put in place to concentrate technology development activities on 16 high priority areas:
  - 1st generation device and array trials;
  - Performance data collection;
  - Installation methods;
  - Recovery methods;
  - Cost effective O&M techniques;
  - 2nd generation device development;
  - Control systems;
  - Energy conversion systems;
  - Foundations and mooring systems;
  - Wet HV connectors;
  - Performance guidelines/specifications;
  - Design of installation tools;
  - Device modelling tools;
  - Array design and modelling tools;
  - Resource analysis tools; and
  - Reliability modelling tools.

- A coherent and adaptive approach to policy with regard to technology developments is ensured, across international energy arenas, to provide an appropriate combination of support mechanisms, and ensure effective distribution of investments as the sector matures.

# 8 Infrastructure

For the full commercialisation of the offshore renewable energy sector, a wide range of facilitating infrastructure is necessary. It is important to note that this infrastructure includes a wide ranging offshore supply chain for the sector. However, the entire supply chain will not be considered in this roadmap which will focus on the offshore part of the supply chain and infrastructure. From manufacturing infrastructure and assembly ports to grid connections and vessels for installation as well as operation and maintenance (O&M), the necessary facilitating infrastructure can be broken down into three distinct categories which will be the focus of this roadmap:

- **PORTS & OFFSHORE SUPPLY CHAIN** infrastructure;
- **VESSELS** infrastructure; and
- **GRID** infrastructure.

Critical infrastructure requirements will be identified across countries, across regions and across technologies along with key actions required to build on infrastructure opportunities. The Resource section of the roadmap has highlighted the ‘hotspot’ areas where natural resource exists. It is clear that infrastructure developments across the three categories identified above will all be necessary to facilitate the development of the sector in these ‘hotspots’. Mobilising the necessary facilitating infrastructure surrounding these areas of intense resource presents an immediate opportunity for combined wind, wave and tidal infrastructure development, and this should be recognised and acted on accordingly.

## *8.1 Port and Offshore Supply Chain Infrastructure*

Ports are a critical part of the infrastructure needed to facilitate large scale deployment of the offshore renewable energy sector in the coming years. Port facilities are primarily required for three functions:

- **Manufacturing hubs;**
- **Assembly and load-out hubs;** and
- **O&M and service hubs.**

These different port functions within the offshore renewable energy supply chain have different requirements. For example, the spatial and infrastructural requirements for ports to undertake O&M work are lower than for the other activities and the main factors for port choice are location and flexibility. The port requirements for an offshore wind assembly port and an offshore wind-single site manufacturing and assembly facility are described in Figure 37 below.

**Offshore wind port requirements for different functionalities:**

**Offshore wind assembly port requirements:**

- At least 8 hectares suitable for lay down and pre-assembly of product.
- At least 200m length of quayside with high load bearing capacity (up to 20 tons/$m^2$) and adjacent access.
- Gantry cranes with high lifting capacities.
- Water access to accommodate vessels of up to 140m length, 45m beam, and 6m draft, with no tidal or other access restrictions.
- Overhead clearance to sea of 100m minimum (to allow vertical shipment of large components such as towers).

**Offshore wind single site manufacture and assembly facility requirements:**

It is advantageous in terms of flexibility and logistical costs to locate the sector's manufacturing facilities coastally. Also, technological developments (such as high speed jack-up vessels and transfer-at-sea technologies) could mean that single site manufacturing and assembly facilities become increasingly advantageous.

- Up to 500 hectares of flat area for factory and product storage.
- Direct access to a minimum length of 500m of dedicated high load bearing deep water quayside.
- Ease of landside logistics and access to skilled workforce.

[Source: DECC (2009) UK Ports for the Offshore Wind Industry: Time to Act]

**Figure 37:** Offshore wind sector requirements for port facilities of different functionalities.

It is important to note that these requirements were developed from interviews with offshore wind stakeholders[9]. The manufacturing and port requirements are device related, and therefore the needs are different for fixed offshore wind structures, floating offshore wind structures, wave energy devices and tidal stream devices. Due to the lack of technology consensus around a specific type of device in the wave and tidal energy sectors, it is too early to define the exact requirements for port and manufacturing facilities for the sector. The port requirements are highly dependent on the size (and weight) of the devices, the type of foundations used, and how much draft the devices need to be towed to site (or the draft of the vessels required). Therefore drafts in excess of 10m, load out capacities in excess of 1500 tons over a wide span, and a range of other requirements over and above those set out above, the current requirements of the offshore wind sector, will be required. As novel devices such as semi-submersible floating wind turbines, or tidal devices with gravity foundations, are utilised in the future, the port requirements will evolve with the weight, size and installation requirements of the devices.

However, despite the fact that it is too early to define the exact details for port requirements for the wave and tidal energy sectors (and for new technologies such as floating offshore wind devices), it is clear that the development of ports represents an immediate major opportunity. The Resource section of the roadmap has identified regions where 'hotspots' of natural resource exist, and whilst avoiding details of specific port requirements it is clear that clusters of port developments (across the three types of port facility identified above) will be required in these 'hotspots' areas to facilitate the development of the sector.

[9] DECC (2009) UK Ports for the Offshore Wind Industry: Time to Act

### *Where should ports for the offshore renewable energy sector be developed?*

Due to the large geographical spread of likely combined future developments, the geographical spread of ports will have to be large. In many cases, ports and facilities will be needed in locations not yet used for offshore energy developments. The question of where ports should be developed is usefully split into two:

1. **In which areas or regions does opportunity exist to develop ports and supply chain infrastructure to support the sector?**
2. Which individual ports within this area/region are the best suited to hosting the necessary port and supply chain developments?

This roadmap will concentrate on answering the first of these questions, and analyse the port requirements at the highest level, revealing where the opportunities exist across Europe.

The second question, deciding exactly which ports to develop, will require a more detailed analysis, similar to the DECC (2009) study of UK ports for the offshore wind sector[10]. At this level of detail, it will be important to focus on three areas of opportunity:

- Developments focussed on where capacity for the offshore renewable sector already exists;
- Developments focussed on ports which have high capacity devoted to other industries, such as container shipping; and
- Developments focussed on currently undeveloped sites which are suitable for new developments to support the sector.

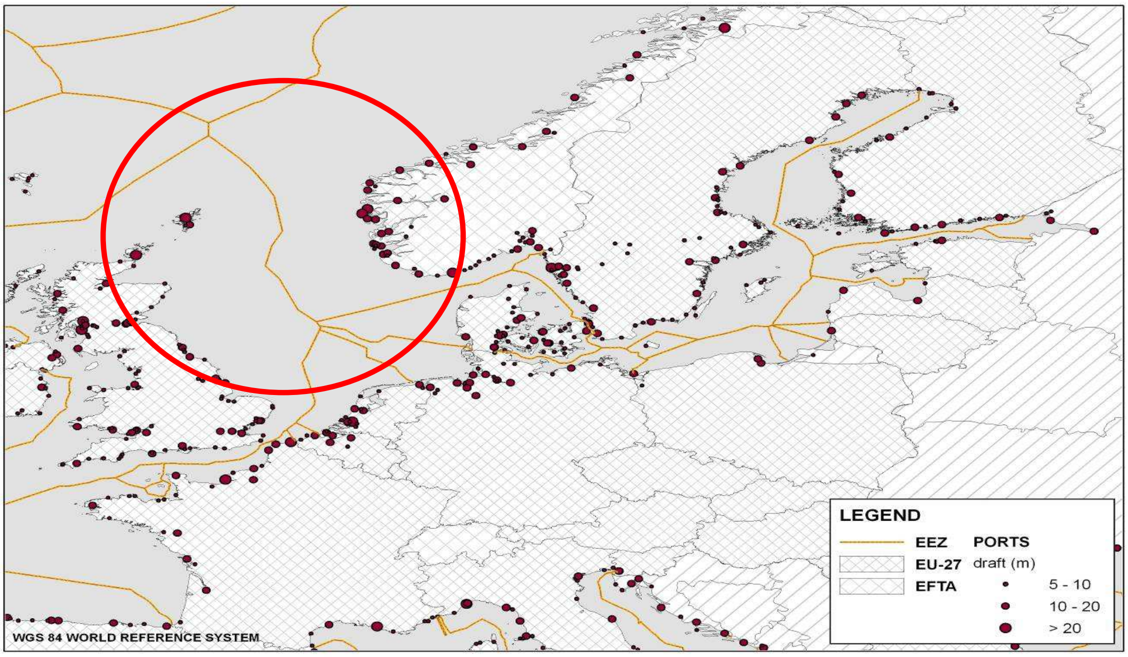
In the following sections, each of the three project areas will be analysed to reveal where the opportunities for port development exist.

### *Port developments in the North and Baltic Sea area:*

Many ports have already been used for offshore wind and ocean energy and several ports, particularly in Denmark and Germany (where there is a high concentration of industry players), are already well established as manufacturing and assembly facilities for offshore wind. Figure 38 overleaf shows that there are a large number of existing ports right across the area.

[10] DECC (2009) UK Offshore Wind Ports Prospectus

**Existing ports in the North and Baltic Sea area with the resource 'hotspot' in the region highlighted:**

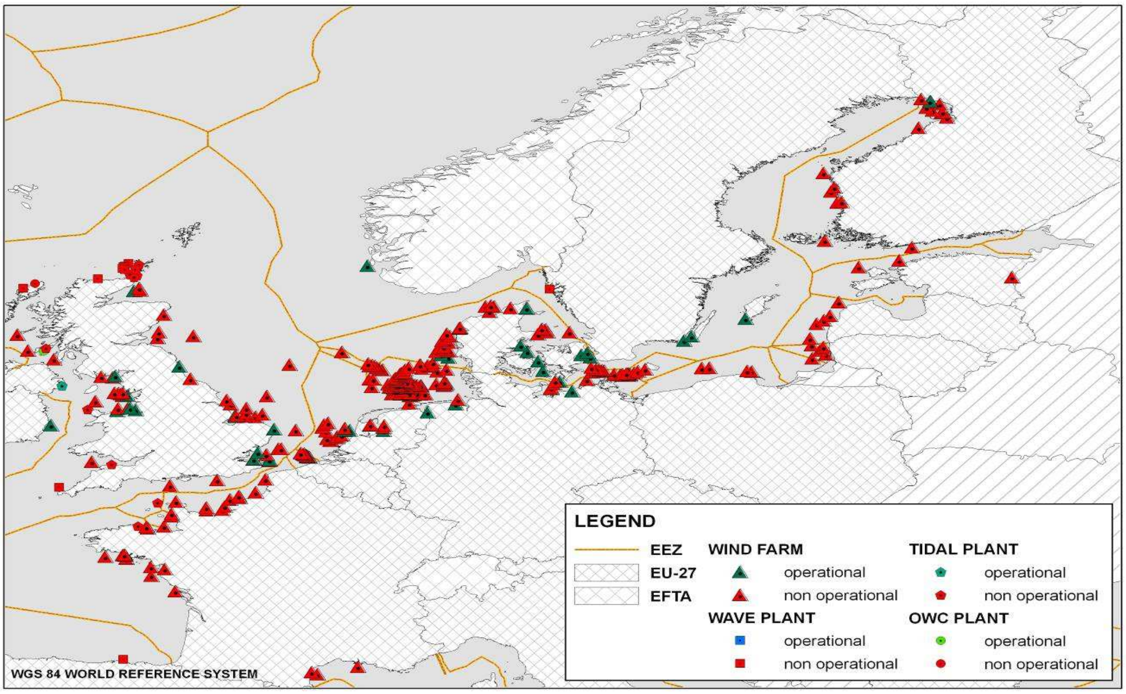



[Source: ORECCA WP2 Report: 'GIS Project & Calculations']

**Figure 38:** Existing ports in the North Sea and Baltic area. The natural resource 'hotspot' of combined resource in the region, identified in the Resource section of the roadmap, is highlighted in Red.

As identified in the Resource section of the roadmap, a large amount of combined resource, particularly wind and wave, exists in the North Sea and Baltic area. As shown in Figure 39 overleaf, the North Sea and Baltic area is already home to a large number of both operational and planned offshore renewable energy plants. However, it is important to note that these are concentrated in the Southern part of the region. As identified in the Resource section of the roadmap, the highest intensity combined wind and wave resource in the area exists in the Northern part of the area, primarily off the coasts of the UK and Norway. This represents a large opportunity to the sector, to mobilise port infrastructure surrounding the Northern part of the North Sea to facilitate deployments in this area of intense natural resource. The reasonably close proximity of the 'hotspot' area to the large manufacturing and assembly facilities clustered around the Southern North Sea means that the largest opportunity in the area is for the development of assembly and O&M port facilities clustered around the Northern part of the North Sea, closer to the 'hotspot' natural resource. It is important to reiterate that these developments must be made in the context of further research to consider where ports need to be developed to support the exploitation of offshore renewables in the 'hotspot' area in the most efficient possible way.

**Offshore renewable energy plants in the North Sea and Baltic area:**




[Source: ORECCA WP2 Report: 'GIS Project & Calculations']

**Figure 39:** Existing and planned offshore renewable energy plants in the North Sea and Baltic area.

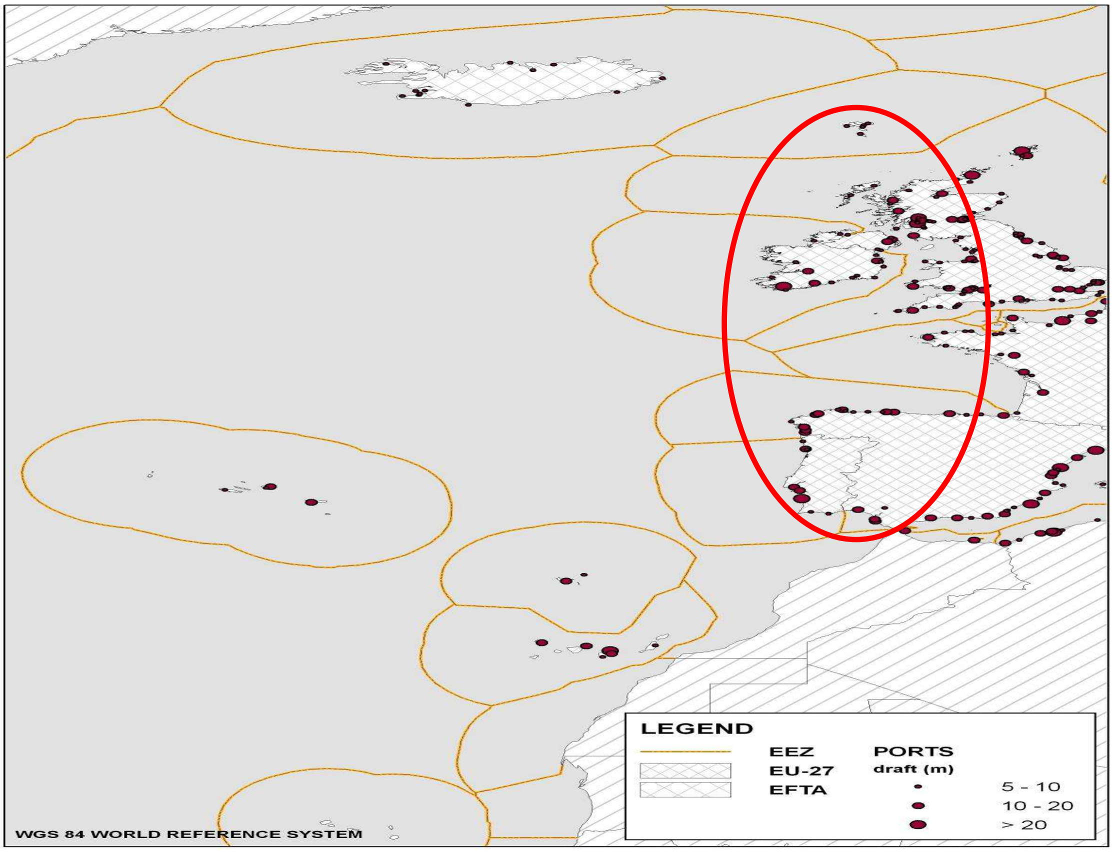
**Important points to highlight regarding port developments in the North and Baltic Sea area:**

- Large number of offshore renewable energy plants (mainly offshore wind farms) already deployed in the region particularly concentrated in the Southern North Sea.
- The resource chapter identifies that a large amount of combined resource exists in the Northern part of the North Sea. This represents a large opportunity for the sector, developing clusters of port infrastructure to facilitate the exploitation of the large amounts of resource in this area.
- Need further research to identify the most efficient way to develop the port infrastructure around the North Sea to exploit the 'hotspot' resource.

### *Port developments in the Atlantic Ocean area:*

As highlighted in the Resource section of the roadmap, the Atlantic Ocean region contains a large amount of high intensity natural resource. This primarily exists in the Northern part of the area, off the West Coasts of the UK, Ireland and France, with less intense but still significant combined resource off the coasts of Spain and Portugal in the South of the area. As can be seen from Figure 40 overleaf, there are a large number of ports in this region, with the exception of the North and West coasts of Ireland.

**<u>Existing ports in the Atlantic Ocean area with the resource 'hotspot' in the region highlighted:</u>**

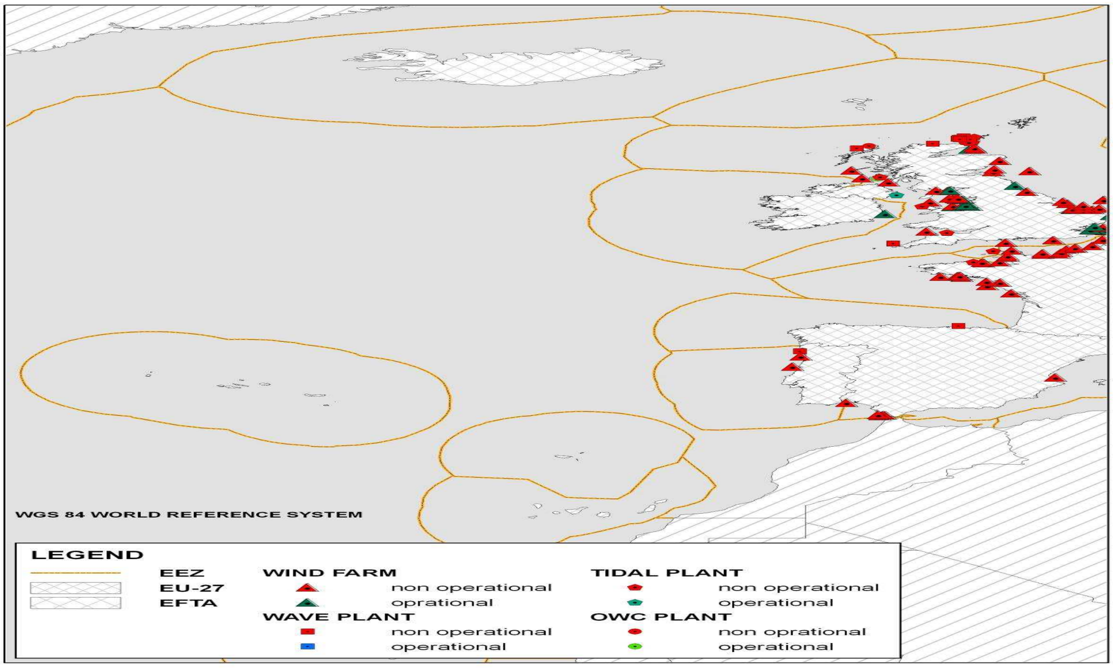



[Source: ORECCA WP2 Report: 'GIS Project & Calculations']

**Figure 40:** Existing ports in the Atlantic Ocean area. The 'hotspot' of combined natural resource in the region, identified in the Resource section of the roadmap, is highlighted in Red.

Figure 41 overleaf shows currently operational and planned offshore renewable energy plants in the region. It is clear that there are a large number of planned deployments, particularly in the Northern parts of the region. However, all currently operational deployments are limited to the Irish Sea area. Therefore, a number of ports in the area, particularly in the Irish Sea, have already been utilised for offshore wind deployments. A large opportunity for the development of ports exists in the area, particularly in the North of the region, off the coasts of Scotland and Ireland where the most intense natural resource exists. The high level of resource in this area, coupled with the relatively high distance to the large manufacturing and assembly facilities clustered around the Southern North Sea mean that there is a large opportunity for the development of manufacturing facilities as well as assembly and O&M facilities.

**Offshore renewable energy plants in the Atlantic Ocean area:**




[Source: ORECCA WP2 Report: 'GIS Project & Calculations']

**Figure 41:** Existing and planned offshore renewable energy plants in the Atlantic Ocean area.

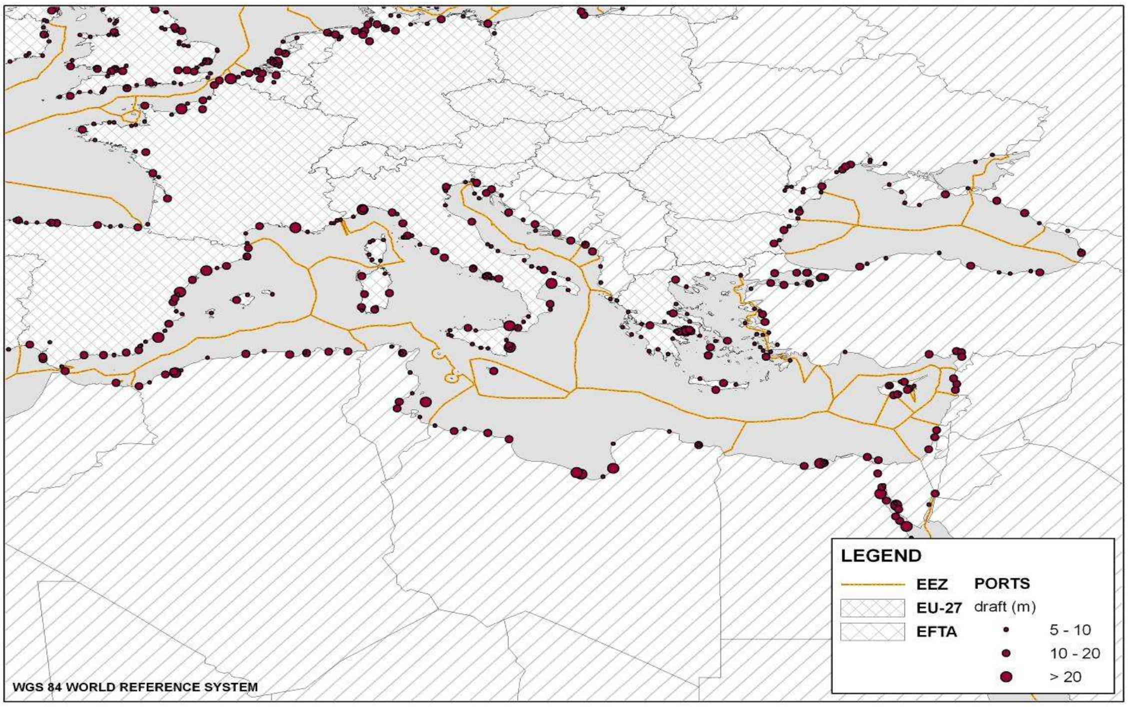
**Important points to highlight regarding port developments in the Atlantic Ocean area:**

- A limited number of offshore renewable energy plants (mainly offshore wind) are already deployed in the region primarily concentrated in the Irish Sea.
- The resource chapter identifies that a large amount of combined resource exists in the Atlantic region, particularly off the Western facing coasts of Scotland, Ireland, the UK, Portugal and Spain. This represents a large opportunity for the sector, developing clusters of port infrastructure to facilitate the exploitation of the large amounts of resource in this area.
- Need further research to identify the most efficient way to develop the port infrastructure to exploit the 'hotspot' resource in the region.

### *Port developments in the Mediterranean and Black Sea area:*

As shown in Figure 42 overleaf, there are a large number of existing ports, along all coasts of the Mediterranean and Black Sea area. However, it is important to highlight that, as identified in the Resource chapter of the roadmap, there are limited natural resources in the Mediterranean and Black Sea area. Tidal resources exist in a number of locations, however, the intensity of the wind and wave resources in the region are in general, much lower than for the other two regions analysed.

**Existing ports in the Mediterranean and Black Sea area:**




[Source: ORECCA WP2 Report: 'GIS Project & Calculations']

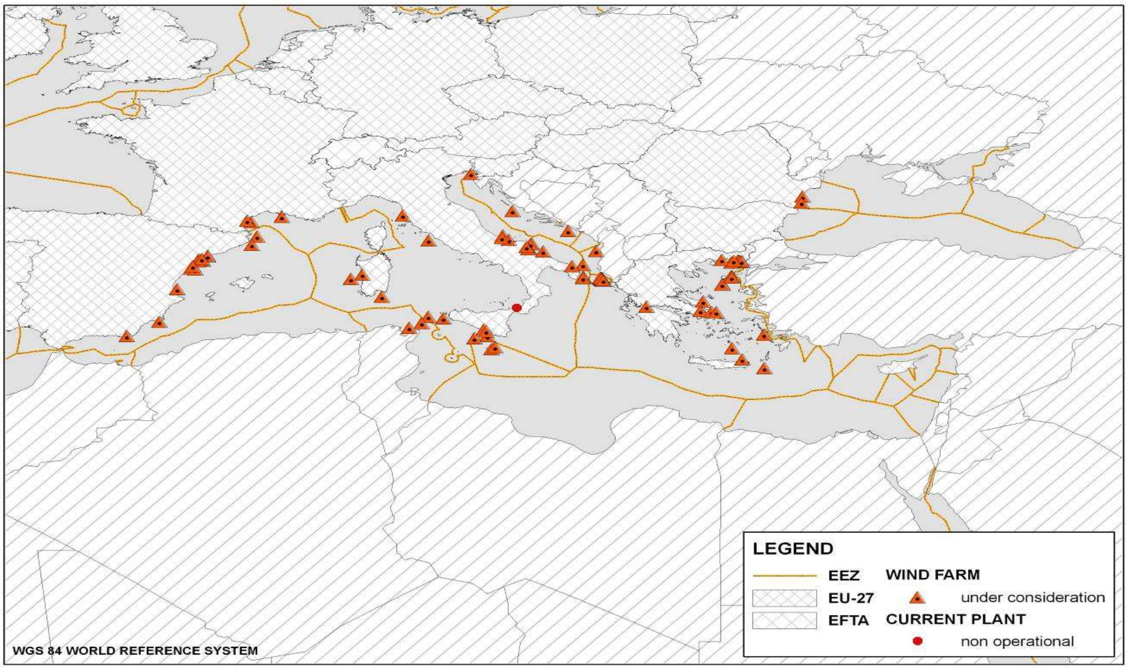
**Figure 42:** Existing ports in the Mediterranean and Black Sea Area. As identified by the Resource section of the roadmap, there are no 'hotspots' of combined natural resource in the region.

It is important to highlight that there are currently no operational offshore renewable energy installations in the region, and this is illustrated in figure 43 overleaf. However, despite this, the figure shows that there are a number of sites under consideration, particularly for offshore wind. A moderate wind resource exists in the region despite the fact that the wave resource is very low, so the opportunities for combined resources are limited. However, this less harsh environment and reduced wave loading may mean that the area is well suited for test sites for developing new offshore wind technologies.

As described above, the natural resources which exist in the Mediterranean and Black Sea area are of lower intensity than in the 'hotspot' areas identified, and they are therefore are not a priority for the sector over the short to medium term. However, as the sector becomes more mature and costs fall, the area may present opportunities for the sector as a secondary market.

Despite being a lower priority for the sector, and presenting a more limited opportunity, ports will still need to be developed in the area to facilitate offshore renewable energy deployments. These deployments will not be on the same scale as in the other regions identified, as the amount of natural resource available and the intensity of this resource is much lower. The development of ports in the region is also likely to be constrained by the complex terrains and high population density surrounding a large number of the ports to the North or the Mediterranean basin.

**Offshore renewable energy plants in the Mediterranean and Black Sea area:**




[Source: ORECCA WP2 Report: 'GIS Project & Calculations']

**Figure 43:** Existing and planned offshore renewable energy plants in the Mediterranean and Black Sea Area. There are no currently operational plants in the area.

**Important points to highlight regarding port developments in the Mediterranean and Black Sea area:**

- There are currently no operational commercial offshore renewable energy plants in the region.
- No 'hotspots' of combined resource have been identified in the region. The area however, whilst not being the principal priority areas of opportunity for the sector, still has resource which can be exploited. In the short and medium term, limited resources in the sector should be focussed on the 'hotspot' areas where the highest intensity combined resources have been identified. As the sectors develop, costs are reduced, and experiences gained, areas of less intense combined resource will form important secondary markets for the sector. Therefore they are not immediate priorities for the sector, as the largest opportunities exist elsewhere, but they still harbour an opportunity which should not be ignored over the longer term.
- Opportunities for developing clusters of port infrastructure to facilitate the exploitation of combined resource 'hotspots' identified are much more limited than for the other two regions.

### *Offshore Service Hubs:*

The concept of offshore service hubs represents a large opportunity for the sector. As identified in the Resource section of the roadmap, a large proportion of the available natural resource in Europe exists far from shore. To exploit this resource, cost reductions could be achieved if different functions could be housed as part of an offshore service hub. This hub could take various roles, including:

1. Solely accommodation focussed hub housing O&M crew and their vessels and a helipad for efficient transport of crew and small equipment;
2. A more developed service hub with workshops, storage space for spare components and equipment and docking areas to facilitate deliveries of large components;

This concept could also be expanded to allow the hub to take on a more developed role in the construction phase of nearby deployments which it is responsible for servicing.

**Key messages – PORTS**

Port infrastructure developments should be focussed around the two key resource 'hotspots' identified where large amounts of high intensity resource exist:

1. The Atlantic Ocean region, off the Western facing coasts of Scotland, the UK, Ireland, Portugal and Spain; and
2. The Northern part of the North Sea, off the coasts of Scotland, the UK and Norway.

-Clustered port infrastructure should be developed to facilitate the exploitation of the large amount of combined resource which exists in these areas.

The four countries with the largest resource endowment (Norway, Ireland, the UK and Scotland) should prioritise further detailed studies (such as the DECC (2009) UK Offshore Wind Ports Prospectus) to plan the finer details of how these clusters of port infrastructure should be developed.

It is important to note that this approach to thinking about port infrastructure in a coordinated way, aiming to develop clusters of port infrastructure to facilitate the exploitation of 'hotspots' of resource identified, is new and has not yet been utilised. This is an important approach for the sector to ensure that the necessary facilitating infrastructure is developed in the most cost effective and efficient way possible.

## *8.2 Vessels Infrastructure*

There are four distinct types of vessels are critical to the sector:

- Transport vessels;
- Installation vessels;
- Cable installation vessels; and
- O&M vessels.

The currently most popular model of offshore energy plant construction utilises separate manufacturing and assembly ports. Therefore transport vessels are utilised to transport components to the assembly ports, and the installation vessels then shuttle the devices to the nearby development site and finish the construction. However, it is important to note that other potential models could be facilitated by technological developments such as high speed jack-up vessels and technologies for transfer-at-sea. These developments could alter the requirements for different types of vessels for the sector.

### *Transport and installation vessels:*

There is a large synergy between the three offshore renewable energy technologies and also with the offshore oil and gas sector with regard to transport and installation vessels. Multipurpose vessels continue to lead the market. Vessels such as jack up barges and heavy lift vessels are flexible and can be used by a number of sectors. Vessels also have a geographic flexibility to travel to different areas to work. For example, they could be developed for the offshore renewable energy sector in Europe, but, they are flexible enough to move around the globe to work in different sectors, particularly the offshore oil and gas sector, as the market dictates.

Despite the large usage of multipurpose vessels that can be used across sectors, specialised vessels for the installation of offshore wind turbines have also been developed. The high deployment rates and long term investor certainty in the offshore wind sector has been necessary to achieve this. In offshore wind, the recent trend in terms of vessels has also been away from having separate vessels for the installation of towers, turbines, foundations and cables, towards large scale vessels which are able to carry out all of these functions. This trend favours the largest vessels which are even able to carry multiple pre-assembled wind turbines.

As the offshore wind, wave and tidal energy sectors progress to deeper waters and further from shore, the installation vessel requirements will change. Therefore, it is useful to break down the synergies between the three sectors with respect to installation vessels in terms of synergies for shallow water installations and synergies for deep water installations:

1. Shallow water installation vessels. Fixed structure offshore wind turbines, fixed structure tidal devices, and shallow water wave deployments all have similar requirements, and these deployments in shallow waters can utilise common installation vessels.
2. Deep water installation vessels. As we progress towards floating offshore wind structures, and wave and tidal devices deployed in deep waters, the installation vessel requirements will be different to those for shallow water deployments. However the requirements (such as dealing with anchors, tension leg platforms, mooring deployments etc.) will be similar across the three sectors, and therefore synergies will exist with respect to installation vessels for these deep water deployments.

It is important to highlight that, in contrast to the installation vessel synergies identified above, for a range of deep water offshore wind and ocean energy technologies, specialised installation techniques and vessels are under development. These include, amongst others, catamaran type transport and installation vessels equipped with heavy lift winches and transport and installation equipment for spar type floating wind turbines. Such solutions have the advantage of being very efficient for the designated purpose but cannot be used to install other technologies. The balance of risk is affected by the decision to use specialised/dedicated, technology specific installation vessels, in contrast to the generic solutions as described above. Some risks are reduced, such as risks of detrimental competition for installation vessels with other technologies and other sectors, while other risks, such as those associated with making a large vessel investment that is tied to the fate of a particular technology, will be increased.

### *Foundation installation vessels:*

Synergies exist between the offshore wind, wave and tidal sectors, where similar foundation types, such as gravity foundations or monopiles are used. These synergies are projected to increase further as the sectors progress into deeper water and further from shore. The mooring technologies and solutions, and consequently the foundation installation techniques will become increasingly common across the three sectors as they progress to deeper water and novel devices such as floating offshore wind turbines etc.

### *Cable installation vessels:*

There is large synergy across the sectors. Cable installation vessels are the same for each technology, and more related to the seabed conditions than the type of technology.

### *O&M vessels:*

O&M vessels is an area where large synergies could exist across the sectors, depending on design. The small type of vessels often utilised are very versatile and able to adapt to a range of roles across a number of sectors. This area of synergy is highly dependent on the design of devices. If wave energy and tidal stream devices are designed to be accessed at sea, similarly to offshore wind turbines, the synergies could be significant. However, if wave and tidal devices are designed to be towed to port for maintenance requirements, the O&M synergies with offshore wind will be significantly reduced.

### *Synergies or competition?*

Synergies have been identified for all four types of vessels. However , it is important to note that, while this means that the sector can take advantage of vessels developed primarily for use in a different sector, and can share vessels across sectors and across regions, it also means that there will be competition. For example, the sector will have to compete with the offshore oil and gas sector, not only for vessels, but also for the expert crew required to operate these vessels. This may have time and cost implications for the sector, and it requires careful consideration.

**Key messages – VESSELS**

- Synergies exist for shallow water and deep water installation vessels. However, these vessels are primarily multipurpose (such as jack up barges and heavy lift vessels) which can be used by a variety of sectors. Therefore it is important to ensure that useful synergies in terms of installation vessels do not manifest themselves as detrimental competition to the sectors.
- Cable installation vessels represent an immediately exploitable synergy between the sectors.
- Vessels suitable for deployments in more extreme weather conditions will need to be developed. By focussing developments in areas where combined resources exist, conditions such as wave loading will be much greater than for the locations of many current offshore wind deployments. Vessels for construction and O&M will have to be developed to take account of these more extreme conditions. Increasing the weather window for which it is possible to operate construction or O&M vessels is also likely to reduce costs.

## *8.3 Grid Infrastructure*

The grid connection requirements are a significant challenge for the three sectors. As identified in the Resource section of the roadmap, two principal hotspots with a large amount of high intensity combined natural resource exist in Europe:

- The Northern part of the Atlantic Ocean Region, off the coasts of the UK, Ireland and France.
- The Northern part of the North Sea, off the coasts of Norway and the UK.

It is important to answer the question: what are the main grid challenges which will have to be overcome to realise the potential in the ‘hotspot’ areas indicated, and which areas have high combined resource level but limited grid capacity? To take advantage of the opportunities presented by developing the offshore renewable energy sector to exploit these natural resources, significant grid infrastructure will be required. As shown in Figure 44 overleaf, the grid infrastructure across Europe is centred around the centres of population, and at its weakest in the areas where some of the ‘hotspots’ for combined resource have been identified, particularly off the North and West coasts of Ireland, Scotland and Norway.

**Electrical transmission grid and combined resource 'hotspots' across Europe:**

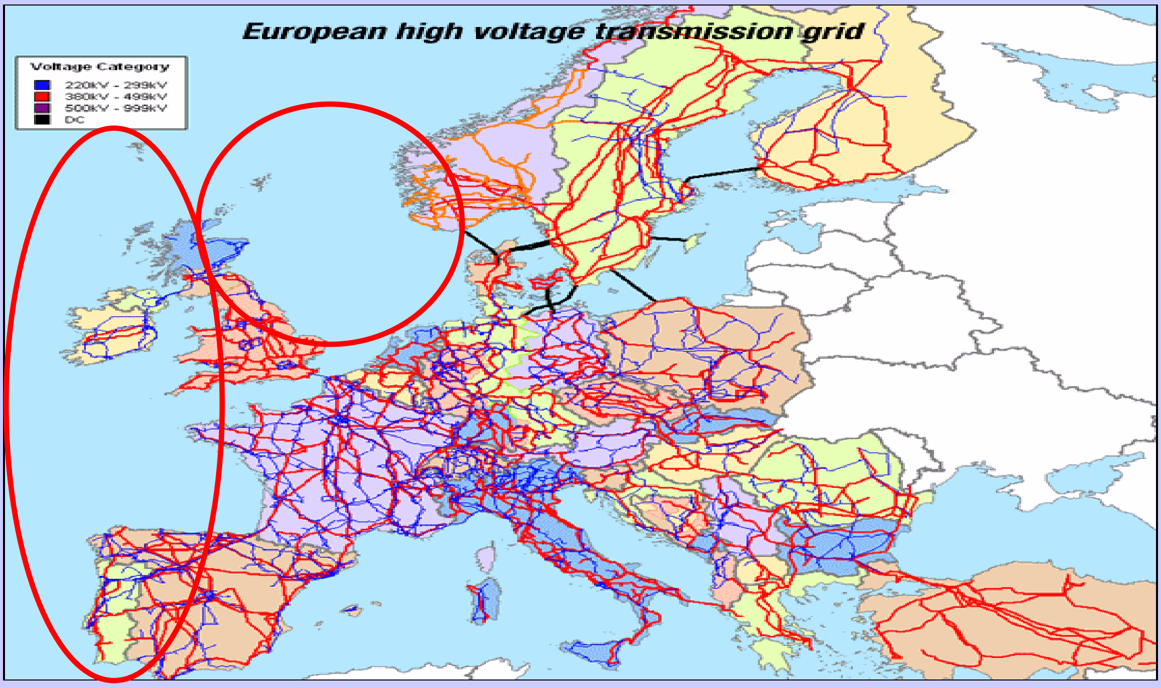



**Figure 44:** Map of the high voltage electrical transmission grid across Europe, with the 'hotspots' highlighted in red where are large amount of high intensity combined natural resource (across wind wave and tidal) exists. (Source: Adapted from Global Energy Network Institute, www.geni.org)

The integration of significant penetrations of energy generation from ocean energy and offshore wind into the European electricity grid will have large implications beyond the physical capacity of the grid infrastructure. A large contributing factor to this is the variability of power production, which varies according to the variability of the primary resources and is therefore very different across the offshore wind, wave and tidal sectors. Integrating these energy sources into the grid whilst ensuring security of supply, especially as large penetrations are reached, is likely to require fundamental changes in the way the electricity system is managed.

Developing smart grids to predict and respond to the behaviour of all electric power users connected to it – suppliers and consumers alike – as well as increasing the role which storage providers and demand response play in managing electricity systems, will be of the utmost importance. To complement this, it is also highly important to improve the accuracy of short-term predictions of the availability of offshore renewable energy sources and their energy production.

A number of important studies are focussed on further investigating issues surrounding grid infrastructure developments. These include the OFFSHORE GRID project [11] which focuses on the issues surrounding the development of an offshore grid in Northern Europe.

[11] www.offshoregrid.eu

**Key messages – GRID INFRASTRUCTURE**

Grid developments to facilitate and support the large scale deployments necessary to exploit the 'hotspot' areas where large amounts of resource have been identified are twofold:

1. European level grid developments. The main priority in this regard is to develop a more advanced and interconnected grid between countries to facilitate the developments. In areas such as the North Sea which is bordered by a large number of countries, European level planning will be required to ensure that offshore grid developments are optimised to support the sector.
2. Nation state level grid developments. The main priority in this regard is increasing the grid capacity in regions where 'hotspots' of resource have been identified, but the current grid infrastructure is inadequate. The four priority areas in this regard are:
    i. The North and West coasts of Ireland;
    ii. The North, West and East coasts of Scotland;
    iii. The North and West coasts of Norway; and
    iv. The East and West coasts of the UK.

[Some of the coastline in the 'hotspot' areas identified, such as the Western facing coastline of Portugal, already has grid infrastructure in place to facilitate significant deployments.]

### *Co-location and grid infrastructure synergies:*

Currently, offshore wind, wave and tidal energy technologies are relatively immature. In the short term, it is therefore generally seen as too early to deploy combined platforms, with a single structure exploiting natural resource from multiple sources (eg. a wind-wave device), until significant amounts of research and modelling to understand the complex interactions for combined platforms is completed. However, combined platforms present a large opportunity for the sector in the longer term and this should not be overlooked.

Despite the current immaturity of combined platforms as a concept, co-location of devices can realise significant benefits with respect to infrastructure. As identified in the Resource section of the roadmap, the most attractive combined natural resource in existence in Europe is combined wind and wave resource, and this presents a large opportunity. There are two principal benefits of co-locating devices (so, for example, an array of wind devices and an array of wave devices either exist in the same area or in closely adjacent areas):

1. Joint utilisation of a single electrical infrastructure (which will allow cost reductions and smoothing of power output from the combined farm).
2. Potential joint utilisation of O&M teams, vessels and infrastructure (this relates closely to the 'offshore service hub' concept outlined above).

As well as co-location, there are other grid infrastructure synergies between the three technologies; offshore wind, wave and tidal. These should be prioritised as areas which will have a large impact on accelerating not just one, but all three of the offshore renewable energy sectors. Important synergies include:

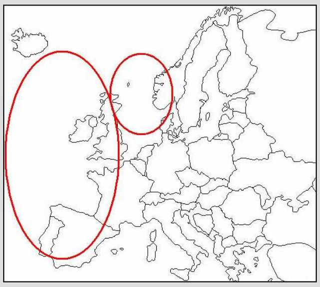
- Submarine cables;
- Marinisation of technologies;
- Development of HVDC allowing power transmission over large distances;
- Technologies for electrical connections to floating platforms; and
- Offshore substations.

**Key messages – CO-LOCATION & GRID SYNERGIES**

- Co-location of technologies represents an important opportunity for the sectors over the short term. The principal benefits are from shared electrical infrastructure and shared O&M teams, vessels and infrastructure. This could help to reduce costs.
- There are important components of grid infrastructure developments which are common to all three offshore renewable energy sectors. These should be prioritised as any efficiencies achieved will have a large impact across the sectors. – Offshore floating or sub-sea substations are an important example, and will be extremely important for all three offshore renewable energy sectors (and have large cost implications).

## 8.4 Key recommendations from this Infrastructure chapter

**The ORECCA roadmap recommends that:**



- Port developments should be clustered to exploit the two broad regions where 'hotspots' of combined resource exist.
- Further research should be conducted to consider where ports need to be developed to support the exploitation of offshore renewables in the 'hotspot' areas as efficiently as possible.
- Countries around the resource 'hotspot' areas identified should conduct further detailed port infrastructure studies (such as the DECC (2009) UK Offshore Wind Ports Prospectus) to determine how their infrastructure clustering should be optimised.
- Countries - particularly Norway, Ireland and the UK - need to prioritise important grid reinforcements to facilitate large scale deployments of offshore renewable energy in the 'hotspot' regions where large amounts of high intensity resource has been identified.
- The European Commission need to prioritise grid developments and reinforcements to improve interconnections across Europe to optimise the exploitation of the resource 'hotspots' identified.

- The necessary infrastructure is prioritised to facilitate the progression to deployments further from centres of population, further offshore, and in deeper waters. This infrastructure will be across grid, ports and vessels. As outlined in the Resource section of the roadmap, this progression is vital to ensuring that a large portion of Europe's theoretically available resource becomes potentially exploitable.

- Efforts should be focussed on the co-location of technologies to exploit areas of combined resource in the most efficient way (joint utilisation of grid and O&M infrastructure).

- The development of the 'offshore service hub' is encouraged as a concept to realise synergies from co-location of technologies and reduce the costs associated with deployments far from shore.

# 9 Environment, Regulation and Legislation

Legal and regulatory issues surrounding environmental protection will have a large impact on the rate of development and sustainability of offshore renewable energy. This roadmap's principal focus is pan-Technology and pan-European, and therefore, in this section, particular attention is paid to how knowledge can be transferred from countries which are at a more advanced stage of development with respect to offshore renewable energy technologies, and how knowledge can be transferred between the nascent wave and tidal stream sectors and the more mature offshore wind sector.

This chapter of the roadmap will focus on three principal aspects:

- The current regulatory and legislative framework in Europe (a detailed analysis of the national regulatory and legislative frameworks across Europe will not be conducted, rather a high level approach will be taken to highlight where gaps exist across countries).
- Key current and projected environmental impacts.
- Important environmental and regulatory/legislative recommendations.

Key gaps, needs and required actions are identified across regions, across countries, and across the three technologies: wind, wave and tidal stream. For example, the issues faced in the Mediterranean area with predominantly deep water, no significant existing deployments and limited research data on environmental impacts will be very different to the issues and, therefore, priorities in other regions. Priority research areas are highlighted, and the time evolution of requirements is reported. As the industry progresses (for example, further offshore and into deeper waters) the environmental issues of most concern will change, and cumulative impacts are expected to become increasingly important.

## *9.1 Existing legislation at the European level*

European legislation that applies to offshore wind, wave and tidal energy is principally constituted by four closely related Directives:

- **Strategic Environmental Assessment (SEA) Directive –** applies to strategic programmes and plans, such as national plans for each type of offshore renewable energy and requires that environmental impacts are identified and integrated into the programme and the plan at the planning stage. Appropriate national authorities will have to complete SEAs ahead of any significant developments. An SEA focuses on identifying the 'likely' significance of 'potential' effects and should therefore be useful to any developer in selecting a site and preparing for an EIA.
- **Environmental Impact Assessment (EIA) Directive.** Offshore wind projects fall into Annex I of the Directive, and therefore an EIA is compulsory. For wave and tidal energy projects, the requirement for an EIA is dependent on whether significant environmental impacts may occur.
- The **Habitats Directive** and the **Wild Birds Directive** (which require the conservation of natural habitats and wild birds respectively) are both referred to in the EIA Directive. This provides that the environmental sensitivity of sites designated under the Birds and Habitats Directives which are likely to be affected by development projects must be explicitly covered in an EIA.

As well as these four Directives, there are other, more recent legislation that will also affect offshore energy. These include:

- The **Water Framework Directive –** aims to achieve good ecological and chemical status of freshwater, transitional and coastal waters. In order to comply with this directive, offshore renewable energy projects should not contribute to the classification of the water body falling below the category ‘good’.
- The **Marine Strategy Framework Directive (MSFD) –** aims to achieve ‘good environmental status’ of the EU’s marine waters by 2020. This is determined on the basis of qualitative descriptors contained in Annex 1 of the Directive. These descriptors include maintenance of biological diversity; concentrations of contaminants at levels not giving rise to pollution effects; and introduction of energy, including underwater noise, at levels that do not adversely affect the marine environment and consequently will have implications for offshore renewable energy devices.
- Offshore wind is also affected by **airspace legal requirements**.

It is important to note that, given the importance of EIAs and SEAs, identifying key environmental issues is not sufficient in itself. Managing impacts by identifying measures to avoid, minimise, reduce or compensate for adverse effects and environmental monitoring are also integral parts.

## *9.2 Regulation and legislation at the national level*

Each country within the EU is responsible for transposing EU legislation into their respective legal system, as well as implementing their own licensing processes for the consenting of projects. National legislative frameworks reflect the EU Directives, but often there is variation between how countries administer such legislative requirements and many associated policies are at different stages of development in different countries.

### Adaptive Management:

Adaptive management is an iterative process of optimal decision making in the face of uncertainty, aiming to reduce uncertainty over time. Regulators and legislators are presented with uncertainty with regard to the offshore wind and ocean energy sectors due to their relatively early stages of development and the fact that not all impacts are yet known and well understood. However, the offshore renewable energy sector lends itself well adaptive management or a ‘deploy and monitor’ approach where data obtained from early deployments – particularly demonstration projects – provides the input which is used as a basis for legislation and regulation decisions. The principal reason the sector is well suited to this approach is the fact that deployments in the sector are incremental. As the sector moves from prototype devices, to small arrays, and eventually medium sized and large arrays, there is much opportunity for learning and the gathering of information. Regulators and legislators should be able to take large comfort from this. In this vein, demonstration projects should be encouraged to obtain reliable data to inform future policy, regulation and legislation.

### Maritime Spatial Planning (MSP):

The principal purpose of Maritime Spatial Planning is to optimise the use of maritime space to benefit both economic development and the marine environment. Comprehensive spatial planning is a necessary and an important step towards considering all environmental issues, and Maritime Spatial Plans, based on a common approach are urgently required in all EU Member States. In this context the European Commission developed a roadmap for MSP in 2008 to facilitate the development of MSP by Member States. This contains key principles for MSP and seeks to encourage the development of a common approach among Member States. In December 2010 the Commission adopted the Communication 'Maritime Spatial Planning in the EU – Achievements and future development'. This concludes that action is now needed at EU level and in this regard an impact assessment has been launched to explore a range of options to promote and develop MSP and Integrated Coastal Zone Management (ICZM). The outcome of this work will be presented in late 2011.

Maritime Spatial Plans are an important tool for social cohesion, industrial development and environmental protection and are important to effectively manage the interaction between offshore renewable energy systems and other users of the sea. MSPs also need to consider cumulative effects[12] and far field effects[13], which are both extremely important for the sector. In some countries, plans exist, or are in an advanced stage of development. If it is not possible to complete a national or regional statutory MSP in time ahead of significant developments in the sector, non-statutory national or local guidance may suffice. Figure 45 overleaf outlines a best practice example from Scotland in this circumstance.

### "One stop shops":

In all countries many laws will apply to offshore renewable developments (laws on environmental protection, electricity, coastal protection etc.). Currently, in many countries, the planning and consenting processes are not optimised for offshore renewable energy, with different requirements (such as submitting an EIA, obtaining planning permission, obtaining a licence to generate, obtaining a grid connection licence, etc.) implemented by different organisations such as government departments or regulators. Streamlined planning processes are important to accelerate developments in the sector, and are already at various stages of implementation in some countries. Some countries have already developed 'one-stop-shops' for offshore renewable energy projects, with a single organisation responsible for providing guidance through the administrative process. An example of best practice in this regard is described in figure 45 overleaf. There are two important principal aspects of a 'one-stop-shop' being placed at the centre of a marine consenting system:

1. Guidance should be readily available on the applicable laws and processes to provide current information necessary to comply with legislation and regulation; and
2. A single organisation is responsible for providing this advice and guiding project developers through the planning and consenting process.

[12] A cumulative effect can be defined as one resulting either from different activities at the same site (multi-activity), or a similar activity at more than one site (multi-site), such that the effect could not be calculated by considering each activity in isolation.

[13] Far field effects are effects of an activity far from the location of the activity.

**Example of best practice for MSP and 'One stop shops':**

Scotland's **"Pentland Firth and Orkney Waters Marine Spatial Plan Framework and Regional Locational Guidance for Marine Renewable Energy"** is a non-statutory guidance document which was drafted in 2009 to guide wave and tidal developments in Scotland, in the absence of a statutory national MSP at that time.

- This is a good example of comprehensive guidance issued where a statutory plan could not be completed ahead of significant development.

[Available at: http://www.scotland.gov.uk/Publications/2009/06/03120519/0]

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In Scotland, advice on the applicable laws and processes for offshore renewable energy projects is readily available through a single authority, Marine Scotland. This advice includes three principal documents:

- "Marine Renewables Licensing in Scotland" (Marine Scotland Topic Sheet no. 11) (http://www.scotland.gov.uk/Resource/Doc/295194/0112269.pdf);
- "The one stop shop for marine licensing in Scotland: Introduction of the Marine License, April 2011" (Marine Scotland Topic Sheet no. 80) (http://www.scotland.gov.uk/Resource/Doc/295194/0116739.pdf); and
- "Scotland's Marine Atlas – 'Information for the National Marine Plan" (http://www.scotland.gov.uk/Publications/2011/03/16182005/0). This document outlines some important environmental impacts and is a useful example of an informal statement of priorities that underlies the likely requirements of an EIA for offshore renewable developments in Scotland. -Similar guidance would be useful throughout the EU.


**Figure 45:** Scotland as an example of best practice with respect to Maritime Spatial Planning and issuing guidance on applicable laws, processes and requirements for offshore renewable energy projects in a 'one stop shop' fashion.

**Key points to highlight:**

- The offshore renewable energy sector is well suited (due to the incremental nature of deployments in the sector) to an adaptive management approach where the information gained from early deployments is used to guide future regulation and legislation.

- Maritime spatial plans and Strategic Environmental Assessment at a large scale and broad perspective, together with Environmental Impact Assessments at site scale can positively promote the sustainable development of the offshore renewable energy sector.
- One stop shops for marine consenting will realise large efficiencies over current, often fragmented consenting processes. This can alleviate barriers to development associated with a slow and complicated consenting process.

## *9.3 The national planning and consenting policy landscape across Europe*

Countries across Europe are at different stages of developing and implementing the necessary regulatory and legislative frameworks to facilitate the development of the offshore renewable energy sector. Three principal factors are identified in Figure 46 below which are illustrative of how developed the regulatory/legislative frameworks are in each country:

1. **Does the country have a Strategic Environmental Assessment (SEA) in place (broken down by wind, wave and tidal)?;**
2. **Does the country have a Maritime Spatial Plan (MSP) in place?; and**
3. **Does the country have a streamlined or one-stop-shop marine consenting process?**

**National policy landscape across Europe:**

| Country | Is there an SEA in place: | | | Is there an MSP in place? | Is there a 'one stop shop' marine consenting process? |
|---|---|---|---|---|---|
| | For offshore wind? | For wave? | For tidal? | | |
| **Belgium** | Yes | No | No | Yes | No |
| **France** | Yes | No | No | Partially | No |
| **Germany** | Yes | No | No | Yes | No |
| **Ireland** | Yes (provisionally) | Yes (provisionally) | Yes (provisionally) | Preparatory steps | Pending |
| **Italy** | No | No | No | No | No |
| **Netherlands** | Yes | No | No | Yes | No |
| **Spain** | Yes | No | No | Preparatory steps | No |
| **UK** | Partially, Pending | Pending | Pending | Partially and pending | Partially |
| **Portugal** | Under Development | Partial | No | Under Development | No |
| **Norway** | Yes | No | No | Partially | No |
| **Denmark** | Yes | No | No | Partially | Yes |
| **Scotland** | Yes | Yes | Yes | Partially | Yes |

**Figure 46:** Matrix showing three important factors for supporting the development of the offshore renewable energy sector, analysed across Europe. (Source: ORECCA WP2 – Environment, Regulation and Legislation; Full report). [14] **[Green: Yes. Orange: Partially/pending. Red: No].**

[14] N.B. The table is completed as accurately and completely as possible with information available July 2011. Much greater detail including notes for each of the countries included in the table is included in the full report.

It is clear from figure 46 above that different countries are at different stages of implementing MSPs, SEAs for each of the three sectors and one stop shop marine consenting systems. Some countries (such as Scotland and Ireland) are at further stages of implementing these three important national policies, with important progress made on all three aspects. Other countries, especially the UK, France, Norway, Portugal and Spain (which have been identified in the Resource chapter as having a large amount of combined offshore wind, wave and tidal resource) need to continue to progress in this regard to realise the large opportunities presented by the sector.

The variation and uncertainty in the application of legislation and associated policies across Europe is perceived as a barrier to development of the sector and there is a clear case for harmonisation across countries. Most national policies have moved, or are in the process of moving, towards 'one-stop-shop' administration of marine consenting. Further legislation will be enacted as marine energy enters national markets and will be updated in the light of experience. Developers will need to keep abreast of changes in legislation, emerging policy areas and also the evolving requirements of EIAs.

**Key points to highlight from the analysis of the national policy landscapes across Europe:**

- Different countries are at different stages of putting an MSP in place, implementing a 'one stop shop' for marine consenting, and putting SEAs in place for each of the offshore wind, wave and tidal sectors.
- These have been identified as important factors for facilitating the development of the offshore renewable energy sector.
- Some countries (such as Scotland and Ireland) are at further stages of implementing these three important national policies. Other countries, especially the UK, France, Norway, Portugal and Spain (which have been identified in the Resource chapter as having a large amount of combined offshore wind, wave and tidal resource) need to continue to progress in this regard to realise the large opportunities presented by the sector.

## *9.4 Key Challenges*

### Environmental Issues:

A wide breadth of environmental issues must be considered by offshore energy developers, and many authors (such as EquiMar[15]) have discussed potential impacts. All information will not be repeated here, but rather key issues are identified, and illustrated in Figure 47 overleaf. While there are clear environmental principles and requirements set out by EU Directives, these don't immediately translate into simple guidance for a prospective developer. The appropriate national authority (or authorities) should be able to provide guidance, but particularly in the case of wave and tidal energy, this guidance is not yet comprehensive. It is possible to predict many of the likely effects from the experiences of other offshore sectors, and some key issues follow directly from the applicable EU Directives. However, there are some more broadly based, strategic requirements which follow much less obviously from

[15] http://www.equimar.org/

other legislation (under legislation such as the Water Framework Directive and the MSFD which are potentially very significant, especially for wave and tidal stream developments which are likely to alter water flow and wave exposure and introduce noise to the marine environment).

**Important considerations when investigating the environmental impacts of offshore renewable energy developments:**

- **Direct impacts on species;**
- **Indirect impacts on species (via habitat impacts);**
- **Public perception;**
- **Impacts on the fishing and shipping industries that will have knock on consequences for the environment;**
- **Impacts on the historic environment**;
- **Cumulative impacts;**
- **Impacts of necessary additional activities such as subsea cables;**
- **Impacts of activities during all stages of development** (survey, construction, operation, maintenance and decommissioning);

**Figure 47:** Important considerations when investigating the environmental impacts of offshore renewable energy developments.

## Cumulative impacts:

While individual developments might be insignificant or benign, numerous developments together might have different and greater effects. Cumulative impacts are necessarily difficult to assess. More predictions, measurement and monitoring of the inherently complex cumulative impacts will be required as the level of deployment increases, and these cumulative impacts may be one factor which sets a practical limit for the scale of development of the sector. While these cumulative impacts are a distant and common interest rather than the concern of any individual developer, they cannot be ignored in the near future. Since offshore wind has developed to a much larger scale than wave or tidal, the consideration of cumulative impacts has also developed further, particularly with respect to birds. However, some progress has been made also for wave and tidal. The Habitats Directive requires an assessment of “in-combination effects” and thus cumulative impacts should be considered as an integral part of any EIAs and SEAs conducted.

## Public Perception:

Public perception and acceptance is important for offshore renewable energy developments, and depends on many factors, including factors covered by the EU directives and related to the environment:

1. Concern for the environment and especially some species;
2. Perceived or actual visual and noise impacts on their own environment; and
3. Socio-economic factors including conflict with economic or social activity.

- Relatively little significant research exists on aspects of public perception of the offshore renewable energy sector. Therefore, addressing the public perception and factors affecting the public acceptability of offshore energy is both an immediate and an ongoing priority.

## 9.5 *Commonalities Across Sectors and Across Countries*

Different sectors and regions are at different stages of development. For example, some regions (e.g. North and Baltic Seas for offshore wind) and nations are at a further stage of development than others (e.g. Mediterranean region). The offshore wind sector is also at a higher level of maturity than the relatively nascent wave and tidal energy sectors. It is important to highlight that some factors are entirely transferable across countries and across the three sectors, whilst others, such as public perception are very different across countries and sectors and experiences cannot be easily transferred. European Directives that determine a large part of the national policy landscape in individual countries are pan-European but there is a limited amount of scope for the Directives to be applied differently in different countries in the national legislation and the associated national policies that ultimately govern the requirements in a given country.

**Differences across countries and across offshore wind, wave and tidal:**

Some factors are entirely transferable across countries and across the three sectors, whilst others, such as public perception are very different across countries and sectors and experiences cannot be easily transferred. Some important differences between offshore wind, wave and tidal stream devices (which mean that many issues are not transferable between the sectors) are displayed in figure 48 below:

| | Offshore Wind | Wave | Tidal stream |
|---|---|---|---|
| **Rotating parts subsurface:** | ✗ | ✗ | ✓ |
| **Moving parts above surface:** | ✓ | ✗ | ✗ |
| **Remove hydrokinetic energy from the oceans:** | ✗ | ✓ | ✓ |
| **Remove kinetic energy from the atmosphere:** | ✓ | ✗ | ✗ |

**Figure 48:** Differences between the offshore wind, wave and tidal stream sectors which have a significant impact on their environmental impacts and the applicable legislation and regulation.

There is nevertheless transferable knowledge on environmental impacts. Experimental design, data management, surveying and monitoring techniques may be broadly similar between nations and sectors. The identification of piling as a hazard (through acoustic trauma) by national studies (especially UK; Huddleston, 2010) are likely to translate to all nations. EMF effects (highly uncertain at present) mainly relate to cabling and are a common concern for all of the industry. Generally while species, devices and sites will vary, there should be generic lessons on the way in which large organisms behave near wave and tidal devices. Similarly, once the effects of flow alteration can be effectively monitored in one region, those methods should be successfully applied elsewhere (indeed for far field effects the modelling should not be limited by national boundaries).

## 9.6 *Time Evolution of Priorities*

The relationship between progression of the industry and the priority of environmental issues is related to the following:

1) **Resolution of environmental issues:**
    a. Proof that issues are not significant, or
    b. Issues are significant, but a suitable EIA protocol is agreed

2) **Changing technology and methods:** Novel devices and industry methods may interact differently and thus existing protocols may have to be rethought. Issues surrounding methods such as piling are a current priority, but this will change if the methods cease or effective mitigation is proven. The principles of 'adaptive management' should therefore be central to any applicable governance regime.
3) **New development sites:** The progression to deeper water and further offshore, particularly for offshore wind and wave energy, is predictable. However this is unlikely to raise many genuinely new issues, rather mainly involving similar environmental issues further offshore and in deeper water.
4) **Increasing cumulative effects:** Cumulative effects are an immediate issue for offshore wind, and will become progressively more important. For wave and tidal, cumulative effects are relatively unimportant while there are only a few small developments (though an assessment of cumulative impacts is required in an EIA).

The projected progression of impacts for the ocean energy sector (wave and tidal energy) is shown in Figure 49 below, as it develops from its current, nascent stage of development where the only deployments are prototypes undergoing testing, through to large scale commercial deployments.

**Progression of impacts and priorities as the sector develops:**

1. **Demonstration and small arrays:** (<10MW) - Environmental effects mainly related to individual devices. Limited cumulative effects. Allaying fears with respect to the direct interaction with marine species and understanding local alterations in habitat will be the principal priority.
2. **Locally high exploitation:** Some large arrays (10-100MW) - Interaction between nearby developments resulting in significant cumulative impacts in terms of migration, flow, sedimentation etc. More predictions and measurement of flow alteration (including far field alterations) will be required, particularly for tidal stream deployments. The greater physical barrier of large arrays may have significant impacts such as on migration, navigation and fishing. Interactions significant for individual devices are likely to become progressively more significant, and could impact upon population levels of species.
3. **Major power generation capacity:** (>10GW) - Energy extracted becomes a significant fraction of the energy responsible for stirring the sea, potentially requiring a transboundary assessment of cumulative impacts. This alteration in the state of the seas is a very complicated interaction. Note however that other pressures, such as climate change, are already acting on the seas, therefore predicting the effect of energy extraction is only a part of predicting the changing seas and there is not an option simply to preserve the *status quo*.

**Figure 49:** Description of how the impacts and priorities for the ocean (wave and tidal) energy sector progress as the sector develops through three simplified levels of deployment.

It is important to note that the progression of impacts and priorities will be very different for the offshore wind sector as capacity grows. Very large offshore wind farms (> 100 MW) already exist. The effect of removing large amounts of wind energy (> 100 GW) from the environment may be significant, but further research in this regard is required. The cumulative effect on bird migration of very many large offshore wind farms also requires further research and investigation. Due to the level and scale of current offshore wind deployments, cumulative impacts should be a priority for future research.

**PRIORITY RESEARCH AREAS**

In light of the key environmental impacts which have been identified and the important progression of the environmental priorities of the sectors as they develop, outlined above, the following should be prioritised as priority research areas in the sector:

- Cumulative effects of offshore wind, wave and tidal;
- EMF effects of sub-sea power cables;
- Behaviour of species near wave and tidal devices (risks need to be established);
- Flow alteration, sedimentation and habitat change near devices, particularly wave and tidal stream devices;
- Mitigating actions for the detrimental effects of piling.
- The effectiveness and desirability of offshore renewable energy developments to act as *de facto* Marine Protected Areas (MPAs);
- Optimising design (with respect to technology, location, timing and scale) to maximise beneficial effects of developments and minimise damage.

## 9.7 Key recommendations from this Environment, Regulation & Legislation chapter

**The ORECCA Roadmap recommends that:**

- Legislation and regulation should be harmonised across Europe, as far as practical.
- Implementation of streamlined one-stop-shop marine planning systems should be encouraged for countries which haven't already implemented these.
- Maritime spatial plans should be developed in countries where these are not already in place.
- Developers and authorities should share experiences on EIAs and EIA requirements should be clearly defined and communicated to developers by the responsible regulatory authority.
- An SEA should be conducted in each country, for each of the three technologies, preceding commercial-scale development
- Appropriate national authorities should issue guidance necessary to ensure compliance with current legislation and regulation.
- Legislation and regulation should anticipate the growth and trends of the industry, such that the industry has foreknowledge of the requirements facing them
- Since anticipating all impacts ahead of development is impossible, an "adaptive management" or "deploy and monitor" approach should be adopted that is facilitated within legislation and regulation. This approach allows valuable learning by implementing.

- There should be recognition of broader issues (e.g. competing pressures of climate change, fishing and marine transport). The positive impacts of developments might outweigh some localised environmental impacts.
- There must be recognition that scientific understanding is incomplete and therefore protocols may require alteration (including the possible removal of some EIA requirements if they prove unnecessary) as understanding improves.
- Test sites for demonstration and development should be encouraged, as an important opportunity to investigate potential environmental impacts and further increase understanding of environmental issues. Test centres should have a comprehensive environmental baseline and EIA in place to allow them to become not only R&D centres for devices, but also for environmental effects.
- Policies should be put in place to ensure that research is focussed on the priority areas outlined above, including cumulative effects, EMF effects of sub-sea power cables, behaviour of species near devices, flow and sedimentation alteration by devices, and mitigating actions for the detrimental impacts of piling.

# 10 Key Actions and Recommendations

Each of the roadmap's five principal streams (Resource, Finance, Technology, Infrastructure, and Environment, Regulation & legislation) has included key messages and important recommendations for the development of the sector and the realisation of the large opportunities presented by the sector which have been identified. –This section of the roadmap will draw together the key actions and recommendations from across the other sections of the roadmap and present a way forwards for the sector.

Key points to highlight and key recommendations have been highlighted in red and grey text boxes throughout the roadmap. However, they will not all be repeated in this section. Rather, the key and priority actions will be drawn out and presented.

It is important to reiterate the target audience of the roadmap's recommendations. The principal target audience of the recommendations and actions are policy makers at the EU and Member State level. Policy makers at EU and Member State level are the principal decision makers for many of the principal actions identified to progress the sector, and they have therefore been chosen as the primary audience of this roadmap. However, the recommendations and the way forwards for the sector are also of high importance for other stakeholders to the offshore renewable energy sector, as identified in the roadmap's introduction.

Two principal hotspots of large amounts of high intensity natural resource have been identified in Europe. These are located:

1. In the Northern North Sea; and
2. In the Western facing Atlantic coastline.

In the short to medium term, all of the recommendations should be focussed on facilitating developments in these two areas which present the largest opportunity for the sector.

A less intense, but still significant combined natural resource also exists in other regions. This resource presents a future opportunity for the sector once floating wind and offshore wave power are commercial. –This is an important example of an area where a combined resource exists, but not of the same intensity as the 'hotspot' regions identified in the Resource section of the roadmap. These areas, whilst not being the principal priority areas of opportunity for the sector, still have a significant amount of natural resource which can be exploited. In the short and medium term, limited financial resources in the sector should be focussed on the 'hotspot' areas where the highest intensity combined natural resources have been identified. As the sectors develop, costs are reduced, and experiences gained, areas of less intense but still significant combined natural resource will form important secondary markets for the sector. Therefore they are not immediate priorities for the sector, as the largest opportunities exist elsewhere, but they still harbour a significant opportunity which should not be ignored over the longer term.

**The ORECCA roadmap recommends that EU and member state administrations:**

1. **Develop more R&D funding opportunities specifically targeted at the offshore renewable energy sector.** This clearly allocates funds to the sector and allows government to steer investments.
2. **Maintain a careful balance between market-pull and technology push support for the sector** to ensure that both large scale deployments and research into technologies which could realise large cost reductions for the sector are supported.
3. **Maintain technology-push capital support measures** to ensure step change cost reductions and performance improvements.
4. **Ensure a long term market signal in all countries to increase investor certainty in the sector.**
5. **Develop funding opportunities (particularly production incentives) in countries where a large natural resource exists but no market mechanisms are in place to support the development of the sector.**
6. **Develop new risk sharing mechanisms to facilitate investment in the sector**
   - Government underwritten guarantees and utilisation of public funds as a form of guarantee for private financial bodies can help to mitigate risks, especially to develop the first deployments of new technologies (when reliable data on investment returns and device performance is limited) and to complete the construction phases of projects (when investors are exposed to higher risks).
7. **Continue to encourage cross border collaboration on projects** in the sector to drive costs down and promote knowledge transfer.
8. **Continue funding for demonstration projects** to accelerate the development of the sector by 'learning by experience'.
9. **Provide targeted financing to support the development of the necessary technologies to facilitate deeper water and far from shore deployments** to realise the large potential resource in these conditions identified in the Resource section.
10. **Create policies to develop design consensus within the ocean energy sector.**
11. **Design policies which ensure that all possible subcomponent development activities are developed in a way so as to provide common solutions across the three offshore renewable energy sectors.**
12. **Put policies in place to provide guidelines for funding bodies** to ensure that allocation of development funding is in line with the technical timelines and priorities set out in the technology chapter of this roadmap.
13. **Put policies in place – for the offshore wind sector - to concentrate technology development activities on 9 high priority areas:**
    - Offshore dedicated turbine system demonstration;
    - Ultra reliable turbine demonstration
    - Large blade rotors (>150m);
    - Jacket foundations;
    - Concrete foundations;
    - Design standards (structural, mechanical, electrical, control etc);
    - Testing and installation standards;
    - Health and safety standards; and
    - Advanced drive train research.

14. **Put policies in place – for the ocean energy sector – to concentrate technology development activities on 16 high priority areas:**

- 1st generation device and array trials;
- Performance data collection;
- Installation methods;
- Recovery methods;
- Cost effective O&M techniques;
- 2nd generation device development;
- Control systems;
- Energy conversion systems;
- Foundations and mooring systems;
- Wet HV connectors;
- Performance guidelines/specifications;
- Design of installation tools;
- Device modelling tools;
- Array design and modelling tools;
- Resource analysis tools; and
- Reliability modelling tools.

15. **Ensure a mature coherent and adaptive approach to policy with regard to technology** developments, across international energy arenas, to provide an appropriate combination of support mechanisms, and ensure effective distribution of investments as the sector matures.
16. **Develop clustered port and offshore supply chain infrastructure** to facilitate the exploitation of the two key natural resource 'hotspots' identified. - This represents a large opportunity for the sector.
17. **Prioritise further detailed studies** (such as the DECC (2009) UK Offshore Wind Ports Prospectus) **to plan the finer details of how their clustering of ports and offshore supply chain infrastructure should be optimised**.
18. **Prioritise important National level grid reinforcements** (particularly in Norway, Ireland, and the UK). In these four countries, a large amount of natural resource has been identified, but the current grid infrastructure is inadequate to facilitate its exploitation and the full realisation of the opportunity presented for the sector.
19. **Prioritise important European level grid developments and reinforcements** to improve interconnections across Europe to optimise the exploitation of the natural resource 'hotspots' identified. The main priority in this regard is to develop a more advanced and interconnected grid between countries to facilitate the developments. In areas such as the North Sea which is bordered by a large number of countries, European level planning will be required to ensure that offshore grid developments are optimised to support the sector.
20. **Take a coordinated approach, at the European level, when considering the development of grid, ports and offshore supply chain infrastructure.** The approach outlined here, of taking a coordinated approach and developing clusters of port infrastructure to facilitate the exploitation of natural resource 'hotspots' will need firm commitment at the EU level if it is to achieve success and ensure that the necessary facilitating infrastructure is developed in the most cost effective and efficient way possible.
21. **Concentrate on providing the necessary infrastructure** (across grid, ports, supply chain and vessels) **to facilitate the progression to deployments further from centres of population, further offshore, and in deeper waters.** - This progression is vital to ensuring that a large portion of Europe's available natural resource becomes potentially exploitable.

22. **Focus on co-location of technologies to exploit areas of combined natural resource in the most efficient way** (joint utilisation of grid and O&M infrastructure). Co-location of technologies represents an important opportunity for the sectors over the short term. Benefits from shared electrical infrastructure and shared O&M teams, vessels and infrastructure will drive down costs for the sector.

23. **Encourage the development of the 'offshore service hub' as a concept** to realise synergies from co-location of technologies and reduce the costs associated with deployments far from shore.

24. **Focus efforts on** developing important infrastructure subcomponents common to all three offshore renewable energy sectors (such as offshore substations and HVDC systems allowing efficient power transmission over large distances). Cost reductions and performance improvements in these components of grid infrastructure will have a large impact across the sectors.

25. **Focus research into the environmental impacts of offshore renewable energy devices into seven priority areas**: cumulative effects, EMF effects of sub-sea power cables, behaviour of species near wave and tidal devices, flow alteration, sedimentation and habitat change near devices, mitigating actions for the detrimental effects of piling, the effectiveness and desirability of offshore renewable energy developments to act as *de facto* Marine Protected Areas, and optimising design (with respect to technology, location, timing and scale) to maximise beneficial effects of developments and minimise damage.

26. **Harmonise legislation and regulation across Europe, as far as practical.**

27. **Implement streamlined one-stop-shop marine consenting systems for countries which haven't already implemented these.** One stop shops for marine consenting will realise large efficiencies over current, often fragmented consenting processes. This can alleviate barriers to development associated with a slow and complicated consenting process. Different countries are at different stages of implementing a 'one stop shop' for marine consenting. Denmark, Scotland and Ireland are the only countries which have progressed towards a fully implemented one stop shop system for marine consenting.

28. **Develop Maritime spatial plans in countries where these are not already in place.**

29. **Conduct an SEA in each country, for each of the three technologies**, preceding commercial-scale development. Most countries have an SEA in place for offshore wind. However this is not the case for the ocean energy sector, and this should be an important priority, especially for countries such as the UK, Norway, and France which have been identified as having a large amount of natural resource, but do not yet have fully implemented SEAs in place for the wave and tidal energy sectors.

30. **Ensure that appropriate national authorities issue guidance necessary to ensure compliance with current legislation and regulation.** This includes ensuring that EIA requirements are clearly defined and communicated to developers by the responsible national regulatory authorities.

31. **Encourage and facilitate developers and authorities to share experiences on EIAs.** Information sharing on EIAs would realise large efficiency savings, but mechanisms to allow this need to be developed to avoid commercial issues.

32. **Promote and encourage an "adaptive management" or "deploy and monitor" approach** and ensure that this is facilitated within legislation and regulation. - Since

anticipating all impacts ahead of development is impossible, this is a valuable approach, allowing learning by implementing.

33. **Ensure that legislation and regulation evolve and anticipate the growth and trends of the industry, such that the industry has foreknowledge of the requirements facing them.** This includes ensuring that there is recognition that scientific understanding is incomplete and therefore protocols may require alteration (including the possible removal of some EIA requirements if they prove unnecessary) as understanding improves.

34. **Consider competing pressures** (such as climate change, fishing and marine transport) **when assessing environmental impacts of developments.** There should be recognition that the positive impacts of developments on issues such as climate change might outweigh some specific, localised environmental impacts.

35. **Encourage the use of test sites for demonstration and development as an important opportunity to investigate potential environmental impacts** and further increase understanding of environmental issues. Test centres should have a comprehensive environmental baseline and EIA in place to allow them to become not only R&D centres for devices, but also for environmental effects.

# 11 Appendix 1 – Existing Roadmaps in the offshore renewable energy sector

**Existing Wind Energy Roadmaps:**

- International Energy Agency (IEA): Wind Energy Technology Roadmap

http://www.ieawind.org/wnd_info/IEA_Paris/Wind_Roadmap.pdf

- European Wind Energy Association (EWEA): Oceans of Opportunity Roadmap

http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/Offshore_Report_2009.pdf

- TP Wind: Strategic Research Agenda Market Deployment Strategy: From 2008 to 2030 (SRA/MDS)

http://www.windplatform.eu/fileadmin/ewetp_docs/Bibliography/SRA_MDS_July_2008.pdf

- European Wind Initiative

http://www.greenpeace.org.uk/MultimediaFiles/Live/FullReport/6204.pdf

- Greenpeace & Garrad Hassan: Sea Wind Europe

http://www.ewea.org/fileadmin/ewea_documents/documents/publications/EWI/EWI_2010_final.pdf


**Figure 50:** Existing roadmaps in the wind energy sector, written by various authors.

**Existing Ocean Energy Roadmaps:**

- EU Ocean Energy Association (EU-OEA): Oceans of Energy Roadmap
  http://www.eu-oea.com/euoea/files/ccLibraryFiles/Filename/000000000827/ocean%20vectorise%2010%20mai%202010.pdf
- UK Energy Research Centre (UKERC): Marine (Wave and Tidal Current) Renewable Energy Technology Roadmap
  http://ukerc.rl.ac.uk/Roadmaps/Marine/Tech_roadmap_summary%20HJMWMM.pdf
- UK Department of Energy and Climate Change (DECC): Marine Energy Action Plan
  http://www.decc.gov.uk/assets/decc/what%20we%20do/uk%20energy%20supply/energy%20mix/renewable%20energy/explained/wave_tidal/1_20100317102353_e_@@_marineactionplan.pdf
- Forum for Renewable Energy Development in Scotland's Marine Energy Group (FREDS MEG): Marine Energy Roadmap
  http://www.scotland.gov.uk/Resource/Doc/281865/0085187.pdf
- US Department of Energy: The United States Marine Hydrokinetic Renewable Energy Technology Roadmap
  http://www.oceanrenewable.com/wp-content/uploads/2010/05/1st-draft-roadmap-rwt-8april10.pdf

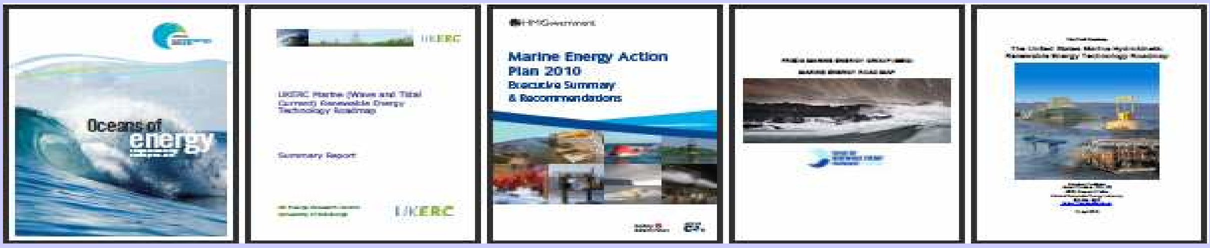


**Figure 51:** Existing roadmaps in the ocean energy sector, written by various authors.