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Overview of European innovation activities in marine energy technology

Teodora Diana Corsatea
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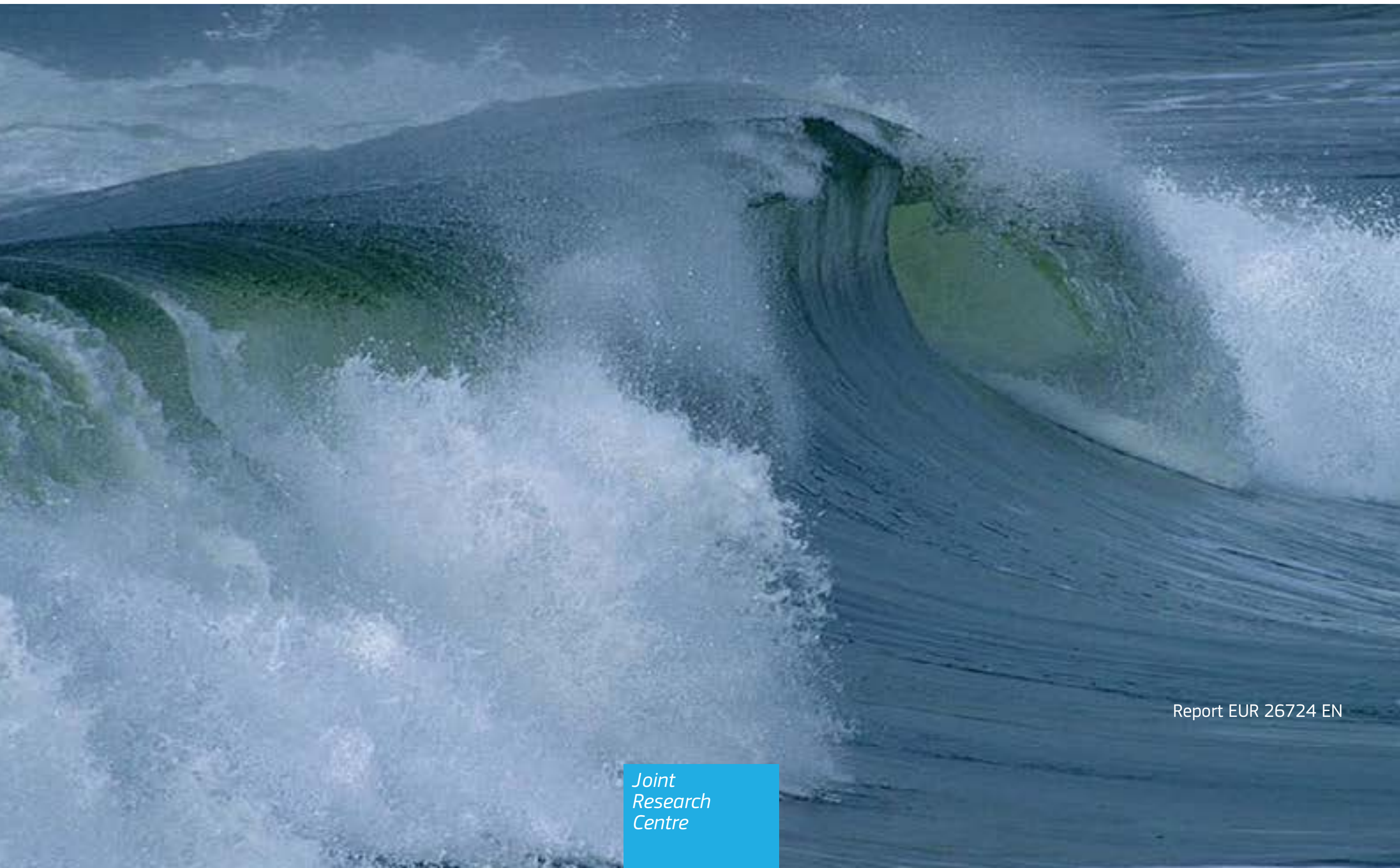

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LIST OF ACRONYMS

€	euro
bn	billion
DoE	Department of Energy (USA)
EC	European Commission
EERA	European Energy Research Alliance
EII	European Industrial Initiative
EIB	European Investment Bank
ERBD	European Bank for Reconstruction and Development
EPO	European Patent Office
EPSRC	Engineering and Physical Sciences Research Council
EU or EU-28	European Union
EWTEC	European Wave and Tidal Energy Conference
FP	Framework Programme
FiT	Feed-in-Tariffs
FiP	Feed-in-Premiums
GDP	Gross Domestic Product
GWh	Gigawatt hours
IEA	International Energy Agency
IEE	Intelligent Energy Europe
INORE	International Network on Offshore Renewable Energy
JRC	Joint Research Centre (of the European Commission)
JTI	Joint Technology Initiative
MS	Member State of the European Union
MEC	Marine Energy Converters
MRE	Marine Renewable Energy
MW	Megawatt
n.a.	Not available
NACE	Statistical Classification of Economic Activities
NREAP	National Renewable Energy Action Plans
OECD	Organisation for Economic Co-operation and Development
PJ	Petajoule
PTO	Power Take Off
R&D	Research and Development
RD&D	Research, Development and Demonstration
TRL	Technology Readiness Level
TWh	Terawatt hours
SETIS	Strategic Energy Technology Plan Information System
SET-Plan	(European) Strategic Energy Technology Plan
WIPO	World Intellectual Property Organization
WEC	Wave Energy Converters
WP	Working Papers

1. Introduction and overall assessment

Marine energy, also sometimes referred to as ocean energy, has enormous potential for development: theoretically, global resources are estimated to be over 30 000TWh/year[1], providing a net potential greater than that of wind and solar energy. Besides its energetic potential, marine energy has key features which make it a good candidate for contributing to the renewable energy mix of European countries:

- Predictability: tidal energy resources are highly predictable; wave resources, although more intermittent, can be predicted with high accuracy compared to those of wind.

- Seasonal availability of resources: tidal, and in particular wave resources, tend to be of greater magnitude during the winter season, providing the opportunity to feed electricity to the grid during the most demanding periods.

European countries located on the continent's Atlantic arc – the United Kingdom, France, Portugal, Ireland, Spain, Denmark and Norway – have a high potential for developing marine energy technology. Some of the strongest currents in the world are found around Orkney (UK), Pentland Firth (UK) and Anglesey (UK) [Tedds et al., 2011]. Accessible tidal resources in the United Kingdom alone have been estimated at 95TWh/yr, with a further 69TWh/yr potentially available via wave power[2]. Given this potential, some European countries are planning to install wave and tidal plants (2118 MW in Europe) by 2020 able to generate 5992 GWh (21.6 PJ) of electricity. In 2020, the largest volume of wave and tidal energy will be generated in the United Kingdom (3950 GWh) and in France (1150 GWh). In addition, the Netherlands, Italy and Sweden have the possibility to exploit localised resources.

Many studies report the technology's potential, whereas fewer reports assess the state of the sector at the European scale. Usually, countries such as Norway, Sweden and Finland focus less on evaluating marine energy integration in the national energy mix, since there are no national targets formulated in their future plans, thus no particular immediate constraints present in the medium term for marine energy development.

Using an alternative approach, this report contributes to the overall evaluation of marine energy activities in Europe, taking into account investments in knowledge creation, diffusion and commercialisation of marine energy technology as a proxy for their commitment to developing the technology. Particular attention is paid to the national innovation system in 10 European countries: Denmark, France, Germany, Ireland, Italy, Norway, Portugal, Spain, Sweden and the United Kingdom. The scope of the assessment is limited to the most technologically advanced marine energy technologies: wave and tidal. Other marine energy technologies, such as the salinity gradient, are not fully developed yet, whilst ocean thermal energy technology implementation in Europe is limited due to low temperature gradients in European waters.

The scope of this report seeks to describe the innovation patterns of marine energy technology development in Europe[3].

The difficulties facing the present task should be highlighted. Marine energy is confronted with a variety of limitations, deriving from uncertainties associated with the new technology, such as: the diversity of concepts, lack of data, the definition of targets, and inclusion of risks from different stakeholders. The presence of so many limitations hinders the possibility of producing an unbiased overview of the state of marine energy technology, although key features remain unquestionable.

1 Mork G., Barstow S., Pontes M.T. and Kabuth A., 2010. Assessing the global wave energy potential. In: Proceedings of OMAE2010 (ASME), 29th International Conference on Ocean, Offshore Mechanics and Arctic Engineering, Shanghai, China, 6 - 10 June 2010.

2 The Crown Estate, UK Wave and Tidal Key Resource Areas Project (2012).

3 Some of the countries, such as the Netherlands, have not been included due to data availability for all the aspects that are treated in the analysis.

Ocean energy technology is still not marketable, despite advanced levels of technology readiness (TRL) achieved by some developers. There are many aspects that must be addressed before commercialisation. One of the most important constraints is the cost of marine energy farms. In France, total costs of wave and tidal have been estimated at 200-250 €/MWh (France Energies Marines), and at 540 €/MWh for the British pre-commercial demonstrators (Ernst & Young, 2010), whereas the wholesale energy prices in Europe are in the order of 50 €/MWh[4]. Considerable efforts are still required for the technology to become commercially viable.

Furthermore, most energetic locations for marine devices are found in harsh environments and are currently unexploited. The first generation of tidal farms is expected to be installed in shallow waters, where the power is lower. To overcome the cost constraints, ongoing research to commercialisation proposes the optimisation and design of *arrays of turbines* able to increase the power generated (Giles et al., 2011, Myers et al., 2011). To include the first commercial-scale arrays of wave and tidal devices in the energy mix, important investments in sub-sea transmission systems and grid connections are required (Beale, 2011).

Important research efforts are being mobilised to bring the technology closer to market. At the European level, a cross-country exploration of their national research intensity at different stages of the technology life cycle could help in identifying the barriers to overcome en route to preparing the technology for the market. Key results are summarised below:

- *Knowledge diffusion* is taking place between Nordic countries (Denmark, Norway) and newcomers such as France, Germany and Italy. Countries such as the United Kingdom, Ireland and Norway are identified as leaders in the knowledge-creation process.
- *Commercialisation*, assessed by the markets in which developers seek protection through patents, is more important for the United Kingdom. French applicants find the national market for patent protection most attractive, whereas British technology developers aim for both national and international protection, in particular in North America and East Asia.
- *Financial mobilisation of resources*, in the fiscal year 2011, gathered together approximately € 0.125 bn (EU-FP7, corporate and public R&D) for research activities in marine energy technologies. Distribution is not uniform across countries, with higher R&D investment in the United Kingdom than in other countries. The amount barely represents 10 % of the aggregated (public and private) investment in wind technology. The *private sector*, driven by the engineering knowledge provided by academic spin-offs and start-ups, plays an important role in technology development, contributing to more than 50 % of overall investment in marine energy research. Moreover, public funding has been effective in mobilising efforts towards the demonstration of marine applications. For every euro invested by European funding (FP7 or INTERREG) almost € 0.6 of national money is mobilised. The support incentive remains fairly similar at the country level, where national funds are able to lever € 0.80 of private money (United Kingdom and France), with higher mobilisation observed in France.
- *Human resources* are relatively scarce: approximately 2400 people were active in the marine energy sector in 2011, 1000 of whom were employed in the industry, whereas 700 people worked in research organisations. Compared to the 35 000 people employed in the offshore wind[5] industry, marine energy is still in its childhood. Public support for this industry can be assured through domestic production subsidies, tariffs or quotas, although the level of protection should be linked to the industry's learning potential (Melitz, 2005).
- A final dimension evaluates the level of risk induced by rapid changes in national targets. Accordingly, public policies at national level are examined with respect to their effectiveness in stimulating innovation activities. In particular, policies are evaluated on their *stringency in* encouraging innovation activities and their *stability in assuring* the necessary planning horizon for investors to undertake risky investments in innovation. Ireland demonstrates highly stable targets in its efforts not to discourage business opportunities within this sector. On the other hand, although the United Kingdom is committed to the development of offshore wind technology, it does not provide stringent and stable targets for wave and tidal technology.

4 Source: Platts, European power exchanges, Quarterly report on European Electricity Markets, Market Observatory for Energy, DG Energy, Volume 6, issue 2, Second quarter 2013; http://ec.europa.eu/energy/observatory/electricity/doc/20130814_q2_quarterly_report_on_european_electricity_markets.pdf

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

The current assessment has identified that research activities are relatively specialised within Europe: the United Kingdom is most representative in terms of high public financial support for early-stage research and demonstration projects, accounting for 40 % of total European R&D investment in 2011. Sweden and France are involved in demonstration projects towards the commercialisation of the technology, whereas German companies are involved in demonstration of the technology in foreign "nursery markets". Spain, Portugal and Sweden are mostly involved in demonstration projects of national devices (Sweden) or foreign technology (Spain, Portugal). Since knowledge diffusion involves greater participation by countries such as Ireland, Denmark and Norway, greater synergies between countries could further endorse the development of the technology.

This report contributes to an assessment of the recent evolution of marine energy technology, and tries to identify factors or barriers to a conducive environment, favouring the emergence of innovation activities in marine energy technology.

2. Methodology and data considerations

The present analysis seeks to explore the development of marine energy technologies in terms of interaction between nursing markets, technology developers and policy-makers during the different stages of the knowledge development and diffusion process. The final goal of the present analysis is to identify factors or causes that hamper the functioning of the marine energy innovation system. Based on these findings, smart policy instruments can be proposed to correct explicit innovation-system deficiencies.

2.1. Methodology

A functional approach to innovation systems is used in order to analyse the formation and evolution of marine energy innovation activities, based on the methodology presented by Johnson and Jacobsson (2001), Bergek and Jacobsson (2003), and Jacobsson and Bergek (2004). Such an approach was previously applied to the offshore-wind innovation system (JRC 25410, 2012), suggesting a coordinated approach to overcome challenges in terms of infrastructure, of institutional alignment (public policies), and increased synergies among the actors of the offshore-wind innovation system.

The marine energy innovation system is described using a functional assessment, designed to identify bottlenecks in the mobilisation of public and private innovation efforts according to life cycle (box 1).

Previous studies focused on induced renewable-energy innovation take into account unidirectional relationships, ignoring subsequent private research efforts responding to policy changes, and the consequent variations in public policies adapting to changes in private initiatives. The pertinence of the functional approach is linked to the presence of an institutional framework, which is crucial for the development of marine energy technologies.

Accordingly, institution-related functions (Bergek et al., 2006), such as *legitimation (function 7)* and *influence on the direction of search (function 4)* are introduced. These functions set out to examine

Functions in the innovation system

Function 1: Knowledge development reflects a process of knowledge creation involving public and private actors.

Function 2: Knowledge diffusion and development of externalities. The innovation process is reinforced and locked in through both pecuniary and non-pecuniary externalities.

Function 3: Entrepreneurial experimentation identifies a process through which new knowledge, networks and markets are turned into concrete actions to generate, realise and take advantage of new business opportunities (Schumpeter, 1929).

Function 4: Influence on the direction of search. This function seeks to identify whether the market mechanism, as well as public policies, induce innovation in marine energy technology systems.

Function 5: Market formation. In cases where markets have yet to exist, this refers to protected spaces, such as "nursing markets" (Erickson and Maitland, 1989).

Function 6: Resource mobilisation identifies the extent to which existing human and financial resources contribute to development of the technological innovation system.

Function 7: Legitimation. The function refers to concerted actions by advocacy coalitions (Aldrich and Fiol, 1994; Suchman, 1995) represented either by the industry or policy induced (Janicke, 1997) for the development of the sector.

The methodology is inspired by A. Bergek, M.P. Hekkert, S. Jacobsson (2006): Functions in innovation systems: A framework for analyzing energy system dynamics and identifying goals for system-building activities by entrepreneurs and policy makers.

how the interaction between entrepreneurial initiatives and policy-makers either creates opportunities or blocks the development of the innovation system. Such interdependencies are crucial, especially for technologies for which the market mechanism is weak, and for which the state creates nursing markets.

By taking into account the level of risk induced by unexpected changes in public policies, the report states that building system activities should be directed towards building the TIS legitimation; thus efforts "should be directed towards increasing the strength of inducement mechanisms and reducing the power of various blocking mechanisms" (Johnson and Jacobsson, 2001). Moreover, an exploration of the interactions between entrepreneurs, networks and policies could provide useful insights into the level of risk faced by both the industry and technology.

2.2. Data considerations

Taking into account the availability of data for the various aspects investigated, the present analysis is limited to a sample of 10 countries: the United Kingdom, France, Germany, Portugal, Ireland, Spain, Denmark, Norway, Italy and Sweden. Additional information is provided where relevant or available. The assessment of the innovation patterns of marine energy technology is undertaken for the year 2011.

The list of data sources by system function is presented in Table 1.

Table 1: Data sources for innovation activities by knowledge-system function

System function	Indicator	Source
Knowledge development	Number of patent applications by national applicants to national patent offices	Patstat, October edition 2011[6], WIPO (World Intellectual Property Office)
	Scientific articles and peer-reviewed conference papers	ISI Web of Science, Science Direct, EWTEC
	Human skills	United Kingdom PhD database[7], Ireland MRIA, France-CNRS, Italy –MIUR, Portugal-IST, Norwegian NTNU, Demark-Aalborg, Germany-DAAD, INORE
Knowledge diffusion	Scientific network: co-authored papers	ISI Web of Science, Science Direct, EWTEC
	Patent applications filed at foreign patent offices	Patstat applications, October edition 2011
	Public-private collaborations	CORDIS, FP7
Entrepreneurial initiatives	Academia spin-offs and start-ups	EMEC website, Patstat, EWTEC, Thetis EMR[8] and Nordic green website[9]
Influence on the direction of search	Deployment subsidies	Res-legal and SI-Ocean NER 300[10] (launched in 2012)
Market formation	Wave and tidal centres – public infrastructure Number of projects at different stages of development	Bloomberg, Sowfia, DOE, MHK, PMNL database SI-Ocean, companies' websites, Patstat, Thetis EMR, Nordic green website, EMEC website
Resource mobilisation	Financial resources: public RD&D data and European funding Human resources: co-authors of scientific papers and average employment in start-ups	IEA RD&D database CORDIS, FP7, INTERREG, IEE-funded projects EWTEC, ISI, EMEC, SEAI, Renewable UK 2011
Legitimation	Ocean energy targets Offshore wind installed capacities	NREAP, 2009 European directive for the national targets for 2020, SOWFIA and SI-Ocean

6 The assessment does not take into account the patent family.
7 Up to 10 PhD programmes were identified in 2013 as being directly involved in the development of skills/knowledge relevant to marine energy in 2013. These programmes reflect the fragmented feature of marine energy knowledge.
8 http://www.thetis-emr.com
9 http://www.nordicgreen.net/startups/wavehydro/aqua-energy-solutions
10 http://www.ner300.com/

3. Functional analysis

3.1. F1 – Knowledge creation and diffusion

The exploration of fundamental research involves describing the pattern of research activities within universities and research centres. In addition, patenting behaviour of both public and private entities is also portrayed.

3.1.1 Basic research in marine energy topics

The evolution of basic research in marine energy mainly reflects the scientific community's participation in developing the sector, as can be seen through the intensity of scientific interaction and knowledge dissemination. This exploration enables the main research directions to be identified in the different technologies involved as well as an indication as to whether the basic research also evolved towards bringing the technology closer to market. The main sources for this are scientific articles collected from the ISI (see Table 1) and EWTEC[11] proceedings database. Publications are evaluated as a fractional account, meaning that the weight of the publication is 1 and if n countries are participating, each country receives 1/n.

3.1.1.1. Recent evolution of marine energy knowledge through publications: 1998-2011

Marine energy science features an interdisciplinary trait, comprising different technical subjects and specific knowledge (electrical, mechanical and civil engineering, oceanography, etc.) to improve technologies aiming to produce electricity from the oceans.

Basic research in wave and tidal energy revealed an impressive growth rate from 1998 to 2011 (see Figure 1): the number of conference papers has increased by 400 %, whilst journal publications have seen a 13-fold increase, reaching a comparable production level with working papers (WP) presented at the EWTEC in 2011. The convergence in production levels is also facilitated by the appearance of topic-specific journals dedicated to the generation of electricity from the ocean.

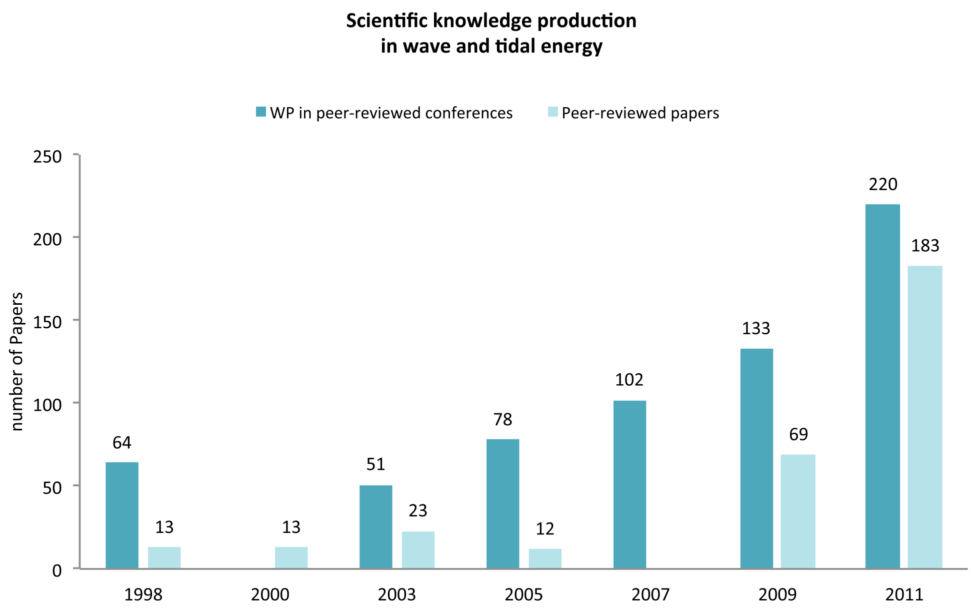


Figure 1: Recent evolution in academic knowledge production on the topic of wave and tidal energy

Source: JRC, based on EWTEC, ISI and Science Direct data.

11 European Wave and Tidal Energy Conference.

The graphical representation includes the years of the EWTEC conference. Dark-coloured bars indicate the peer-reviewed papers presented at EWTEC conferences (WP); light-coloured bars represent peer-reviewed papers published on marine energy topics.

Marine energy research at the end of the nineties was mainly dedicated to research targeting improvements in air turbines. Other scientific themes at the Patras conference (ETWEC 1998) were oriented towards the study of hydrodynamics and control strategies. The testing of concepts is directed to both technology validation and the analysis of the economic context[12].

During EWTEC 2007, wave energy constituted the main core of research activities presented, with 51 % of all papers focusing on wave energy related topics. The topic of *wave arrays* was introduced as a specific section of the conference, marking the acceleration of efforts seeking to bring the technology closer to market.

In 2011, the intensity of research reflected the intense commitment and support from both academia and industry (EWTEC 2011). Key topics addressed at the conference included: environmental and economic assessment, real-sea testing of concepts and, in particular, grid integration. Synergies between actors increased significantly regarding the efforts made to bring the technology to the market place – an increase in the size of teams co-authoring papers was observed for themes such as *Deployment, maintenance, and mooring for wave energy converters (WEC).* In terms of knowledge diffusion, the EWTEC 2011 proceedings exerted an outstanding influence over the scientific community (Table 2).

An important step forward can be observed in terms of the number of publications tackling issues and constraints such as *commercial development of the marine energy sector* and *cost optimisation issues.* In the latter, particular interest was paid to the *clustering of devices (sharing of infrastructure to decrease costs)* and in increasing energy yields through the use of artificial structures. Other topics included the study of *power transmission systems, design challenges for highly energetic seas,* and *interconnection and use of innovative materials*.

3.1.1.2. Knowledge institutes: fundamental research in marine energy topics

Over 280 European knowledge institutes have been identified as being involved in knowledge creation, development and the commercialisation of marine energy related activities. The most important contributors are presented in Table 3 which shows: (i) the total number of knowledge institutes per country; (ii) the total number of publications per analysed country (fractional account – see methodology); and (iii) the top organisations publishing in the field per country, including the number of publications per institute and the national percentage.

A joint analysis of these indicators enables us to describe a first set of findings related to the organisation of research in marine energy topics: first-mover countries (the UK) and late movers (Italy and Germany) show a widely scattered scientific network. Conversely, Nordic countries concentrate their local research initiatives and provide knowledge spillovers to other countries (Table 3). Likewise, Ireland and Portugal exhibit a concentrated organisation of research in marine energy topics.

The United Kingdom shows a high commitment to knowledge creation and technology commercialisation.

Besides the British actors, intensive publishing activity involves Irish, Danish and Portuguese institutes. Among the leaders are the University of Southampton, the University of Edinburgh, the Technical University of Lisbon, Aalborg University and University College Cork.

Table 2: Impact indicators of scientific works on wave and tidal energy technology (2011)

	Peer-reviewed publications	Conference proceedings	All documents
Documents	183	241	424
Total citations	1392	316	1708
Average number of institutions	1.8	1.5	1.7
Average number of countries	1.4	1.3	1.4

12 Technologies such as *SPERBOUY*, *Poseidon's Organ*, *Wave Dragon*, *Point Absorber*, *The Rock OWC* and *The FROG* presented their latest developments and model testing.

Table 3: Number of knowledge institutes and scientific publications on wave and tidal energy topics (2011)

Country	Organisa-tions	Publica-tions	Most important organisations (occurrences and national percentage)
UK	96	145.06	University of Southampton (19, 10 %), University of Edinburgh (18, 9.5 %), University of Strathclyde (11, 6 %), University of Oxford (12.6 %),University of Plymouth(12, 5 %), Lancaster University (6, 3 %), GL Garrad Hassan (6, 3 %)
France	31	19.03	Université de Toulouse + Institut de Mécanique des Fluides de Toulouse (7, 17 %), Ecole Centrale de Nantes (6, 13 %), Institut français de recherche pour l'exploitation de la mer (5, 11 %), Guinard Energies, Le Gaz Intégral (both 2, 5 %)
Spain	30	23.81	AZTI Tecnalia (14, 27 %), CIEMAT (3, 6 %), Centro de Investigaciones Energéticas (3, 6 %), University of Almería (3, 6 %)
Ireland	22	29.50	Hydraulics and Maritime Research Centre, University College Cork (17, 33 %), Wavebob Ltd (7, 14 %), National University of Ireland, Maynooth (8 %)
Portugal	14	22.28	Instituto Superior Técnico, Technical University of Lisbon (17, 42 %), WavEC (11, 27 %), Laboratório Nacional de Energia e Geologia (3, 6 %)
Germany	14	8.4	Federal Maritime and Hydrographic Agency (3, 16 %), Institut für Fluid- und Thermodynamik Siegen (2, 11 %), HYDAC Electronic GmbH (2, 11 %), Voith Hydro Ocean Current Technologies (2, 11 %)
Norway	12	14.22	Norwegian University of Science and Technology (11, 55 %), Fred. Olsen Ltd (3, 15 %)
Italy	13	14.52	University of Bologna (4, 17 %), University of Naples Federico II (4, 17 %), Università di Padova (3, 13 %), Politecnico di Torino (2, 9 %)
Denmark	11	13.34	Aalborg University (17, 59 %), WaveStar A/S (3, 10 %), Dexawave Energy ApS, SPOK ApS (both 2, 7 %)
Sweden	8	9.33	Division for Electricity, Uppsala University (7, 50 %), Chalmers University of Technology (2, 14 %)

In terms of knowledge creation, the UK shows outstanding scientific performance**.** The number of British institutes working on marine energy topics is large (91) – it is three times greater compared to France (31), Spain (30) and Ireland (22). One would expect that marine energy research would also require a considerable research budget for knowledge-creation institutions. However, the current work is unable to identify the availability of resources as an important constraint for basic research activities.

> Basic research is highly concentrated at the national level in Denmark, Sweden, Norway and Portugal.

Research activities in the UK are widely scattered, involving a range of universities. The commitment to developing these diversified initiatives is greatly endorsed by public grants, such as SuperGen UK Centre for Marine Energy Research (UKCMER)[13], which explains the scattered distribution of British research on this topic. Compared to other countries, UK institutions play an active role in the commercialisation of the technologies developed within their departments (Robert and Malone, 1996), with a higher rate of university spin-offs and start-ups making use of universities' intellectual property (Lawton-Smith and Ho, 2006). However, despite the scattering of research across the country, it should be noted that research activities in marine energy demonstrate the specialisations of the institutes. For example, *Plymouth University* focuses on costal/environmental studies, whereas the *University of Edinburgh*, *University of Exeter* and *University of Strathclyde* concentrate on ocean engineering. *Southampton* and *Oxford* focus on tidal energy conversion, whilst *Belfast* concentrates mainly on wave energy. Private organisations and consultancy firms GL Garrad Hassan, Black & Veatch, IT Power and QinetiQ are also involved in knowledge creation.

13 http://www.supergen-marine.org.uk/drupal/

On the other hand, in Scandinavian countries fundamental research tends to be concentrated in a few institutes: Denmark has the highest national concentration of marine energy research with 59 % of research efforts taking place at Aalborg University. Private companies, such as Wave Star A/S and Dexawave Energy ApS, are also carrying out important research initiatives. In other countries, focused national research is evident in Sweden with Uppsala University leading marine energy research, while the Norwegian University of Science and Technology fronts the effort for Norway. In recent years, Norway, Sweden and Denmark have also been actively involved in the testing and validation of the technology, and their institutes make a significant contribution in terms of international scientific collaboration.

> The organisation of research activities in France, Italy and Germany is scattered.

Countries like France, Italy and Germany display a spread of research initiatives across many institutes. Their initiatives include those within the industry, whose more recent commitment has pushed the development of marine energy initiatives. However, to a large extent, publishing activities are dominated by public research institutes. Ecole Centrale de Nantes has a long tradition of marine energy engineering and is involved in the development of SEM-REV, a nearby wave energy test centre. Italy is represented by institutes working on environmental assessments, although they also demonstrate entrepreneurial initiatives. EERA states that around ten universities and important research centres are involved in the development of the sector.

Ireland and Portugal both show an allocation of resources focused on marine energy. Irish research activity is highly concentrated around University College Cork. Similarly, in Portugal the Instituto Superior Técnico is the hub of many research initiatives. Countries such as these provide the appropriate logistics for devices to be tested with room for improvements to be made.

In Spain, private institutes dominate the creation of knowledge/validation of the technology (e.g. Tecnalia). In addition, Spanish public institutions have also offered their support to marine energy initiatives (i.e. Centro de Investigaciones Energéticas, University of Almería).

3.1.1.3. Educational programmes for future researchers

Several technology skills, as well as interdisciplinary approaches, are required to develop the necessary expertise to tackle marine energy challenges. Although training in engineering (in particular electrical and mechanical engineering) is vital for the creation of human capital in marine energy, other skills may be required. Examples of PhD topics on marine energy technologies are presented below:

- Theory of Marine Design
- Investigation and Analysis of Accidents
- Active Fishing Methods
- Fracture Mechanics Design of Welded Structures
- Analysis and Design of Marine Structures against Accidental Actions
- Advanced Topics in Structural Modelling and Analysis
- Structural Reliability
- Stochastic Methods Applied in Non-linear Analysis of Marine Structures
- Dynamic Analysis of Slender Marine Structures
- Hydrodynamic Aspects of Marine Structures
- Kinematics and Dynamics of Ocean Surface Waves
- Seabed Boundary Layer Flow
- Modelling and Analysis of Machinery Systems
- Mechanical Vibrations

Future jobs in wave and tidal energy include “electrical engineer, process engineer, marine energy engineer, site development manager, marine operations manager, structural engineer, mechanical design engineer and wave scientist”[14]. The potential benefits for the development of the offshore sector have triggered additional investment in higher education initiatives. Among the most notable, the € 7.8 million in the United Kingdom allocated to engineering education stands out.

14 *National Skills Bulletin 2010*, Expert Group on Future Skills Needs, Fas, July 2010.

United Kingdom

Public organisations in the United Kingdom offer a significant range of doctoral programmes[15] that develop skills/knowledge relevant to the marine energy sector. Key examples include the Industrial Doctorate Centre for Offshore Renewable Energy (IDCORE) programme run jointly by the universities of Edinburgh, Exeter and Strathclyde, and aimed at developing specialised scientists.

Another example is the EPRSC- funded programme SUPERGEN, led by the University of Edinburgh, which groups the majority of research institutes working on marine energy and offers early-stage researcher funds and training courses to strengthen their research activities. Universities are also developing targetted Masters courses: Plymouth University has been offering an MSc programme specifically in marine renewable energies since 2011.

> The United Kingdom is a front runner in academic and polytechnic training in marine energy. Active participation of the industry in the publication process is seen as a step in validation of the technology.

Ireland

Among the institutions involved in developing skills in marine energy, the most relevant are University College Cork, the University of Limerick, the National University of Ireland, Maynooth and University College Dublin. University College Cork has a long history of involvement in marine energy and recently launched the new Beaufort Research facilities, a maritime and energy research cluster based in Ringaskiddy. University College Cork leads the FP7 MaRINET project, which devotes part of its funds to training of young researchers.

France

A limited number of doctoral and Masters courses in marine energy are offered in France. Notable for its reputation in marine engineering research is Ecole Centrale de Nantes[16]. Its research team can boast a wide background ranging from mechanical engineering, applied mechanics and fluid mechanics. The university has been directly involved in the development of a French-designed marine energy converter, as well as in the design, development and construction of the SEM-REV wave energy test centre off the west coast of France. IFREMER, another important research centre, based in the north of France, is very actively involved in marine energy, providing test facilities as well support for researchers. The recent interest in marine energy has enabled many universities to develop ad-hoc courses in marine energy technologies and related subjects.

Other countries

In Denmark, a strong doctoral specialisation in marine energy has been provided since 1995, mainly at Aalborg University. This university was selected as an advisory body to the Danish Wave Energy programme and has been developing testing programmes for wave energy converters at the laboratory scale since then. A wide variety of Danish-designed WECs have been tested at its facilities, including Wave Dragon, Wave Star, WavePiston, WEPTO and WavePlane, to name a few. A large array of educational opportunities is provided by the Norwegian University of Science and Technology, Trondheim (Norway). In Germany, Aachen University offers courses on the development of power take-off systems, while the Fraunhofer Institutes devote their activities to developing skills for techno-economic assessment of marine energy.

Educational opportunities for marine energy in Italy are limited, aiming mainly to facilitate student exchanges. Some examples are the exchanges between the University of Naples, Polytechnic of Turin and Bologna with Aalborg, Edinburgh, Southampton and Plymouth universities, which have taken place for years in a cross-university course organised in Naples[17].

Portuguese educational training in this field reveals significant initiatives, with many activities taking place at the Instituto Superior Técnico in Lisbon and the University of Porto. A collaboration between IST and WavEC (formerly the Wave Energy Centre), has helped in the provision of a doctoral courses in offshore renewables, device modelling, power generation for OWC, and cost analysis of wave energy and related environmental impacts.

The diversity of programmes available across the various countries emphasises the importance and commitment each country is giving to developing these technologies. A cross-sector and cross-country initiative has been established by doctoral research topics based in Europe to provide training and exchange opportunities for young researchers to widen their knowledge and expertise (Figure 2).

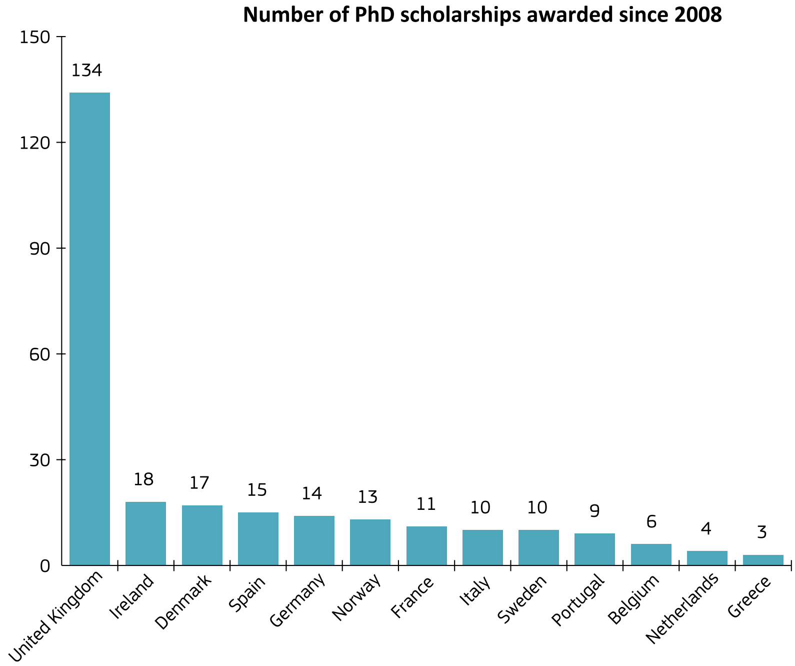
15 PhD database, around 10 PhD programmes in 2013.

16 http://d.campusfrance.org/fria/edsearch/index.html#app=65a8&afaa-si=0

17 http://www.italywavenergy.it/index.php/course

Figure 2: Number of PhD scholarships awarded by EU institutions since 2008 (INORE)

Source: INORE



The cross-country distribution of human capital in marine energy is shown above, using information on the Network of Offshore Renewable Energies, which was established by students of Norwegian University of Science and Technology, Edinburgh University and WavEC.

3.1.2. Applied research in the field of marine energy technology

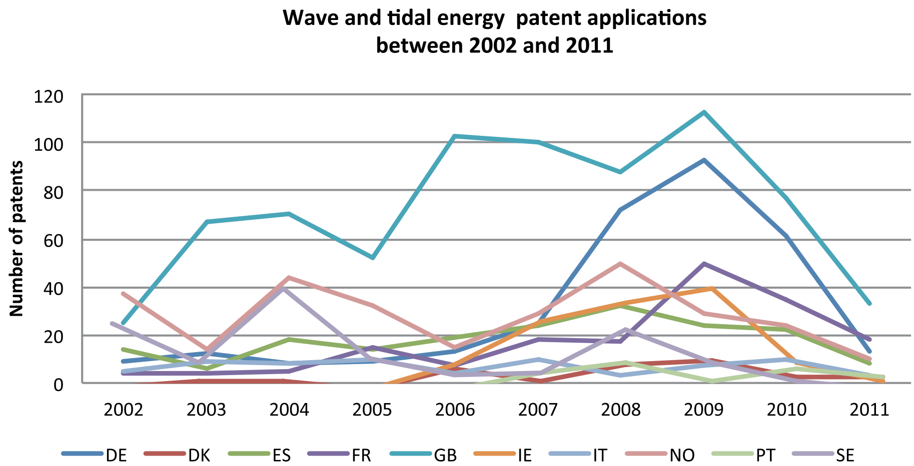
An investigation into the number of patent applications provides a comprehensive picture of applied research in wave and tidal energy technology (Figure 3). Two sources were used to collect data on patent applications: WIPO and the European Patent Office EPO-PATSTAT. This information is crucial in determining the intensity of knowledge transfer between applicants' home country and the different markets chosen for patent protection.

The analysis of patents allows the investment efforts of private and public entities to be quantified. The volume of patenting activities doubled from 2001 (117 applications) to 2010 (266) but declined in 2011 (93). The largest increase was observed in the four-year period from 2007 to 2011, with an average of 30 applications per year per country. Outside this period, the average is 15. Countries such as France, Ireland, Spain and Sweden record an average intensity of 15 applications from 2001 to 2011, whereas Norway patents almost doubled (26) and there were four times more patents in the United Kingdom (69).

The United Kingdom is succeeding in mobilising the commercialisation of the technologies via important universities and research institutes, with many applications filed by academic spin-offs. In addition, applications are being filed by traditional wave and tidal developers, such as Trident Energy Ltd (24), Marine Current Turbines Ltd (25), Aquamarine Power Ltd (21), Rolls-Royce Plc[18] (previous owner of Tidal Generation Ltd, 21) and Tidal Generation Ltd (14).

Figure 3: Evolution of patent applications between 2002 and 2011 for wave and tidal energy technology for sampled European Member States

Source: JRC, based on Patstat data.



18 http://www.rolls-royce.com/news/press_releases/2012/120925_tgl_agreement.jsp

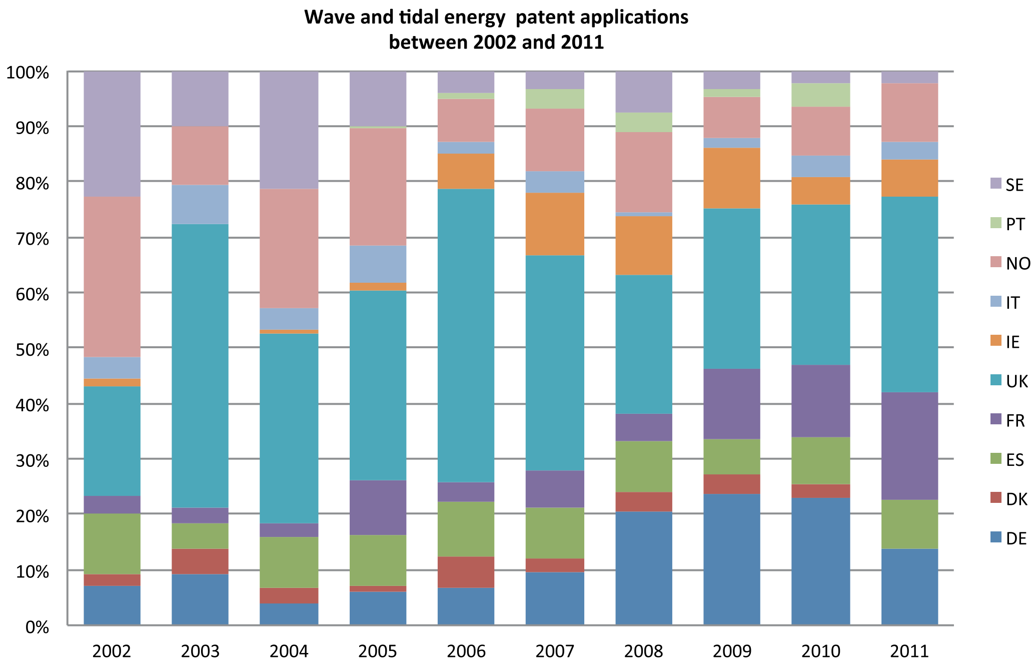


Figure 4: Intensity of patent applications for wave and tidal energy technology for sampled European Member States between 2001 and 2011

Source: JRC, based on Patstat data.

Norwegian actors include among their investors marine energy technology companies such as Fobox AS (20 applications), Hammerfest Strøm AS (11), Straumekraft AS (22), Wave Energy AS (11) and Havkraft AS (4). An increasing trend in patenting can be seen in Germany, where the significant levels of patenting are outmatched only by the United Kingdom, and indicating the involvement of well-known private companies, such as Robert Bosch GmbH and Voith Patent GmbH (71 applications).

A significant increase in patent applications can be seen in France, with patent applications rising from four in 2001 to 18 in 2011. The French patenting landscape mixes public and private initiatives. Among the public initiatives, the Centre national de la Recherche Scientifique (CNRS) reveals significant activity (14 applications). The involvement of SBM Offshore in marine energy extends to its participation in the S3 Innovative Wave Power project, which is being developed in association with IFREMER and the Ecole Centrale de Nantes. The project was selected for public funding (Investments for the Future programme/ADEME (French Environment and Energy Management Agency)[19]. Increasing interest in marine energy is being shown by both small companies (TURBOCEAN SAS) and large companies (DCNS Group, 8 applications) and even by utilities such as EDF.

During the same period, Ireland's share in patent applications decreased from 20 % to 6 %. The country shows a concentrated distribution of patenting activities with OpenHydro Group Ltd filing 62 applications.

Spain has a constant patenting activity, around 10 % share of all countries under consideration with significant knowledge-creation activities achieved by public organisations. Significant activity is noted for one company – PIPO Systems SL – as the result of a previous European project.

Swedish applications reveal research activity highly focused around the Seabased AB technology (98 applications). Other important innovating entities involve private companies, such as Ocean Harvesting Technologies AB (6 applications) and Current Power Sweden AB (12). A below-average number of patent applications have been recorded in Denmark, Portugal and Italy. Activities in Denmark show a constant trend in patenting behaviour with the bulk of applications dominated by well-known wave energy firms: Wave Star Energy ApS (13), Wavepiston Aps (7) and Oxydice A/S (8). In Portugal, a mix of public and private efforts has contributed to technological development. Among the knowledge institutes implicated, the activity of the Instituto Superior Técnico, Lisbon (5) is significant. Private companies filing for applications include Sea for Life LDA, inventor of the Wave Energy Gravitational Absorber (4). An examination of patent applications in Italy identifies wave product innovations by the small Tecnomac Srl company (4), as well as Italian universities involved in developing marine energy, such as the Polytechnic University of Turin (2).

As expected, the countries fostering the majority of innovations in these fields are associated with a diverse technological spectrum of wave and tidal applications. The bulk of patent applications combine public and private research efforts, with a higher commitment from private companies in countries such as Germany, Denmark, Norway and Sweden. Spain and Portugal, in particular, show a greater involvement by public institutes.

19 http://www.hydroquest.net/static/documents/presse/EY_Thetis_Ocean_Energy.pdf

3.1.3. Evaluation of knowledge creation

An assessment of knowledge creation covers both general and specific themes, ranging from knowledge creation (published papers and proceedings) to applied research (commercialisation of technology) to patent applications. Potential capabilities regarding the creation of specialised labour pools are taken into account.

The United Kingdom performs well in all the dimensions analysed and has the potential to create future synergies to enable learning-by-doing activities. This is in line with the activities and role the UK plays in developing marine energy technologies and the potential benefits the country could enjoy by having a specialised sector.

Countries such as France, Germany and Sweden display a similar pattern with significant concern for the commercialisation of the technology but less involvement in knowledge creation (Appendix 1). Public support is considerable in France and Sweden, and reinforces private initiatives, whereas in Germany the road to commercialisation is the result of the diversification of technologies of multi-technology companies already involved in the development of renewable energy technologies. On the other hand, Portugal and Denmark offer more educational programmes, albeit a lower involvement in the commercialisation of marine energy.

Spain provides a good knowledge offer, as well as being able to enhance its skills and knowledge through scientific publications. However, initiatives for the commercialisation of the technology remain limited. Ireland, despite its low commercialisation activities, gets a higher score thanks to its scientific output and knowledge offer. Italy is the lowest performer across all the indicators, revealing limited public commitment to developing the technologies and limited private initiatives, which are the result of knowledge collaboration networks, as described in the following section.

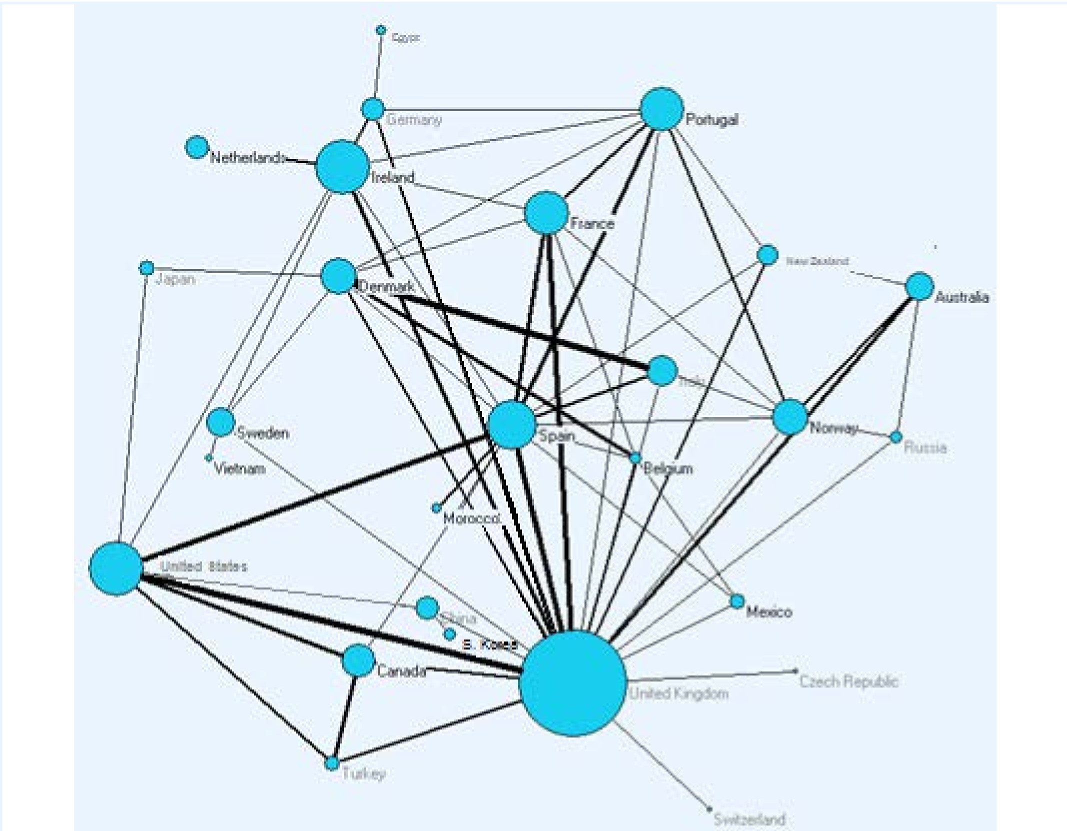


Figure 5: Network representation of academic collaboration of organisations publishing on marine energy topics, aggregated at country level. Size is adjusted for occurrence in scientific publications; the width of each line represents the intensity of collaboration between countries

Source: JRC, based on EWTEC, ISI and Science Direct data.

3.2. F2 – Knowledge diffusion and transfer

In the context of knowledge diffusion, co-authorship of scientific papers is used as an indicator of scientific interactions and the intensity of research in a national/international way. The intensity of collaborations in the sector is largely determined by the pre-commercial stage of the technology. Marine energy knowledge diffusion is mainly dominated by intra-institutional/intra-country partnerships, although inter-university collaborations and industry–academia partnerships are present in the later demonstration stages of marine applications.

3.2.1. Spatial knowledge diffusion of public research: size of academic networks and intensity of scientific interactions among European countries

Structural analysis of the marine energy scientific networks shows that the average size of collaborating entities is 1.65 authors per publication, although it features intense collaborations and a denser network in specific themes, such as marine current resources and modelling, wave energy converter modelling, wave energy converter power take-off systems, and marine current energy converter testing. The intensification of scientific collaborations has been encouraged by national targets that identify wave and tidal device modelling tools as a top priority for the industry (UK), within a framework of six years for its completion (Topper and Ingram, 2011, UKERC/ETI Marine Energy Technology Roadmap).

A large bulk of scientific discoveries is developed by relatively small industrial players, which are spin-offs/start-ups of universities or research centres. The modelling of WEC/TEC and the economic and environmental assessment of marine energy projects involves a small number of researchers. However, the demonstration of marine energy applications enhances cooperation with marine energy centres or even large industrial players in the creation of tacit knowledge. Hence, scientific collaboration increases when the physical and financial needs are addressed.

Much of this cooperation reflects intra-country efforts (Figure 5), largely dominated by the United Kingdom, and followed by Spain, the United States, Ireland and Portugal. A national clustering of knowledge at this stage of the industry's development could be linked to knowledge production in addition to other factors, such as the availability of resources and funding programmes. British academic institutions act as a hub for those international scientific collaborations with a central role in marine energy technology development.

Limited within-country institutional collaboration is observed in Norway and Denmark, which both show extensive international collaborations, especially with institutions from late-movers in the marine energy sectors, such as Italy and Germany (Figure 5). For example, scientific interactions are being cultivated between Denmark and Italy, in particular through doctoral programmes, allowing the spatially bound feature of knowledge diffusion to be overcome. Furthermore, FP7 projects have helped in fostering academic cross-country collaborations: the European project entities succeed in putting in place systemic contacts which enable innovation activities abroad.

3.2.2. Knowledge diffusion of public research across time: citation practices and scientific productivity

The effectiveness of knowledge cooperation can be quantified by assessing the use of knowledge flows developed for future scientific work related to marine energy technology. This can be measured by assessing the number of publications produced and the resulting citations. The density of the network, together with scientific recognition of the publications (measured through citations of papers) can give an indication of average scientific productivity per country.

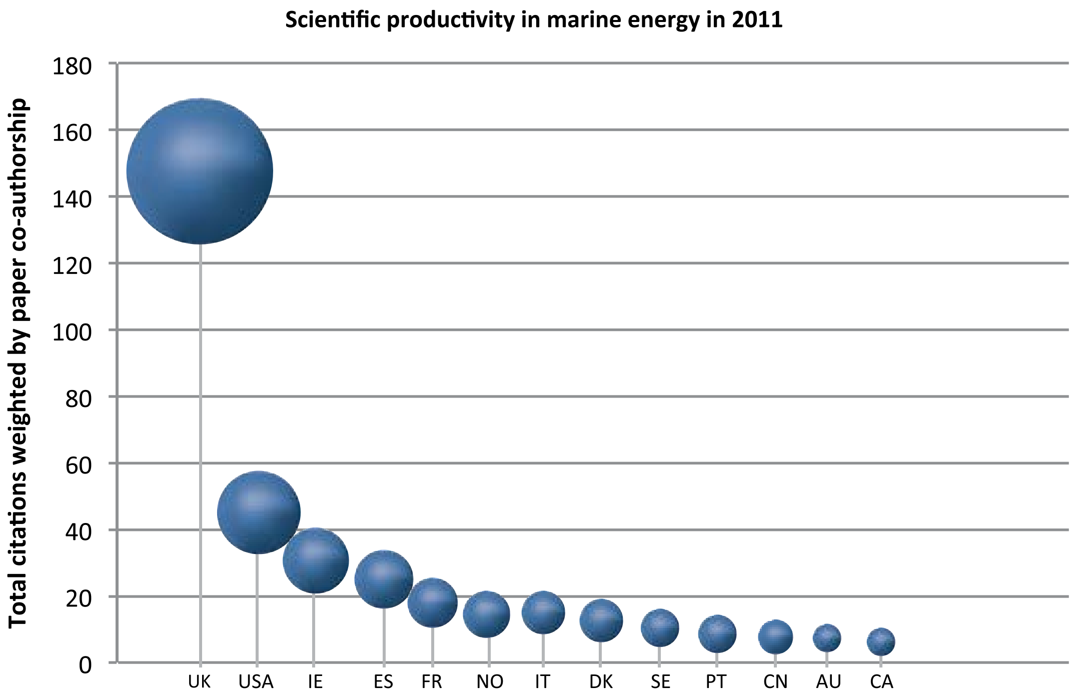


Figure 6: Contribution of countries to the knowledge-diffusion process measured by their scientific productivity in marine energy publications. The indicator was obtained by dividing the number of citations received by paper by the number of co-authors then finally aggregated at country level

Source: JRC, based on EWTEC, ISI and Science Direct data.

As expected from the discussion above, the United Kingdom has high scientific productivity, followed by the United States and Ireland. Figure 6 indicates the importance in knowledge creation in Nordic countries, such as Norway, Denmark and Sweden, as well as the contribution of late-movers, such as France and Italy.

Specific themes, such as wave energy converter modelling and wave energy power take-off, are cited more often than others. The average citation for published papers is 8.75 per paper. For unpublished working papers, it is possible to examine a different intensity of citation by topic. The average number of citations is also linked to the type of network collaborations – i.e. a denser network is likely to attract a higher number of citations.

3.2.3. Spatial knowledge diffusion of private research

The attractiveness of national and foreign markets is derived from an analysis of data on patent application files. Figure 7cumulates both foreign and national market flows to produce an aggregate indication of each market in both inflows and outflows of knowledge.

Figure 7 reiterates the importance of European countries in knowledge diffusion. At the international scale, countries such as Korea, United States and Canada play an important role. National markets are interesting for French and Swedish applicants. Within the bulk of patent applications, a higher degree of openness towards the international market is demonstrated by the Seabased company which applied for intellectual protection at patent offices in different countries.

Knowledge outflow is typically higher than knowledge inflows in countries such as Ireland, the United Kingdom and Norway. In addition, public research is committed to the international commercialisation of the technology with a different market niche.

3.2.4. Public-private partnerships: size of networks by country in European projects

Collaborations in European research projects are much more frequent than in journal articles and indicate more substantial involvement by industry. Scrutiny of the partners participating in EU-funded projects offers additional insight on the investment in emerging marine energy technology (Figure 8). The United Kingdom, France and Spain play a central role in the European collaboration network. An important part is played by French organisations, which are cooperating closely with British counterparts in developing the infrastructure and logistics needed to develop the sector. Projects such as MaRINET (Marine Renewable Infrastructure Network) and the

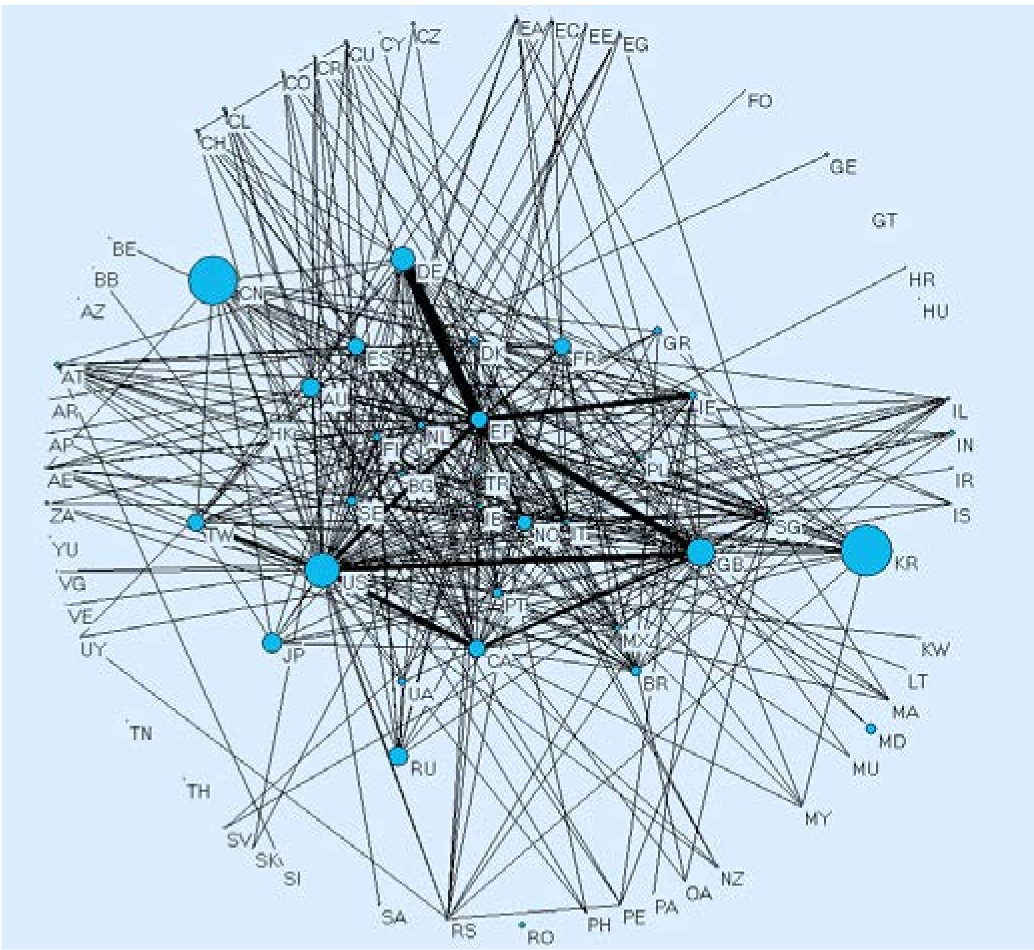


Figure 7: Network representation of commercial interests of public and private entities patenting in marine energy applications between 2001 and 2011, by country and patent office. The width of lines represents the intensity of collaboration between countries; the size of the bubbles indicates the number of patent applications

Source: JRC, based on Patstat data.

MARINA Platform (Marine renewable integrated application platform) succeed in gathering initiatives from all European countries. Targeted projects, such as Standpoint: Standardization of Point Absorber Wave Energy Convertors by Demonstration, and Surge: Simple underwater generation of renewable energy attract a limited number of participants and countries.

3.2.5 Evaluation of knowledge diffusion for main European countries

The fundamental knowledge expressed in terms of scientific publications and citations of scientific work is important when evaluating knowledge diffusion (Appendix 1). In terms of scientific impact, the most important is the contribution of British and Irish researchers. France also enjoys higher scientific recognition than other countries, and is comparable to Spain. In terms of knowledge diffusion through network collaboration, the Irish institutions register similar contributions to those of their French and Spanish counterparts. The German, Norwegian and Spanish developers show interest in foreign markets, such as the Korean, Canadian and American markets. The United Kingdom is the country with the greatest participation in knowledge diffusion. It organises scientific events and searches for commercialisation of the technology through both public and private initiatives.

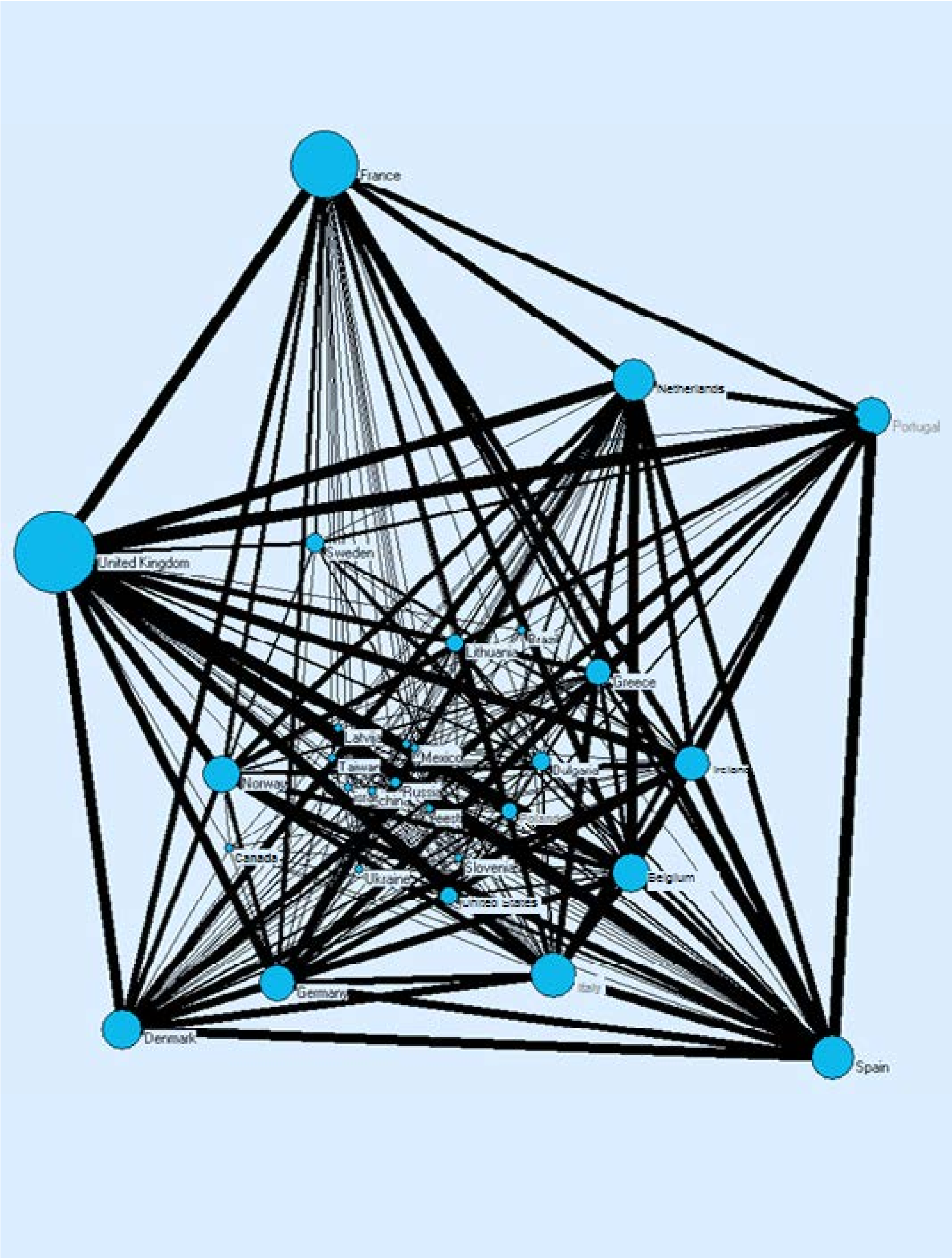


Figure 8: Network representation of public-private partnerships of entities participating in projects listed under CORDIS, related to marine energy topics. The width of lines represents the intensity of collaboration between countries; organisations are aggregated on country level; the size of the bubbles indicates country patenting intensity.

Source: JRC, based on Cordis data.

3.3. F3 – Knowledge commercialisation: entrepreneurs and venture capital

The organisation of marine energy innovation activities reflects a 'structural change' in policy (Boschma, 2004) in which the knowledge-creation organisations provide useful economic knowledge and support the development of new emerging economic activities, such as spin-offs.

3.3.1. Academic spin-offs and new start-ups

Universities play an important role via an intensive process of launching academic spin-offs and start-ups. An example is given by UK universities employing personnel working on technology transfer, where the government provides funds for capacity in higher education institutes to commercialise knowledge generated through research activities, whereas in France, new technology companies are funded through public incubators (Table 4).

UK universities are very active in the commercialisation of marine energy technologies, although such activities also take place in other European countries, too.

Vital support for new technology ventures is provided by public organisations, such as Innovation Norway or Enova, which have lately sustained the funding of Nordic wave and tidal energy developers. A general representation of technology developers by country is shown in Figure 9.

In 2011, British manufacturers of marine energy technology accounted for 33 % of all European developers.

3.3.2. Venture capital and private equity investors

New technology projects are able to structure financing as a combination of a number of debt and equity financing layers with an important technology risk required to increase assurances that a marine energy system will be deployed. Although not as spectacularly as in other energy technologies, some of the marine energy technology developers have succeeded in attracting the investment funds needed for testing their applications. Incumbent energy companies (see box 2) have increased their participation in developing the sector with an important effort being made by countries such as France, the United Kingdom, Germany, Norway and Sweden.

Table 4: Examples of marine energy academic spin-offs by country

Company	University/Public incubator	Country
Energie de la Lune	Université de Bordeaux	*France*
INNOSEA	Ecole Centrale de Nantes	*France*
HydrOcean	Ecole Centrale de Nantes	*France*
Nemos	University of Duisburg Essen, spin-off from DST and ISMT	*Germany*
Wave for Energy Srl	Politecnico di Torino	*Italy*
EolPower Group	Dipartimento di Ingegneria Aerospaziale, Università degli Studi di Napoli "Federico II"	*Italy*
Wirescan AS	Institute for Energy Technology (IFE), Halden	*Norway*
Seabased AB	Uppsala University	*Sweden*
Kepler Energy	University of Oxford	*United Kingdom*
Manchester Bobber	University of Manchester	*United Kingdom*
Nautricity Ltd	University of Strathclyde	*United Kingdom*
Pelamis Wave Power	Institute for Energy Systems (IES), University of Edinburgh	*United Kingdom*
Aquamarine Power	Queen's University Belfast	*United Kingdom*
Wave Energy Centre	IST Lisbon	*Portugal*
Hidromod	IST	*Portugal*
Swanturbines	University of Swansea	*United Kingdom*
Wave Power Solutions	Delft University of Technology	*The Netherlands*
IHFOAM	University of Cantabria	*Spain*

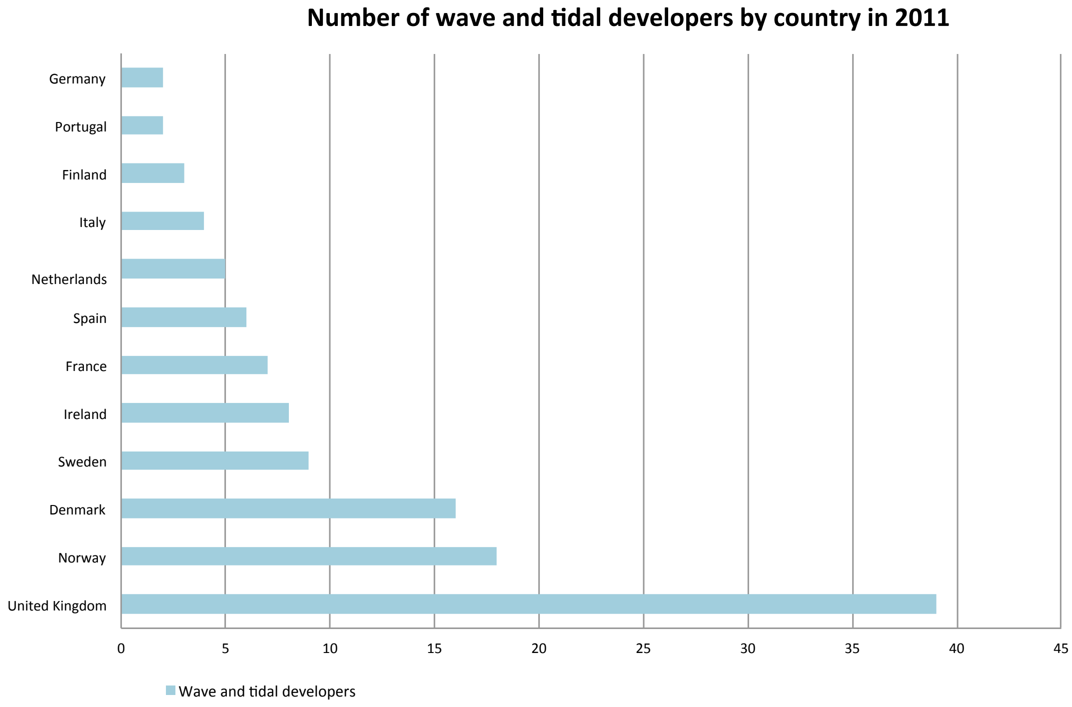


Figure 9: Number of marine energy technology developers by country in 2011

Source: JRC, based on data from EMEC, Nordic green and Brest marine conference 2013.

British government support plays a significant role in demonstration projects: Tidal Energy Ltd received a € 7.7 million grant from the European Regional Development Fund and Ocean Flow Energy received a € 0.7 million grant from the Scottish Government's WATERS fund. Helping marine developers to cross the commercialisation 'valley of death', UK public capital did not crowd out pure private capital: ABB and SSE (Scottish and Southern Energy plc) are major shareholders in Aquamarine Power.

French companies: in 2011, Alstom bought 40 % of the shares in the British AWS Ocean Energy; two years later it acquired Tidal Generation Ltd for around € 57 million. DCNS acquired OpenHydro and started operations in the north-west of France. Actimar, active in marine energy technology, is currently owned by the Suez Group.

German energy companies are also involved in demonstration projects: Siemens AG acquired up to 45 % of the shares in a tidal technology developer Marine Current Turbines Ltd; Schottel GmbH, a marine propulsion specialist, is a major shareholder in TidalStream; Voith Hydro Ocean Current Technologies is in an 80:20 joint venture with the RWE Innogy Venture Capital Fund; new shareholders in Wirescan AS include Sakorn invest and Siemens venture capital; and finally, Andritz AG is shareholder in Hammerfest Strøm SA.

Norwegian tidal-turbine maker, Hammerfest Strøm SA, succeeded in raising € 14.5 million through equity raising. Finnish company Fortum is a major shareholder in AW-Energy Oy, and since 2010 has been involved in a demonstration project with Seabased AB. Among Swedish companies, ABB has contributed to the development of marine technology by acting as shareholder in the SEEWEC Consortium, a major shareholder in Aquamarine Power in 2007.

Spanish companies Iberdrola and Acciona have also been involved in marine energy projects. Iberdrola invested in Oceantec Energias Marinas SL; and Abengoa was attracted by the Wavebob project; however, the project failed to raise the necessary demonstration funding (€ 10 million) and was forced to close recently.

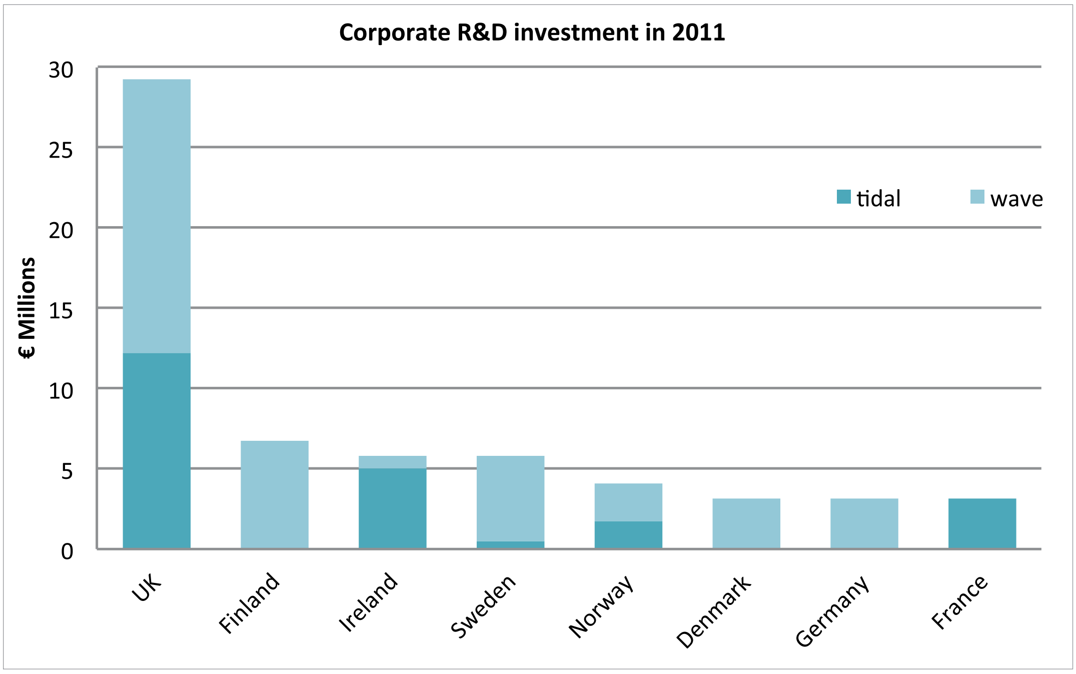
3.3.3. Diversification of research activities for wave and tidal developers

R&D investments by country show the UK as the main investor in wave and tidal technologies. The breakdown of investment by type of marine energy technology is shown in Figure 10, 11, 12 and 13. The assessment relies on patent applications by main wave and tidal developers[20] to which an average intensity of R&D per patent

20 Estimation of R&D investments for tidal and wave technologies performed by main developers and concepts retrieved from the EMEC website, http://www.emec.org.uk/

Figure 10:
Estimation of research investments (in millions of euros and percentages) of private developers by marine energy technology and by country in 2011

Source: JRC, based on WIPO, EMEC and JRC 81432 data.



of € 0.9 million was allocated. The intensity might change for future calculations.

Countries such as the UK, Ireland, France and Norway explain the bulk of private investments in the tidal sector (Figures 10a and b). The United Kingdom shows comparable commitments for both wave and tidal energy technology. According to the information collected, private investors in countries such as Finland, Sweden, Denmark and Germany prefer to invest in wave energy devices, thereby indicating wider European interest for wave technology (with more widely available resources).

A collective interpretation of the figures points out the horizontal axis turbine as possible dominant prototype for tidal energy. A higher fragmentation is observed for wave energy. However, a wider diversity of concepts offers better chances for technologies to rise above the commercialization 'valley of death'. The more diverse the portfolio of wave and tidal technologies, the lower the investor's risk could become. In order to quantify the uncertainty associated with the share of investments across marine technologies, the Shannon Index is computed. The Shannon index for wave and tidal technologies indicates a higher diversity

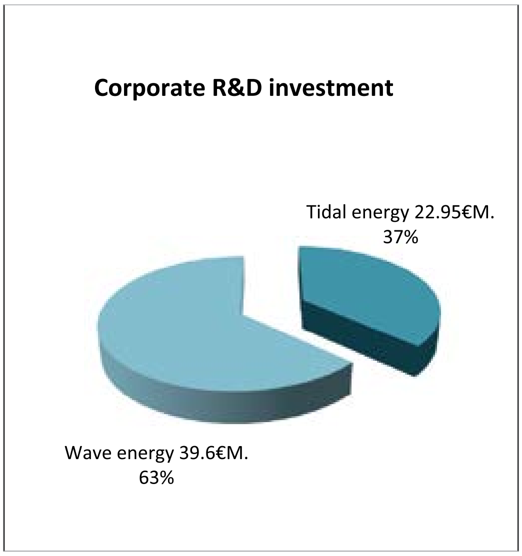


Figure 11:
Distribution of research investments by marine energy technology in 2011

Source: JRC, based on WIPO, EMEC and JRC 81432 data.

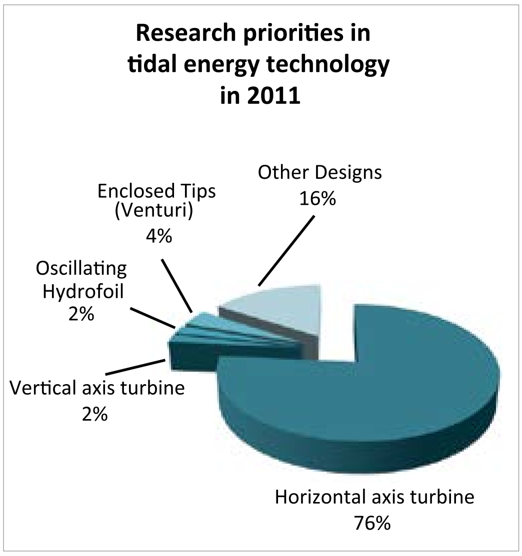


Figure 12:
Estimation of research investments (in percentages) for main concepts developed by tidal energy developers retrieved from the EMEC website (www.emec.org.uk). The assessment relies on patent applications of tidal developers and on an average intensity of R&D per marine patent of € 0.9 million. This intensity may change for future calculations.

Source: JRC, based on WIPO, EMEC and JRC 81432 data.

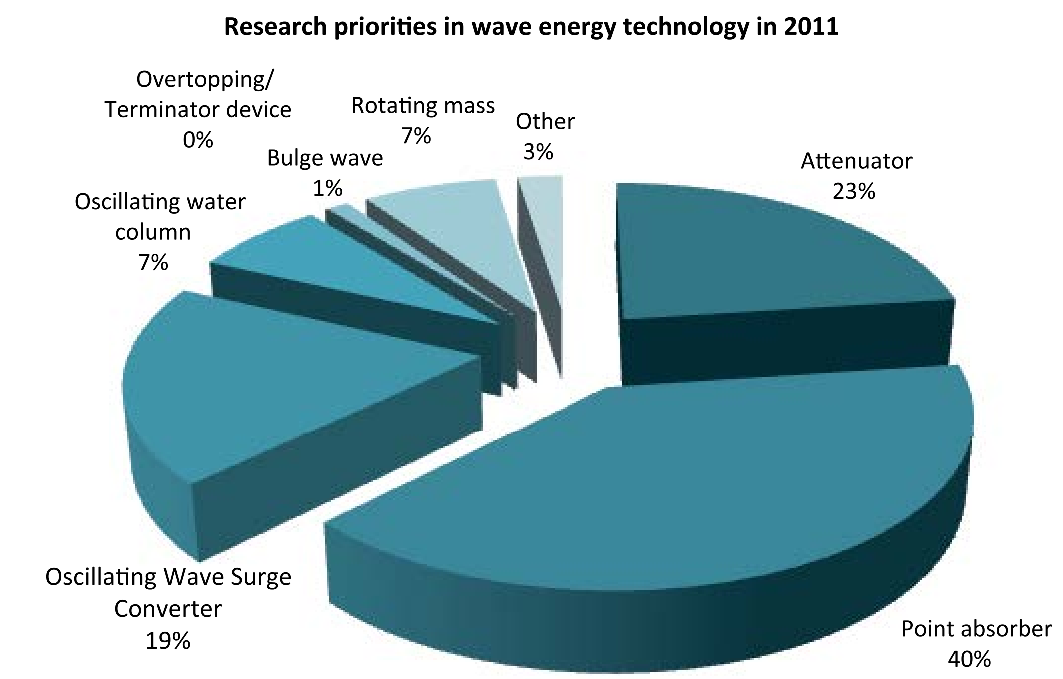


Figure 13: Estimation of research investments (in percentages) for main concepts developed by wave energy developers retrieved from the EMEC website. The assessment relies on patent applications of wave developers and on an average intensity of R&D per marine patent of € 0.9 million. This intensity may change for future calculations.

Source: JRC, based on WIPO, EMEC and JRC 81432 data.

for the United Kingdom and Norway, and a lower one for Portugal and Ireland (Appendix 1).

3.3.4. Assessment of business opportunities across countries

Different efforts are made for the development of the technologies in terms of number of entrepreneurship initiatives, capital rising for demonstration projects and technology risk. The United Kingdom and Norway present a high diversity of concepts, endowed with marine energy developers that develop initiatives in all technologies. Oppositely, a lower fragmentation of knowledge is observed in Sweden and Spain. The United Kingdom, Denmark, Norway and Ireland gather the highest entrepreneurial initiatives (Appendix 1), whereas France, Germany and Sweden are present through numerous initiatives of private equity investors in companies dealing with marine energy technologies. The overall evaluation of commercialization initiatives points out the United Kingdom and Norway as most committed to valorising business opportunities provided by marine energy.

3.4. F4 – Guidance for research

Guidance for research activities is provided by public support for wave and tidal energy deployment. *Targeted policies,* such as public subsidies for deployment (*feed-in-tariffs*, *quota system*) are needed by marine energy developers so that they can plan their investment efficiently. This section refers to the level of public instruments as potential enablers of innovation activities.

Table 5: Support schemes across European countries

	FiT/FiP (€ct/kWh) wave and tidal	FiT/FiP (€ct/kWh) wind	Quota system
Denmark	5-8	1.3	
France	15[21]	Onshore: 2.8 – 8.2 Offshore: 3 – 13	
Germany	3.4 – 12.7	Onshore: 4.87 – 8.93 Offshore: 3.5 – 19	
Ireland	26	6.9	
Italy	34*	30 (plants<1 MWH)	
Portugal	26	7.4	
Spain	7.65 – 7.22	8.12-6.79	
Sweden			0.179 (2012)*Bottom of Form
Norway			0.049 (2013) *
UK			0.050 – 0.104**

** Quota obligation per MWh of electricity sold or consumed;*
*** Number of renewable obligations certificates / MWh;*
it doubles for installations >10MW

21 73 €/MWh and € 200 million of capital support, France Energies Marines.

3.4.1. Deployment subsidies

Besides targeted policies for deployment, such as *feed-in-tariffs* and the *quota system,* additional targets can create opportunities to foster the marine energy market (Pound et al., 2011). Countries with quota systems, such as Norway, Sweden and the United Kingdom, seem to have high levels of policy effectiveness. Table 5 presents the main support for deployment of marine energy projects.

Examples of public incentives to push the development of the technology include:

- ***Subsidies***: an additional difference in Feed-in-Tariffs (FiT) is introduced in the United Kingdom for the first 30MWh in each project. In Italy, significant support for the sector development is reflected through a FiT of 0.34 €/kWh. France has announced a FiT of 173€/MWh which is lower than the UK; however, the French authorities offer capital support grants of up to € 200 million to reduce risk for investors.

- ***Investments:*** the Irish government has put in place a financial package for marine energy[22] covering support for device developers, and the development and enhancement of grid-connected test facilities, such as the Atlantic Marine Energy Test Site in Belmullet and the Galway Bay test site.

- ***Infrastructure:*** Portugal has initiated the first steps for the development of the Wave Energy Pilot Zone and created a dedicated subsidiary of the National Energy Networks.

- ***Targets*:** new Spanish targets seek to install the first 10 MW by 2016, while new planning is taking place in Germany ('National Maritime Technologies Masterplan').

- ***Licensing***: Norway is setting up new legislation for renewable offshore energy production with an efficient licensing process. The Scottish Government (responsible for the implementation of legislation in Scotland and in Scottish Water) has developed a one-stop shop for licensing wave and tidal energy projects that is helping developers to deploy their technologies.

For countries such as Denmark and Portugal, the level of Feed-in-Tariffs and premiums for marine energy is more than double that for other renewables energy technologies (i.e. offshore wind), thus showing the current interest in developing the country's marine energy potential. When choosing between geographical markets, countries such as Ireland, Portugal and Italy offer a higher tariff than other countries. It is important to note that marine energy developments in Ireland and Portugal will provide an important contribution to the amount of electricity provided to the grid, whilst Italian investments are more likely to enable the development of technology-producing companies.

3.4.2. NER300

'NER300' is the name of a financing instrument managed jointly by the European Commission, the European Investment Bank and Member States. The name comes from Article 10(a) 8 of the revised Emissions Trading Directive (2009/29/EC) which includes a provision to set aside 300 million allowances (rights to emit one tonne of carbon dioxide) in the New Entrants' Reserve of the European Emissions Trading Scheme for supporting installations of innovative renewable-energy technology and carbon capture and storage (CCS).

Categories of renewable-energy technology that are eligible for support have been defined in Annex I & II of the NER300 Decision, in which ocean project subcategories are:

- Wave energy devices with nominal capacity of 5MW;

- Marine/tidal currents energy devices with nominal capacity of 5MW; and

- Ocean thermal energy conversion (OTEC) with a nominal capacity of 10MW.

Three wave and tidal projects, to be developed in the United Kingdom and Ireland, have been selected for NER300 funding, from the five submitted from the first Call (Table 6).

Status	Project	Countries	Fund rate €/MWh	Million €
NO	Ocean SWELL	PT		-
YES	Sound of Islay	UK	185.7386	20.65
NO	ETM Martinique	FR		-
YES	West Wave	IE	429.6031	19.82
YES	Kyle rhea	UK	246.4896	18.39

Table 6:
Ocean energy projects submitted to NER300

22 Administered by a new marine Energy Development Unit (OEDU) based in the Sustainable Energy Authority of Ireland (SEAI).

The selected wave and tidal projects feature a funding rate that is five times greater than that awarded to wind technology and two times greater than offshore wind projects. Cumulatively, the financed projects aim at installing around 24MW wave and tidal energy capacity, which represents a tenfold increase on the 2011 level. The ambitious entrepreneurial initiatives are sustained by public intervention, in the case of the United Kingdom (tidal energy) and in Ireland (wave energy):

- The West Wave project identified 32 possible sites with an average wave resource of 40kW/m of the west coast of Ireland to be developed using one of more wave technologies that have reached TRL9. The projected installed capacity of the array is 5MW.
- Four tidal energy twin-rotor turbines each rated at a nominal 2MW, will be installed in the Ocean Kyle Rhea project (8MW).
- Three-bladed, seabed-mounted tidal turbines will be installed in waters between the islands of Islay and Jura off the west coast of Scotland (10MW).

Non-selected projects were submitted by Portuguese (5MW) and French (10MW) bidders. The Portuguese project proposed the implementation of an array of 10 surging-wave energy converters (nominal capacity 500kW each). The French initiative, to be developed on Reunion Island, presents a novel and ambitious technology: ocean thermal energy conversion. OTEC has been identified as a technology where an EU country may have a technical advantage, but difficult implementation in EU waters due to low temperature gradient differences.

3.4.3. Evaluation of public support for development of the technology

The potential of publicly induced innovation as a function of deployment-support instruments indicates that Ireland is the country offering the greatest guidance for research (Appendix 1), followed by the United Kingdom, Denmark and Italy. Compared to offshore wind energy technologies, countries such as Denmark and Ireland offer higher subsidisation (in terms of FiTs and premiums) for the development of marine projects. In absolute terms, the higher levels of FiTs/FiPs in Italy and Portugal than in other countries potentially exert significant inducement concerning innovation activities in marine energy technologies. However, it must be noted that the wave and tidal resources available in Denmark and Italy are lower compared to those of other EU countries and thus these countries may benefit more from developing and commercialising marine energy technology than from national marine energy deployment.

To summarise, *targetted policies* could further promote marine energy technology development, although such support may prove hard to materialise in the absence of a commercially mature technology.

3. 5. F5 – Market formation

The sector has an expectation to reach commercialisation in the coming decades, rising to 30-40 years for wave energy (Pound et al., 2011). The nascent state of the industry is represented graphically by different stages of development of the ongoing projects in 2011 (Figure 14).

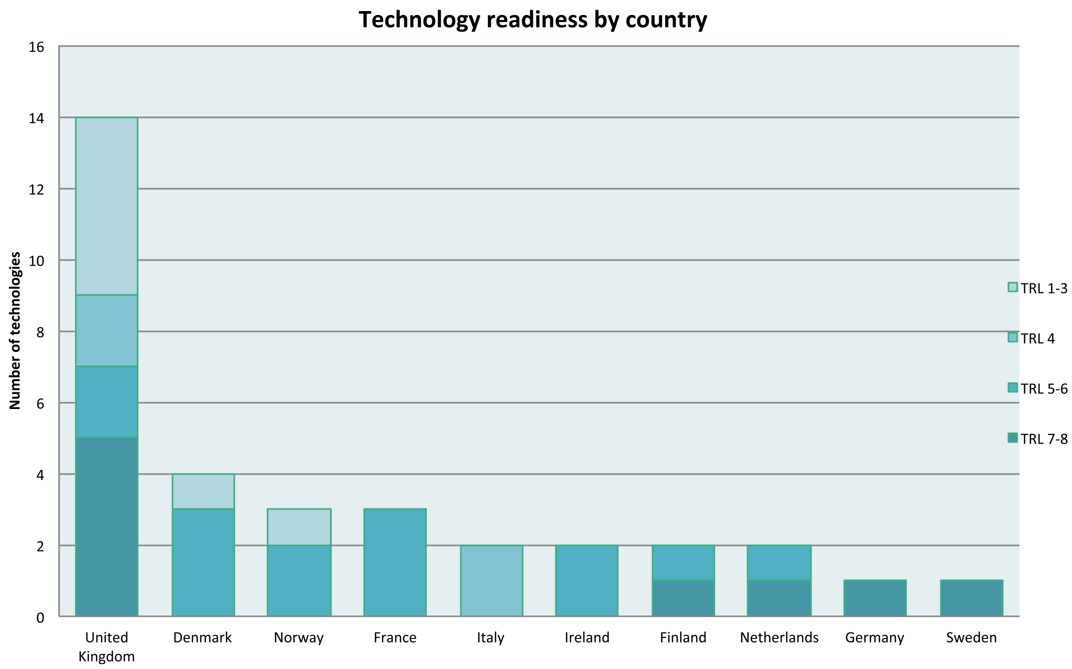


Figure 14: Technology readiness level of wave and tidal technologies by European country (DOE)

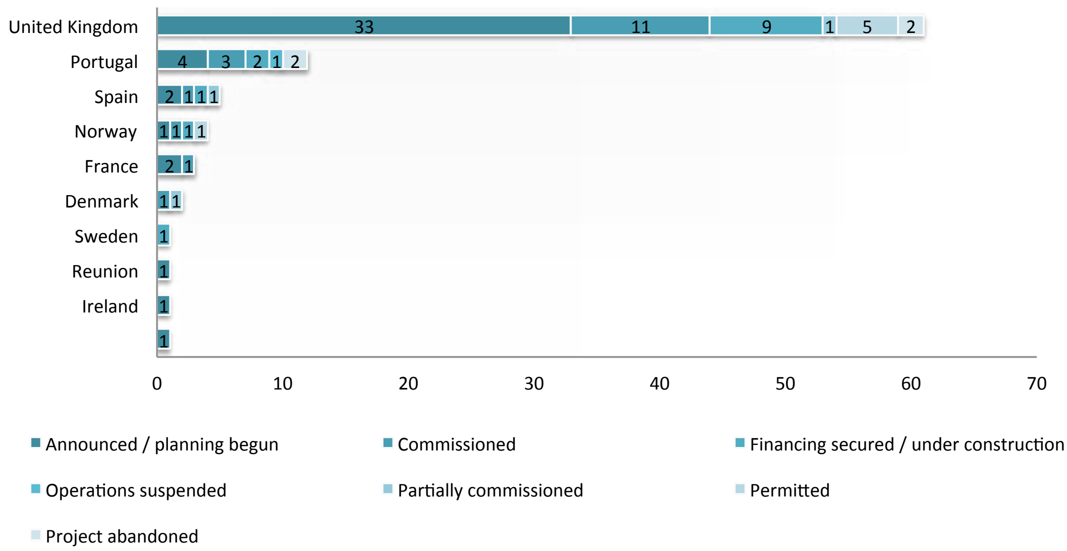
Source: JRC, based on data from Bloomberg energy database.

Within all the marine energy projects being deployed in Europe, only 22 % of them are partially/totally commissioned. As seen in Figure 15, the United Kingdom accounts for a significant share of wave and tidal projects that have been proposed/installed within Europe. Countries such as Portugal, Spain, Norway and France reflect a commitment to develop marine energy projects, with the majority of the projects at the early stages of development: announced/planning begun or financing secured/under construction.

The successful completion of marine energy projects involves a range of services such as insurance and finance, resource assessments, environmental surveys, design, manufacture, offshore construction, operation and decommissioning. The identification and description of such services by individual project would help in understanding the status of marine energy supply chains.

Figure 15: Wave and tidal projects by development stage across European countries (Bloomberg energy database)

Source: JRC



3.5.1. Physical infrastructures and supply chain issues

One of the parameters that can affect the functioning of the innovation system is the presence and status of physical infrastructure. In particular, the need for infrastructure for testing devices and for the deployment of early arrays and demonstration projects is of primary importance. This often relates to the availability of sites for the reliability testing of devices, provision of cables, grid connection and infrastructure. To date, mainly due to the early stage of the technology, little capacity has been installed in Europe, with many single devices deployed in the 0.2-1.MW range.

The nascent status of marine energy technologies is highlighted by the limited number of sites commissioned and built around Europe. Currently, 260MW have been installed, including the La Rance Barrage (France). However, a number of infrastructure sites available for the development and demonstration of the technology, in particular small- to large-scale testing, is available at universities and research centres. A number of European facilities have been made available to developers at different stages throughout the FP7-funded MaRINET project. The list of the facilities available in Europe is presented in Table 7. In addition, other EU and nationally funded projects have provided access to marine energy testing, such as the FP7 Hydralab, which provides access to, among others, the Marintek basin in Trondheim (Norway), and the Deltares basin in the Netherlands (Appendix 2).

The possibility of investigating and investing in marine energy projects has also led the way to the development of dedicated tidal and wave energy facilities, of which EMEC is the leading example comprising grid-connected tidal and wave energy sites. Figure 16 presents the real-sea infrastructure both developed and underdevelopment, in Europe for the testing and demonstration of wave energy devices.

The development of wave energy test and demonstration sites is an indicator of both the progress and the constraints the sector has faced over the past few years. The EMEC test site has been operational since 2003, whilst Wave Hub, developed for array testing, has been ready since 2010 but installation has still not taken place. On the other hand, towards the end of 2000, nursery test sites were developed to help with the structural design of wave energy converters. This highlights the technical difficulties encountered in the development and deployment of reliable offshore devices (Table 8).

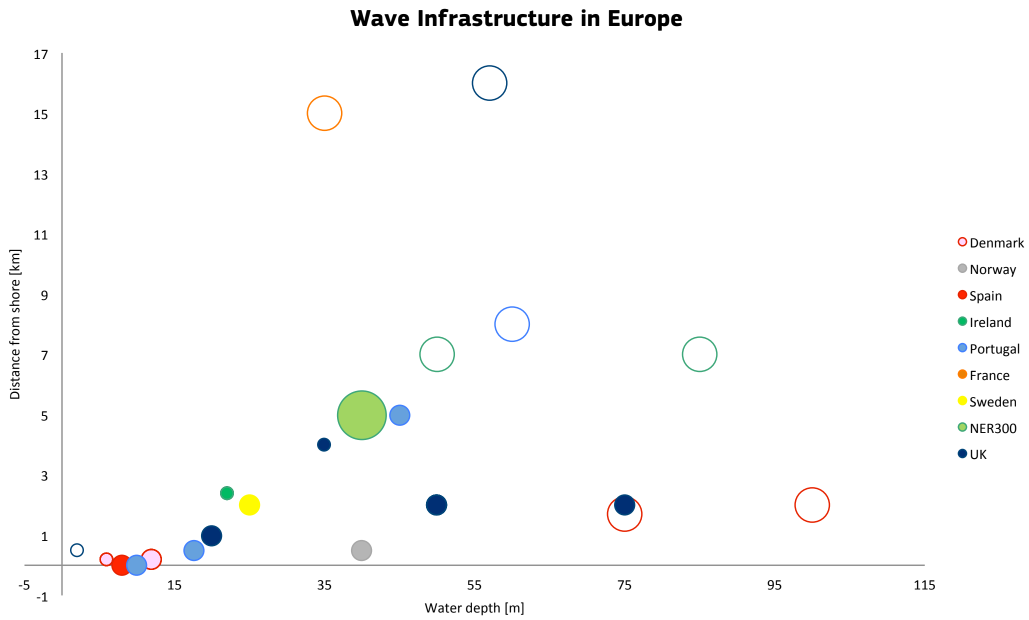


Figure 16: Real-sea demonstration facilities in Europe for wave energy testing; hollow circles indicate planned projects

Source: JRC

Table 7: List of wave energy test centres and related infrastructures

Name of facilities	Country	Purpose	Devices	Start date	Connection	Cable
DanWEC	Denmark	Full scale	Yes	2009	Yes	Yes
Danish Benign Test Site	Denmark	Scale	Yes	2000	Yes	No
EMEC	Scotland	Full scale	Yes	2002	Yes	Yes (2006)
EMEC - nursery	Scotland	Nursery	No	2011	No	No
Wave Hub	England	Array	No	2010	Yes	Yes (2010)
FaB Test	England	Nursery	Yes	2011	No	No
Runde	Norway	Full scale	Yes	2008	Yes	Yes
BIMEP	Spain	Array	No	2013	Yes	Yes (2013)
Plocan	Spain	Array	No	2013	Yes	
Mutriku	Spain	Operational	Yes	2011	Yes	Yes (2009)
Galway Bay	Ireland	Nursery	Yes	2006	No	No
Ocean Plug	Portugal	Array	No	2007	Yes	No
SEM-REV	France	Array	No	2007	Yes	Yes (2012)
Lysekil Wave Energy	Sweden	Array	Yes	2003	Yes	Yes (2003)
Pico Test Plant	Portugal	Operational	Yes	1999	Yes	Yes
Peniche test site	Portugal	Array	No	2007	Yes	No
Aguçadoura	Portugal	Array	Yes	2007	Yes	Yes

On the other hand, the development of infrastructure for testing and deployment of tidal technology has followed another route. Many of the devices have been tested in the strong and resourceful infrastructure provided by EMEC. Following the successful deployment of the technology, tidal farms have been proposed and are currently going through licensing and commissioning. In recent years, the need for testing and furthering the application of the technology has seen a call for the commissioning of new testing facilities. Tidal centres have been established in France and in the Netherlands, whilst a new project is under development in the south of the UK, off the coast of the Isle of Wight. An overview of the tidal facilities developed in Europe is presented in Figure 17 and Table 9.

Figure 17: Real-sea demonstration facilities in Europe for tidal energy testing, empty circles reflect projects currently under development.

Source: JRC, based on data from companies' websites.

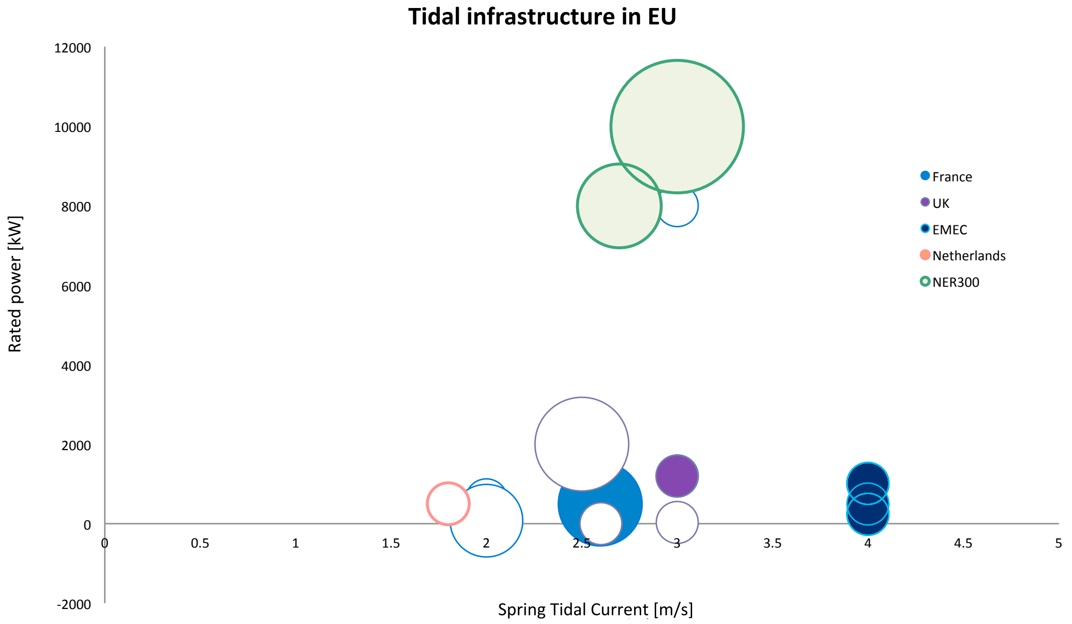


Table 8: List of tidal energy facilities and related infrastructures

Name of facilities	Country	Purpose	Operational date
Paimpol Bréhat	France	Tidal test site	2012-2014
Raz Blanchard	France	Pre-commercial farm	2015
Alderney	France	Pre-commercial farm	2015
Ouessant	France	Prototype	
Raz Blanchard	France	Pilot farm	
Bordeaux	France	Tidal test site in estuary waters	2013
Raz Blanchard	France	Pre-commercial farm	2016
Tidal Test Centre	Netherlands	Test Centre	
Sanda Sound, Scotland	UK	¼-scale mono-turbine demonstrator	2013
Sanda Sound, Scotland	UK	¼-scale twin-turbine demonstrator	2014
Strangford Lough, N. Ireland	UK	Pre-commercial	2008
Skerries, Wales	UK	Demonstration array	2015
Torr Head, Northern Ireland	UK	Commercial array	2017 onwards
Fair Head, Northern Ireland	UK	Commercial array	2018 onwards
Islay Marine Energy Park, Islay	UK	Saltire Lease	2016 onwards
Montrose Bridge, Scotland	UK	Commercial	2015
EMEC	UK	Test Centre	2008
Kylerhea, Scotland	UK	Demonstration Array	2015
Perpetuus Tidal Energy Centre	UK	Test centre	2014 onwards
Tidal Test centre	UK	Test centre	2013

Cables and connections

One of the critical points for the operation of marine energy test centres is the connection to the grid to supply electricity generated at sea. Many of the test facilities developed so far are located in close proximity to the shore, thus providing access to grid and electrical infrastructure and maintenance access to the devices through the provision of ports. EMEC sites are located within a 5 km radius from shore, with both the tidal and wave energy sites grid connected. The MeyGen project, which could reach a total capacity of 400MW, has announced the development of the first 10MW in close proximity to grid infrastructure. The development of wave energy test centres proves a stark contrast – for example, the support infrastructure for BIMEP consists of four cables comprising a total length of 18.5km, whilst cables deployed for the Wave Hub and SEM-REV are 25 km and 24 km long, respectively. Critical to the laying and installation of cables is the use of specialised equipment (e.g. telecom vessels).

The cost of installation is high, ranging from € 4 to 20 million per MW installed, with a cost of submarine cable per kilometre which is rated at a minimum of € 0.5 million (ADEME, 2009). Typical cost of repairs is in the range of € 0.7 to 1.4 million, including the cost of repair joints and spare cables (Beale, 2011); the cost is higher in high-energy environments with swept, rocky and trenching seabed conditions.

Grid

Taking into account the current development and deployment rate within the sector, it is likely that issues related to the development of substations and the increased need for stable grid infrastructure will be considered in the future. These items have already been identified as bottlenecks in the sector. However, it is likely that an integrated and cross-industrial approach, as envisaged for the offshore wind energy sector, will be required to overcome such barriers. Funds made available in the United Kingdom by the Crown Estate require developers to already have in place an application for grid access[23], although issues concerning the development of the required grid infrastructure in Scotland have already arisen, with no expansion forecast until 2017[24]. The Ocean Energy Systems (OES) implementation of the International Energy Agency has started a programme led by Tecnalia in Spain to assess the capabilities for grid integration and transmission of the wave energy arrays that are under development in Spain (Bimep) and in Ireland (AMETS). No significant barriers are expected in terms of grid for the two sites, although the site will provide an important learning experience for future development, both in terms of grid and transmission requirements.

Vessels

The diversity of concepts developed for wave and tidal energy converters requires different installation practices in terms of installation, maintenance and recovery of marine energy devices. Differences can be seen in the need for installation of foundations for bottom-fixed devices (i.e. Oyster, Seagen, TGL, OpenHydro and Hammerfest) compared to moored devices (Pelamis, Scottish Renewable). In the first case, crane-equipped barges are used to install foundations, often equipped with systems providing quick access maintenance. Moored devices require a vessel for transportation and are often towed back to the closest harbour for maintenance. Device developers have worked in closed collaboration with vessel manufacturers to develop specific installation and operation vessels[25]. However, it is likely that no convergence will be achieved on vessel design until technological consensus is reached.

Harbours

A critical point in the development of the infrastructure for testing and deployment of marine energy technology is the proximity to a harbour, offering easy and quick access to maintenance and, in the future, manufacturing and assembling capabilities. As discussed in the case of cable and grid infrastructure, the current stage of deployment has yet to encourage the development of ports designed to serve the marine energy sector. Developments in the field have already been seen in Orkney, where funds of € 9.5 million were provided to expand harbour facilities due to an increase in marine energy related traffic[26]. These funds appear low compared to those made available for the development of wind energy adapted harbours in the UK (€ 70 million); however, they should be considered as substantial given they are for the direct implementation of facilities in one location.

23 http://www.thecrownestate.co.uk/media/362883/first-array-investments-guidance.pdf

24 http://www.bbc.co.uk/news/uk-scotland-20816349

25 http://www.openhydro.com/news/OpenHydroPR-010911.pdf

26 http://www.bbc.co.uk/news/uk-scotland-scotland-business-22358818

3.5.2. Nursery markets

The development of nursing markets represents the most important public support, potentially, for the development of pre-commercial stage technologies. The availability of pre-facilities represents the infrastructure needed by infant projects to connect at sea, thereby reducing the overall marine energy project costs. Large-scale wave and tidal energy test facilities are catalogued in Tables 7 and 8. Among these centres, some relevant examples are included below:

- The Wave Hub, which offers facilities for testing arrays of wave energy devices with a total capacity of 20 MW;
- The AMETS, which offers a berth for testing WECs;
- The Pico OWC, which has been operational in Portugal since the late nineties (although it has sustained periods of abandonment);
- The DanWEC – part of Hanstholm harbour[27] – which has observed the trials of wave energy projects led by WaveStar, Waveplane and Dexa;
- The Lysekil test centre (Sweden) which, since 2002, has actively supported wave power research, being able to host ten WECs, 30 biological buoys, one substation, one observation tower and one subsea power cable to shore until the end of 2013 (Lejerskog et al., 2011). It is considered by the IEA as a pre-commercial test site able to investigate multiple-device performance, device-array interactions and power-supply interaction.

3.5.3. Supply chain description

The marine energy supply chain in the selected countries is presented below in four stages:

The R&D stage: the upstream of the supply chain in which many institutional actors and private firms cooperate in the creation and demonstration of marine energy concepts.

The demonstration of marine energy projects includes, as the main categories, the owners, project developers and managers of the farms.

The construction phase includes installation contractors, component manufacturers (nacelle, gravity-based structure and system assembly, shaft brake, hub assembly and power take-off) and substation developers/suppliers which assure feasibility, planning and design services.

The operation and maintenance phase (O&M) includes all actors involved in offshore services, commercial diving and marine survey, and consultancy firms.

The following section is not intended to present an exhaustive description, but rather an identification of the mix of national or international efforts committed to the demonstration and implementation of marine energy projects. In addition, it points out the extent to which the development of the sector involves traditional oil and gas companies.

Figure 18: Representation of public and private entities participating in the Irish supply chain

Source: JRC, based on data from companies' websites.

The depicted logos are trademarks / trade names of the selected companies

27 Margeritini et al., 2011.

Ireland

At national level, a significant support for the Irish marine energy supply chain was the creation in 2012 of the SmartBay platform. Under the umbrella of a private organisation, the facility assures the "collection of marine data for the national and international R&D communities, the trial, demonstration and validation of novel marine sensors and equipment and the development of collaborative translation projects which aims to develop innovative ICT products and services for the global maritime industry"[28]. Further transparency and support is offered by a publicly available database providing useful information on the Irish marine energy supply chain[29] (Figure 18). The Sustainable Energy Authority of Ireland points out opportunities to develop a national supply chain for wave and tidal devices, enabled by domestic research collaboration focused on device development and testing in Ireland.

However, the same report[30] highlights potential future export opportunities for Irish companies in areas such as precision engineering, mechanical and electrical engineering, wireless communications, control systems and environmental sensors to international ocean energy projects. Despite significant offshore capacities that are or can be mobilised around this technology, marine energy companies are struggling to raise the necessary capital for testing their devices (i.e. WaveBob Limited).

Denmark

A first-mover into the sector, Denmark has just three marine projects (including the Faroe Islands, see Figure 19). The marine energy supply chain reveals opposing situations, with projects run by the mobilisation of national partners (Wavestar) or projects involving international partners (Wave Dragon). The Wave Dragon technology displays a mix of local and international efforts: German, Swedish and British suppliers work together to validate the technology[31,32]. International cooperation in developing the prototype Wave Dragon is reflected within the history of testing:

Figure 19: Representation of public and private entities participating in the Danish supply chain

Source: JRC, based on data from companies' websites.

The depicted logos are trademarks / trade names of the selected companies

28 http://www.smartbay.ie/AboutUs.aspx

29 SEAI marine supply database http://www.seai.ie/Renewables/Ocean_Energy/Marine_Energy_Companies/Marine_Energy_Company_Listings/?keywords=all&cat=161-162-163-164-165&page=2

30 A Study of the Supply Chain Requirements and Irish Company Capability in the Offshore Wind, Wave and Tidal Energy Sector, http://www.seai.ie/Renewables/Ocean_Energy/Ocean_Energy_Information_Research/Ocean_Energy_Publications/A_Study_of_the_Supply_Chain_Requirements_and_Irish_Company_Capability_in_the_Offshore_Wind,_Wave_and_Tidal_Energy_Sector.pdf

31 http://www.spok.dk/consult/wavedragon_e.shtml

32 James Tedd, 2007, Testing, Analysis and Control of Wave Dragon, Wave Energy Converter, PhD thesis defended in public at Aalborg University (101207) http://waterenenergie.stowa.nl/upload/james%20tedd%20phd-thesis%20on%20wave%20dragon%20low%20res%5B1%5D.pdf, pages 46-47.

first tested at the Danish wave energy test centre at Nissum Bredning, a multi-MW device pilot has been further approved, but is not yet installed in Wales. Further testing for validation of the technology is taking place via participation in many European cooperation projects. Conversely, another project developed at the Nissum centre, the Wavestar, presents a supply chain which is nationally dominated (Blandt, Sauer Danfoss) with national testing of the prototype at Aalborg University (2004-2005, Scale: 1/40), at Nissum Bredning (2006-2010, Scale: 1/10) and at Roshage[33].

Nationally, both technologies enjoy the strong offshore expertise available in Denmark, with further potential synergies between wind and wave energy able to ensure the sharing of both the infrastructure costs and the O&M facilities (Figure 18). For example, future collaboration between Wavestar, DONG Energy and Energinet will plan the installation of a 600kW WEC to a wind power plant (owned by DONG) at Horns Rev 2, on the western cost of Denmark[34].

France

Until recently, a limited number of projects were developed in France. In the case of wave energy technology, the ongoing demonstration project (Figure 19) involves foreign-developed technology (SBM S3, Carnegie). However, smaller national initiatives are being developed by the national incubators or research centres (Ecole Centrale de Nantes).

Key partners in tidal energy technology include Gaz de France (GDF Suez) and DCNS (Figure 20). National utility company Gaz de France is developing two projects in locations that cover 80 % of the marine energy potential in France. One project involves the demonstration of the Canadian technology, Sabella, whose 0.5MW devices are planned for demonstration in winter 2013/2014 at Fromveur Passage (Southern Brittany). The total project cost is estimated to be around € 10 million, of which the public support of the French Environment and Energy Management Agency is around one-third. GDF is also involved in another project whereby HyTide turbines of 3-12MW (Voith Hydro, Norway) are expected to be tested at Raz Blanchard. The installation and construction operations

Figure 20: Representation of public and private entities participating in the French supply chain

Source: JRC, based on data from companies' websites.

The depicted logos are trademarks / trade names of the selected companies

33 https://mit.ida.dk/IDAforum/U0637a/Documents/B%C3%B8lgeenergi%20den%2018.%20janaur%202011/Wave%20Star%20presentation%20-%20IDA%20wave%20colloquium.pdf

34 L. Marquis, M. Kramer, J. Kringelum, J. Fernandez Chozas, N.E. Helstrup, Introduction of Wavestar Wave Energy Converters at the Danish Offshore Wind Power Plant Horns Rev 2: http://www.icoe2012dublin.com/ICOE_2012/papers.html

are being carried out in the nearby port of Cherbourg where national partners (Cofely Endel, ACE and CMN) could provide their expertise in developing the project.

Another tidal project involves DCNS, a large group specialising in services for shipyards, naval bases, submarines and surface ships and systems and the associated infrastructure. DCNS' commitment to energy solutions is reflected in its investment in civil nuclear engineering and marine renewable energy (MRE), the latter further reflected in the acquisition of OpenHydro, an Irish tidal energy company. Experimentation of 2MW MRE devices has been taking place at Plateau de la Horaine since 2011 (the plan is to be able to assure the electricity consumption of 1700 inhabitants). The grid connection was originally planned for 2013 and envisaged through Bay of Launay Ploubazlanec. The project is mobilising € 40 million and engaging Alstom as a key partner in the testing stage. In terms of wave projects, ECN is coordinating the development of the SEM-REV test centre.

Norway

Norway has four ongoing projects and is mobilising the research efforts of almost 20 technology developers. Marine energy initiatives are harvested inside the local industry incubator (Knudtzon Senteret AS) which is funded by the initiative of Statoil, SIVA and the municipality of Kristiansund. Furthermore, the Norwegian supply chain includes initiatives for the development of osmotic power, for which the Statkraft initiative is the most relevant. Innovative initiatives in the Norwegian supply chain (Figure 21) feature turbine blades made from laminated wood which are to be used in Morild projects, funded under Renegi programme[35] and developed within initiatives of organisations such as NTNU, CFD Norway, NTI and Moelven Limtre.

Spain

Many of the partners included in the graphical representation (Figure 20) refer to the project sponsored by the Spanish government: Líderes en Energías Renovables Oceánicas[36].

Aside from the LIDER project, three small technology developers (Hidroflot[37], Wedge SL and

Figure 21: Representation of public and private entities participating in the Norwegian supply chain

Source: JRC, based on data from companies' websites.

The depicted logos are trademarks / trade names of the selected companies

35 http://www.forskningsradet.no/en/Newsarticle/Laminated_wood_to_be_used_for_offshore_turbine_blades/1253954822447

36 http://www.oceanlider.com/ndesarrollor.asp?apartado=8

37 http://www.europapress.es/asturias/noticia-empresa-hidroflot-preve-comenzar-comercializar-energia-generada-asturias-olas-seis-anos-20100627143017.html

Figure 22
Representation of public and private entities participating in Spanish supply chain

Source: JRC, based on data from companies' websites.

The depicted logos are trademarks / trade names of the selected companies

Magallanes Renovables[38]) attracted the interest of established marine suppliers (such as Asturfeito, Sodercan, Ecotech Global and Tecformas*)* in the demonstration of marine energy pilots. Small-scale demonstration is being achieved thanks to the expertise of research centres, public institutions, as well as private funding (i.e. Energy Equity Partners and Urbaser).

Portugal

Portugal has different ongoing projects and gathers together only a few technology developers. Key participants in the Portuguese marine energy supply are presented in Figure 22. Kymaner Energetic Technologies is testing stress in the structure under the wave climate in the south of Portugal (Algarve). Innovative technology is being developed by Sea For Life, which is able to harness energy from waves by capitalising on the laws of gravity (wave energy gravitational absorber).

Despite its potential, few national technology developments have been initiated, whereas WavEC is playing a key role in developing an international network of experts in offshore energy projects (SOWFIA, SI Ocean, Atlantic PC, DTOcean, EquiMar, MaRINET).

United Kingdom

A recent study (Pound et al., 2011) estimates that the British market share accounts for 25 % of the marine energy market. In absolute terms, the United Kingdom market is estimated to rise to € 35 billion of annual revenue by 2050, with the wave energy industry generating € 28 billion/

Figure 23:
Representation of public and private entities participating in Portuguese supply chain

Source: JRC, based on data from companies' websites.

The depicted logos are trademarks / trade names of the selected companies

38 http://www.magallanesrenovables.com/

per annum and employing up to 48 000 people. Most of the job creation in wave energy can be expected from 2030 onwards, with the majority of jobs in the export business (Pound et al., 2011). The United Kingdom has a very rich supply chain that spans the different stages of technology development; the participation of key companies is illustrated in Figure 24. Through EMEC and Wave Hub, the country has seen the highest number of devices developed and is currently the leader actor in the deployment, testing and retrieval of marine energy devices. The interest is further highlighted by the leasing rounds announced by the Crown Estate and the development of ad hoc consenting procedures by Marine Scotland, through a proposed one-stop-shop consent process.

3.5.4. Market formation assessment

The United Kingdom and Portugal have a longer experience in building public infrastructure facilitating the deployment of marine energy devices, whereas France and Sweden are rapidly gaining ground in catching up with the first-mover countries. The research institutes are important in the supply chain of these countries.

On the other hand, the United Kingdom, Ireland and Norway have already started exporting their expertise in both technology and business. The latter two countries exported their technology to France, where important national suppliers and utility companies are mobilising the building of the marine energy sector.

Figure 24: Overview of the United Kingdom's supply chain (key players)

JRC, based on data from IEA RD&D database.

The depicted logos are trademarks / trade names of the selected companies

3.6. F6 – Mobilisation of resources

This section seeks to recount the intensity of the allocation of human and financial resources for marine energy by country. The data on human capital is compiled by using the number of researchers either active in publishing/presenting peer-review papers or active in wave and tidal start-up and spin-off companies, while the public funds available for long-term R&D and/or demonstration are collected from the IEA RD&D Statistics database[39].

Appropriate guidance for research and suitable public support create a conducive environment able to enhance the mobilisation of financial and human resources. In 2011, the mobilisation of *financial resources* for the wave and tidal sector remained relatively limited: annual research investments amount to € 100 million at European level, equivalent to less than 10 % of what was invested in the mature wind energy technology. The mobilisation of *human resources* is even more limited: the size of the labour pool for the pre-commercial wave and tidal industry accounts for approximately 2400 people, nearly 6 % of

39 International Energy Agency, R&D Statistics, http://wds.iea.org/WDS/Common/Login/login.aspx, accessed June 2013

the jobs in offshore wind in 2011. An increased demand for jobs related to the operation and maintenance services is expected to arise with the deployment of arrays of marine energy devices.

3.6.1. Mobilisation of financial resources within European countries

A global picture of the financial distribution of resources among public and private investors is summarised in Figure 25 and Figure 26:

The geographical distribution of corporate research is less concentrated than public R&D investments, being made mainly in the United Kingdom (31 %) and Germany (23 %). Conversely, with a high concentration in Europe, 82 % of public R&D investments in wave and tidal energy are being carried out by four countries: the United Kingdom, Sweden, France and Ireland (Figure 26). Reflecting an increased commitment to development of the technology, public investment in wave and tidal related projects has increased tenfold in the last 10 years, from € 4.2 million in 2001 to € 44 million in 2010. Most of this increase has occurred in the last three years and mirrors a mix of prior involvement (taking place in the United Kingdom and Norway), as well as new entries in the industry, such as the novel projects being developed in France and Sweden. For instance, the United Kingdom, among the first-movers in the industry, has seen a yearly increase in RD&D investments of € 3.3 million during the period 2001 to 2010 (Figure 26).

The Sotenas project, under development in Sweden, is being encouraged by public funding (€ 16.11 million) as part of the Swedish Energy Agency initiative to facilitate the demonstration and commercialisation of new technologies. Table 9 presents additional national funding schemes that have been introduced to support the development and demonstration of innovative, new technologies, products and processes in the areas of marine energy, such as the Scottish Government Waters Fund (UK) or the Marine Energy Accelerator Grant Programme (UK). Other types of funding offer capital subsidies such as the ADEME Renewable Energy Grant Programme (France) or the United Kingdom DTI Marine Renewables Deployment Fund.

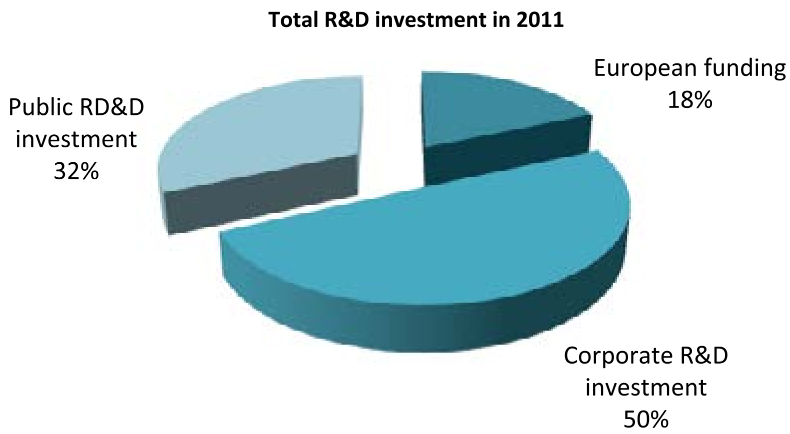


Figure 25: Total RD&D investment in wave and tidal energy projects in EU in 2011

Source: JRC, based on data from IEA RD&D database.

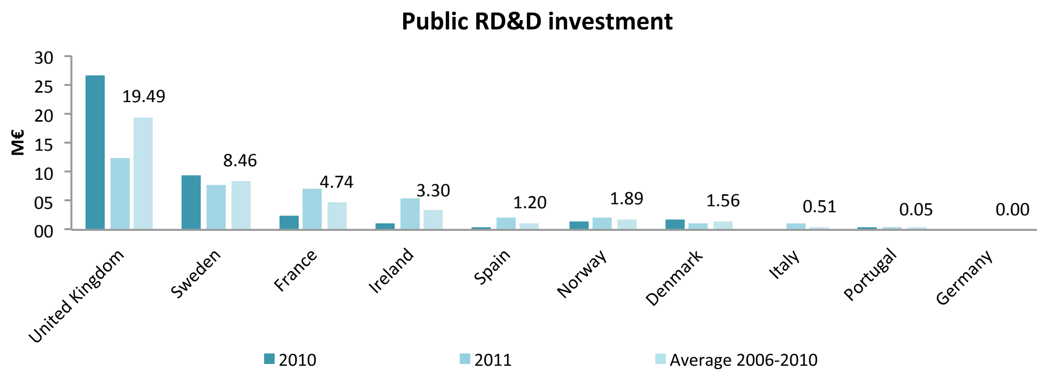


Figure 26: Total RD&D investment in wave and tidal energy projects by European countries for 2011. The assessment of corporate investment relies on patent applications from wave and tidal developers to which an average intensity of R&D per patent of € 0.9 million was allocated. The intensity may change with future calculations.

Source: JRC, based on data from IEA RD&D database.

Grant Programme Name	Countries	Launch Date	Sectors	Value (€ million)
Carbon Trust Marine Energy Accelerator	United Kingdom	2008-12-18	Marine	1
Prototype Development Fund	Ireland	2006	Marine	11
Scottish Marine Renewables Commercialisation Fund	United Kingdom	2011-10-24	Marine	21
Marine Energy Accelerator Grant Programme	United Kingdom	2006-10-10	Marine	5
Marine Renewable Energy and the Environment (MaREE)	United Kingdom	2009-06-23	Marine	5
Carbon Trust Marine Renewables Proving Fund	United Kingdom	2009-09-22	Marine	27
Marine Renewable Deployment Fund	United Kingdom	2004-08-02	Marine	71
UK 2007 Marine Power Grant Programme	United Kingdom	2007	Marine	18
UK DTI Marine Renewables Deployment Fund	United Kingdom	2004-08-01	Marine	66
Scottish Government Waters Fund	United Kingdom	2010-03-23	Marine	13
Scottish Marine Energy Grant	United Kingdom	2006-10-24	Marine	19
DECC Clean Tech Start Up Programme	United Kingdom	2009-10-19	Advanced Transportation; Efficiency: Supply Side; Digital Energy; Efficiency industry; Marine; Solar; Wind	21
ADEME Renewable Energy Grant Programme	France	2010-03-09	Biofuels; CCS; Geothermal; Marine; Solar	1336
Norway Energy Fund	Norway	2011	Also marine renewables	0
Innovation Norway	Norway	2012	Also marine renewables	0
The Marine Energy Array Demonstrator (MEAD) scheme	United Kingdom	2011	Marine	22
Sitra Innovation Fund	Finland	2010	Also marine renewables	
Dansk Research Council	Denmark		Also marine renewables	
Danish Wave Energy Programme	Denmark	1997		
EMEC – European Marine Energy Centre	United Kingdom		Marine renewables	17
Supergen Array Demonstration	United Kingdom	2012		

Table 9: List of grant programmes for research, development and demonstration of marine energy technologies active through 2011 (values are converted into euros)

Marine Renewables Proving Fund

The funding of tidal companies Atlantis Resources Corporation (€ 2.21 million), Hammerfest Strøm (€ 5.12 million), Voith Hydro (€ 2.28 million) and Marine Current Turbines (€ 2.57 million) aims to improve 1st and 2nd generation applications, such as:

- The design and manufacture of a 1MW nacelle, next-generation blades, control systems, gravity-based sub-structure and design of a rotate unit by Atlantis Resources Corporation.
- The design and manufacture of the HS-1000, a 1MW, gravity-based, three-bladed tidal device by Hammerfest Strøm.
- The drive train and control systems, design and manufacture of next-generation blades, including blade-root interface and funding of the operation of SeaGen (1.2MW twin-nacelle tidal device) by Marine Current Turbines.
- The design and construction of the 1MW EMEC tidal device-Voith Hydro.

Funding of wave energy companies Aquamarine Power (€ 5.58 million) and Pelamis (€ 5.86 million) aimed at:

- The design, fabrication and installation of a full-scale, grid-connected 800 kW Aquamarine Oyster 800.
- The development, construction, commissioning, sea trials, deployment, operation and maintenance of the full-scale grid.

Among the different programmes listed in Table 9, one in particular focuses on demonstration of full-scale marine energy devices in open-sea environments. Funding (€ 27 million) and technical support to six full-scale prototypes is assured through the Marine Renewables Proving Fund (see box 3 above). These demonstration programmes are also seeking to reinforce the low number of private initiatives in major companies, as the funders' intention was to scale up demonstration programmes to arrays of several MW. The Fund is managed by the Carbon Trust on behalf of the Department of Energy and Climate Change (see box above). Some of the national programmes are seeking to encourage pure research such as the Carbon Trust Marine Energy Accelerator (UK), while other programmes are looking to encourage product development.

A description of the research priorities in marine energies for the main European countries is given in Figure 27.

Total public RD&D investment in 2011 amounted to € 40 million, with the United Kingdom accounting for one-third of -European investment; most of British funds were devoted to fundamental research, rather than demonstration (Figure 29). In Sweden, most investments went into demonstration projects (Figure 29).

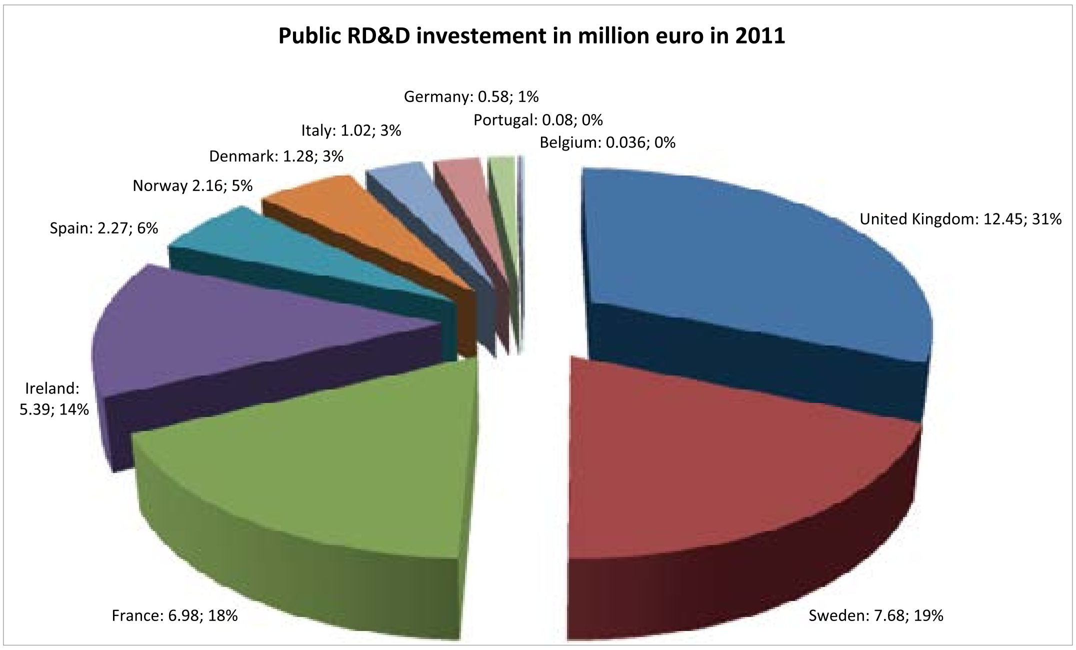


Figure 27: Public RD&D investment in millions of euro and percentages for wave and marine energy technology across European countries in 2011

Source: JRC, based on data from IEA RD&D database.

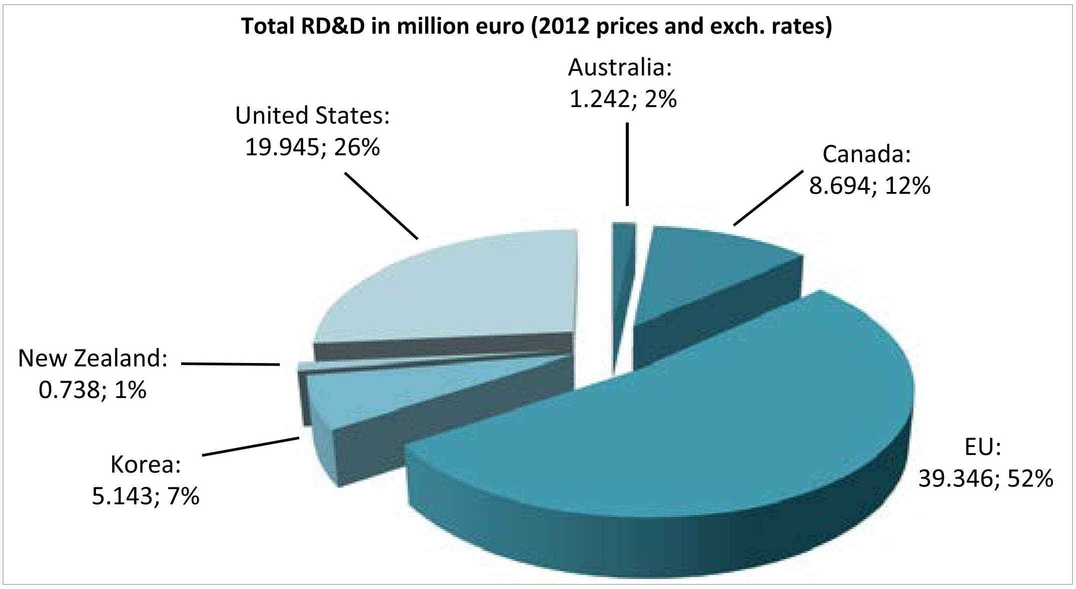


Figure 28: International comparison of public RD&D investement in marine energy technology in 2011

Source: JRC, based on data from Cordis and IEE projects.

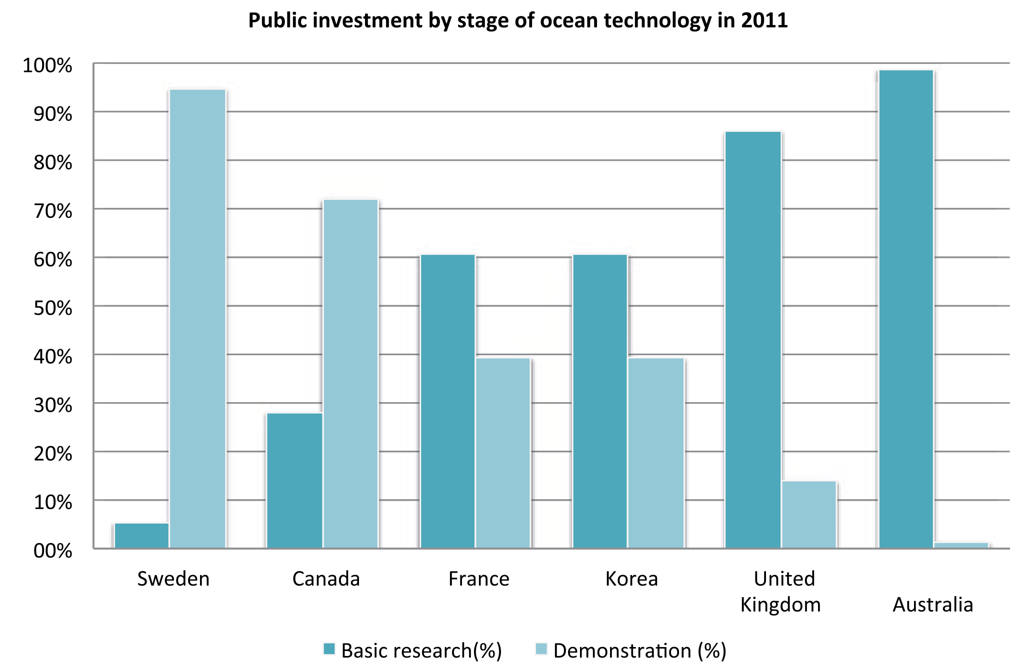


Figure 29: Intensity of basic research versus demonstration projects in total R&D investment for key country investors in marine energy technology in 2011

Source: JRC, based on data from Cordis and IEE projects.

An international comparison of public RD&D investments reveals that Europe held 53 % of global public investments in 2011. Among key investors, France and Korea display a similar intensity in funding basic research (60 % of national funding) and demonstration projects (40 % of national funding). Two opposing groups of countries can be distinguished by their research priorities: public investments focus on research and development in United Kingdom (85 %) and Australia (98 %), whereas a higher intensity of investments in demonstration projects is seen in Sweden (95 %) and Canada (72 %). Although this observation does not point to the country which has brought the technology most closely to the market, it anticipates the potential deployment of the technology within countries: most likely, France, Korea and Sweden will intensify their efforts as they may envisage greater potential and a significant contribution in their energy mix.

Important in the context of future deployment is the effectiveness of public funding in research activities, measured through the level of private investment that public money can encourage. Private investment induced by public support can be examined through leverage ratios (see box 4).

Policy significance reflects the extent to which public money has been multiplied, thus leveraging private investment in ongoing marine energy projects. Such an analysis also allows us to make a comparison across countries[40]. As shown in Table 10, the United Kingdom and Denmark seem to exhibit similar leverage ratios, with one euro of public money raising 80 private euro cents. Norway

40 We have left out projects in which the state had assured the entire financial support.

Table 10: Leverage ratios for sampled marine projects

Country	Number of projects retrieved	Funds mobilised (million)	Average leverage ratios Without contra factual	Average leverage ratios With contra factual
United Kingdom	24	126	2.85	1.85
Sweden	2	25	1.56	0.56
Norway	3	8	3.12	2.11
Denmark	4	4.57	2.79	1.79
France	2	50	4.76	3.76

also exhibits greater power in raising private money, as one euro spent raises 1.12 euros of private money.

Mobilisation of financial resources

Leverage can be defined as the private investment induced by national subsidies for research. In addition, the ratio should take into account that certain research projects could have been developed independently of the availability of public money (contra factual analysis).

Accordingly, the leverage ratio is defined as:

- without contra factual analysis: total money (i.e. the original public 'lever' money, plus the private money induced) divided by the original lever money;
- with contra factual analysis: 'total additional investment' (private money) divided by 'total public grant' (or grant equivalent). The second method accounts for the cases in which some of the private investment would have happened independently of the level of public intervention.

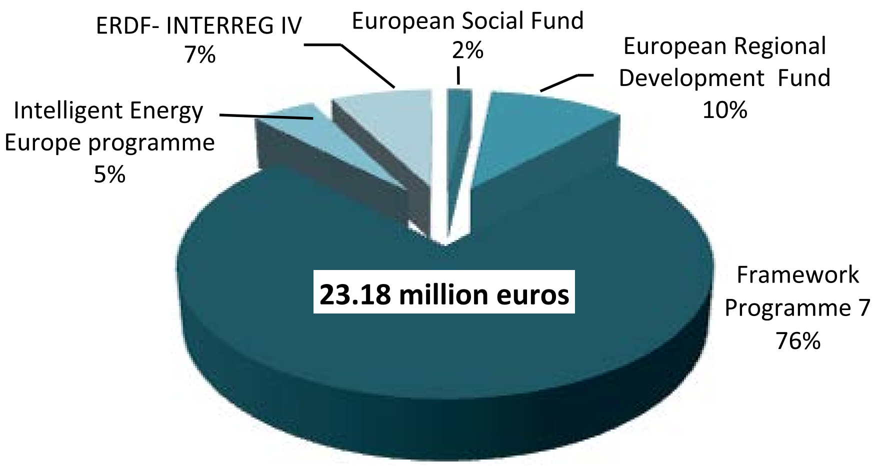
3.6.2. Mobilisation of financial resources at European level

The main European bodies involved in financing low-carbon energy technologies and hence in related RD&D activities are the European Commission, the European Investment Bank and the European Bank for Reconstruction and Development. Large-scale investment is assured through European banks (loans, Sustainable Energy Initiative Programme and Technical Cooperation Funds Programme) and European funding, such as the Seventh Framework Programme, the Competitiveness and Innovation Framework Programme (Entrepreneurship and Innovation Programme and Intelligent Energy Europe) and regional policy (European Regional Development Fund and Cohesion Funds).

In 2011, relatively high interest is found at the European level concerning the development of the technology, with significant efforts to bring it to market. € 23 million have been allocated through European funding for marine energy technology (Figure 30). The majority was allocated through FP7, whose level is comparable with European R&D investments in the electricity grids.

The mobilisation of resources through European funding points to a leverage ratio of 1.6 for Research Framework programmes

Figure 30: The European financial contribution by funding programme for the development of marine energy projects in 2011



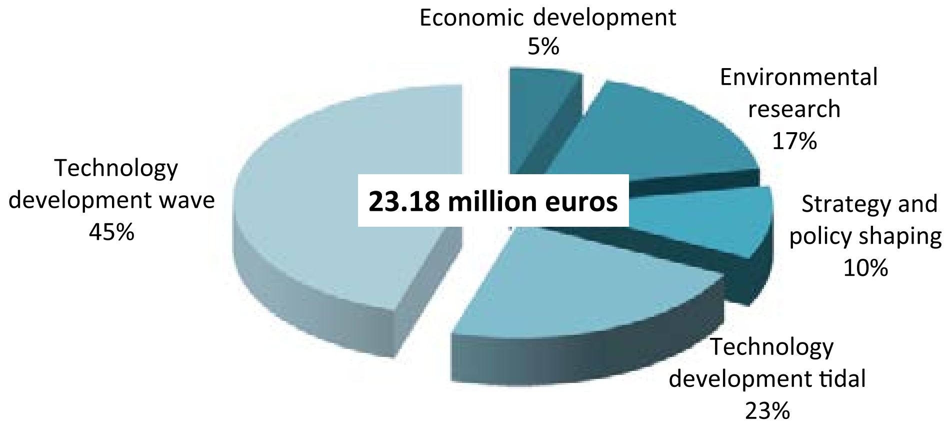


Figure 31: Research themes financed by European funding in 2011

like FP7 and regional initiatives such as ERDF. Accordingly, for every euro allocated through ERDF/FP7 funding, approximately 60 additional euro cents are invested by national public and private organisations in marine energy projects. Almost 70 % of European funding (Figure 31) is directed towards the development of the wave and tidal energy technology. A relatively higher priority in EU funding is the development of wave energy technology (45 % of total funding), which could benefit a large number of countries.

Among the significant projects in the ***creation and diffusion of knowledge*** of wave and tidal technology, MaRINET ties together the collaboration of 28 partners across 11 European countries and Brazil. Significant European funding is directed towards bringing the technology closer to the market, through the Marina platform. In addition, important potential benefits are foreseen for harbours if marine energy technology becomes ***commercially viable,*** such as the project Ports adapting to change (PATCH). The project is considered to be among the best practices in the European Commission's (DG MARE) "Blue Growth Final Report: Scenarios and drivers for Sustainable Growth from the Oceans, Seas and Coasts"[41].

Projects involved in ***economic benefits or policy shaping*** and standards, like Equimar, in marine energy technology accounted for 15 % of total EU funding in 2011. Overall, the European contribution ensures a significant contribution in all the operations of the sectorial innovation system of marine energy technology with an important priority being allocated to knowledge creation and diffusion.

3.6.3. Human capital and skills

The marine energy sector is expected to grow significantly over the next 20 to 40 years. By 2020, the European Ocean Energy Association (EU-OEA)[42] estimates there will be 26 000 direct jobs (or 40 000 direct and indirect jobs) whereas, by 2050, employment in the wave and tidal energy sector should be around 310 000 direct jobs (or 470 000 direct and indirect jobs). At the global level, 1.2 million direct jobs are expected to be created (Sustainable Energy Authority of Ireland)[43]. By country, the estimates for employment from different sources point to the will to develop the industry: by 2035, 19 500 jobs are expected to be created in the United Kingdom (Renewable UK), and 1329 jobs in Ireland[44].

The current situation in the marine energy sector has been estimated from data available on research and private investment, and is shown in Table 11.

Consequently, the volume of human resources allocated in the sector is estimated to range between 2000-2800 people, one-third of whom are directly involved in basic research, working within universities or collaborating with them. This distribution also describes the British marine portfolio in which one-third of the funding was allocated to postgraduate training in 2011. However, the UK shows a good distribution in private-sector employment.

Norway and Denmark are more active in the commercialisation of the technology than in knowledge creation, with the potential of entrepreneurial resources three times bigger than academic resources. On the other hand,

41 "Blue Growth Final Report: Scenarios and Drivers for Sustainable Growth from the Oceans, Seas and Coasts", available at https://webgate.ec.europa.eu/maritimeforum/system/files/Blue%20Growth%20Final%20Report%2013082012.pdf

42 EU-OEA 2010, "Ocean of energy – European marine energy roadmap 2010 -2050" http://www.eu-oea.com/index.asp?bid=436

43 And nearly 1.0 billion tonnes of CO2 emissions saved.

44 Economic Study for Marine Energy Development in Ireland SQW, 2010.

Table 11: Approximation of direct and indirect jobs in marine energy in 2011

Country	Jobs -National statistics	No. Researchers Publishing/ Presenting WP	No. FTE in Technology spin-offs, start-ups	Approximation of direct and indirect jobs 2011	Range of jobs
UK	800	320	305	800[49]	672-928
Ireland	101 only direct FTE	54	35	179[50]	150-206
France	n.a.	63	95	281	236-326
Portugal	n.a.	47	20	119	99-138
Spain	n.a.	64	55	212	178-245
Norway	n.a.	25	120	258	216-299
Sweden	n.a.	41	50	162	136-187
Germany	n.a.	26	55[51]	144	120-167
Denmark	100[52] FTE	26	80	178	149-206
Italy	n.a.	39	19	100	84-116

Italy and Portugal show greater academic involvement in the development of the technology but lower market experimentation. France is succeeding in directing venture capital initiatives into the demonstration initiatives and bringing the technology to market faster.

3.6.4. Evaluation of the mobilisation of resources across countries

Spain, France and the United Kingdom have a higher labour pool than other countries and also mobilise larger public funding for the development of wave and tidal energy projects.

European networks encourage British and Mediterranean initiatives; public-private partnerships able to facilitate knowledge diffusion between first and late-movers in the industry.

3.7. F7 – Legitimation for marine energy TIS

This function refers to concerted actions aimed at developing the sector. Public acceptance for wave and tidal energy technology seems relatively high. The legitimation of the technology is lobbied through political and industrial networks. On the one hand, the offshore wind industry has the same interests as the wave and tidal industry in the reduction of operation and maintenance costs. On the other hand, the level and changes in the wave and energy targets express the level of risk that decision-makers induce/block in the development of the marine energy industry. The long-term stability of public-support schemes should ensure that the Feed-in Tariff will still be available at the time of power delivery (at least 15-20 years). A certain degree of certainty is

45 The number of researchers per country takes into account the authors of scientific articles submitted to peer-reviewed journals and peer-review conferences.

46 The number of jobs triggered by the commercialisation of the technology has been approximated by using the average size of start-up/spin-off companies of 1-10 employees. Some of the companies are registered at International B2B Meetings in the field of marine renewable energies.

47 Also accounting for indirect jobs in ocean energy, the number of direct FTE is multiplied with a multiplier (for indirect jobs) which was calculated for Ireland. Using input-output analysis and the output multipliers for the appropriate NACE sectors, the value of the employment multiplier was found to be 1.78 (Morrissey, 2010). Future calculations may change the information presented.

48 Finally, a margin of error of (+/-0.16) and the range of jobs is calculated across selected countries.

49 Renewable UK.

50 SEAI, Sustainable Energy Authority of Ireland.

51 Much of the uncertainty we are dealing with emerges from limited information available for the companies working within the sector. The least-well-represented country was Germany, for which we only included in the commercialisation activities Siemens with its two acquisitions in wave technology and two newly started technology companies.

52 www.civil.aau.dk: Introduction to Wave Energy Utilization, Aalborg University, Department of Civil Engineering, Wave Energy Research Group. The figure does not account for another 15 companies identified as technology developers.

needed to justify project expenditures[53]. The following investigation seeks to evaluate how strong the institutions are, or respectively how strong the industry lobby is, in acquiring the legitimation of the new technology.

The recent evolution of marine energy policy is described in terms of policy goals and support schemes, as a means of identifying the extent to which the latter have created a conducive environment for the emergence of innovation activities. Table 12 presents the evolution of 2020 targets for wave and tidal technologies with respect to different assessments. A careful look at the table helps in answering two questions:

1. Are public commitments *sufficiently stable?*

Many changes have taken place since the time when governments formulated goals for marine energy and now. These may have contributed to creating an uncertain environment with reduced motivation for venture capital to finance innovative and risky marine energy innovations. In the presence of signals of uncertainty, investors postponed the risky investments which lead to innovation and the deployment of marine technology. Such uncertain signals have also been cited as playing a negative role in the development of technological systems. In a risky environment, technology development requires further public support, since uncertainty in the markets could diverge from private investments.

2. Are public commitments *sufficiently stringent*?

Most of the targets for marine energy are not binding, and thus exert little *stringency* in creating opportunities for marine developers. The real constraint for each Member State is the level of electricity produced from renewable sources. Most likely, the overall targets will not be met by a single renewable-energy technology and therefore a portfolio of strategic energy technology (including marine energy) is needed to achieve the targets. Marine energy currently makes little contribution to the national energy mix. Ambitious targets with respect to the incipient stage of technology development are set by energy White Papers and later in the NREAP of each country. Such ambitious targets have enabled community acceptance with the greater involvement of stakeholders and residents in the implementation of renewable-energy projects. European countries do not show a stringent commitment to marine energy, as many are affected by different constraints, such as the recent economic crisis, or delays in reaching the binding 2020 targets. Only a few countries are succeeding in encouraging entrepreneurial marine energy initiatives and in attracting investments for long-term development of the technology.

Country	**2009 NREAP target (wave, tidal) (MW)**	**2011 Ocean energy scenarios in 2020 (MW)**	**2013 Ocean energy scenarios (MW)**
Europe (total)	n.a.	3600(1)	n.a.
Denmark	n.a.	500	n.a.
France	380	800	380
Ireland	75 / 500	500	500
Portugal	250	300	250
Spain	100	600	100
Sweden	n.a.	n.a.	n.a.
UK	1300	2000	200-300MW
Norway	n.a	n.a.	n.a
Germany	n.a.	0	n.a
Italy	3	3	n.a

Table 12: Evolution of 2020 targets (SOWFIA, EU Communication 2009 and SI Ocean)

53 http://www.marinerenewables.ca/wp-content/uploads/2012/12/The-Role-of-Feed-in-Tariffs-Moving-Ocean-Energy-Ahead-in-Canada.pdf

4. Discussion and conclusion

The marine energy industry features intense product innovation, embodied by the development of diverse marine energy devices, dominant in the early stages, when the market is not yet well defined. Most European countries display significant involvement in this step of the process, with certain countries demonstrating a greater intensity than others (e.g. the United Kingdom, Ireland and Norway). Following the demonstration of prototypes, operational improvements are proposed in order to increase its viability. Once the market has been created and is well defined, one prototype standardised process innovation could occur, as well as, over time, learning effects.

The passage through different phases of the technology development is associated with a specific level of risk linked either to the technology or to the business. In the early stage of the *tank testing* phase, the level of associated risk is low for both business and technology[54]. Most of the countries engage in this phase of research activities, whilst some of them, such as Denmark, Ireland and Norway, even succeed in exporting their knowledge. Sea trials are considered as high risk for technology, as environmental factors cannot be controlled. Different aspects of technology can be assessed, such as the complexity of the technology related to power performance, deployment technology, survivability, manufacturing and commissioning procedures, degradation mechanisms and aspects affecting availability[55]. At this stage, few countries besides the United Kingdom are making considerable efforts to valorise new business opportunities, such as France, Sweden, Norway and Germany. The multi-device arrays stage deals with important risks for business but less so for the technology[56]. The NER300 funding is tackling these risks as novel projects will be deployed in the United Kingdom and Ireland.

Along these stages of technological development, additional uncertainty might be caused by unexpected variations in public support for the development of the technology. Measured through the stringency and stability of public instruments, the present analysis includes an evaluation of an external risk to the technology (or business), which is policy induced. Two functions of the innovation system enable failures to be identified: technology legitimation and public guidance for support. Many countries, even though committed to the development of offshore wind technology, do not formulate stringent and stable targets able to reinforce innovation activities for wave and tidal energy technologies.

Overall, the mobilisation of financial resources for wave and tidal energy attracts only 10 % of the aggregated (public and private) investment in mature technology (wind technology). The human resources in the sector account for less than 6 % of those for young technologies (offshore-wind energy technology). Although mobilisation of resources is relatively low (compared to other technologies), public money is effective in mobilising funding for innovation activities in marine energy technology: one euro of national public money raises an additional 80 euro cents of private money, whereas with one euro of European public money raises an additional 60 euro cents of national money.

Finally, important constraints on technology could be created by unexpected variations in policy support for the technology, and could subsequently influence future development of the technology.

54 Flinn J., Bittencourt C., Waldron B. (2011): Risk Management in Wave and Tidal Energy: http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/Pure_Power_III.pdf

55 Flinn J., Bittencourt C., Waldron B. (2011).

56 Flinn J., Bittencourt C., Waldron B. (2011).

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APPENDIX

Appendix 1: Methodological considerations

A functional approach to innovation systems (Johnson and Jacobsson, 2001; Bergek and Jacobsson, 2003; Jacobsson and Bergek, 2004) is proposed in order to analyse the formation and evolution of technological innovation systems. The innovation system is divided into seven functions:

- Function 1: Knowledge development
- Function 2: Knowledge diffusion and development of externalities
- Function 3: Entrepreneurial experimentation
- Function 4: Influence on the direction of search
- Function 5: Market formation
- Function 6: Resource mobilisation
- Function 7: Legitimation.

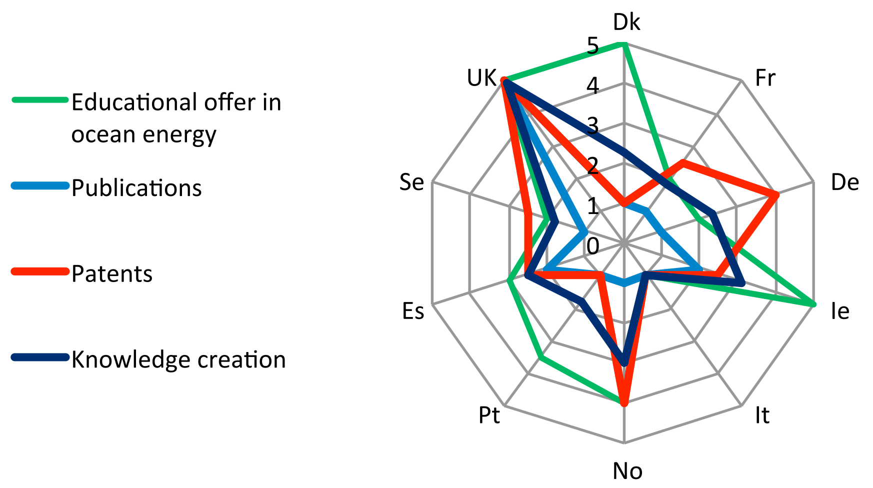
Each of the functions is evaluated through specific indicators, such as those described in the first box. Each indicator is divided into quintiles and each country receives an evaluation, a score from 1 to 5 based on its performances: 1 - 1st quintile, 2nd - second quintile and so on. A final aggregated score attained for each function, and aggregated at the system level, should point out the weakness of the innovation system.

A functional approach has been used previously to identify bottlenecks for an offshore wind innovation system (JRC 25410, 2012). The methodology is able to propose that a policy instrument is advised to meet the challenges in terms of infrastructure, institutional alignment (public policies) and connectivity of the actors within the innovation system.

An illustration of each function of the marine energy innovation system is provided hereafter.

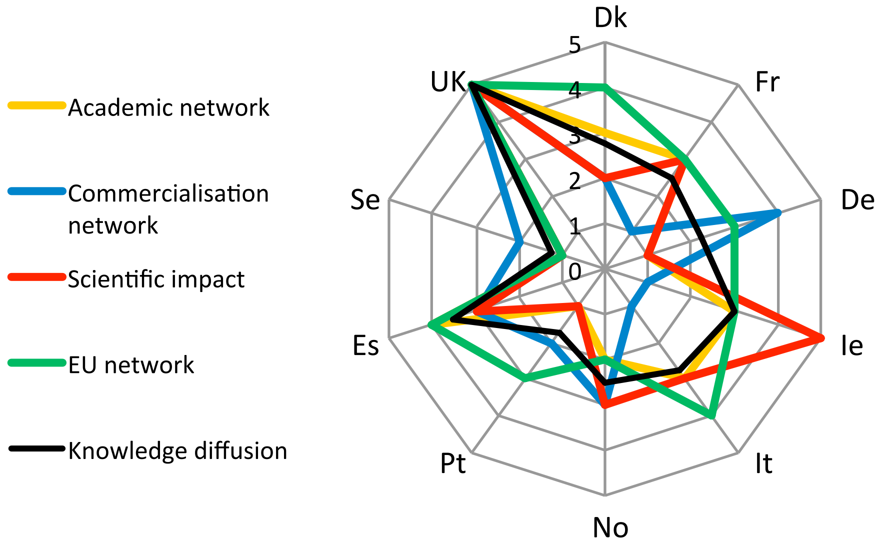
Ocean energy knowledge creation intensity by country

Function 1:
Knowledge development



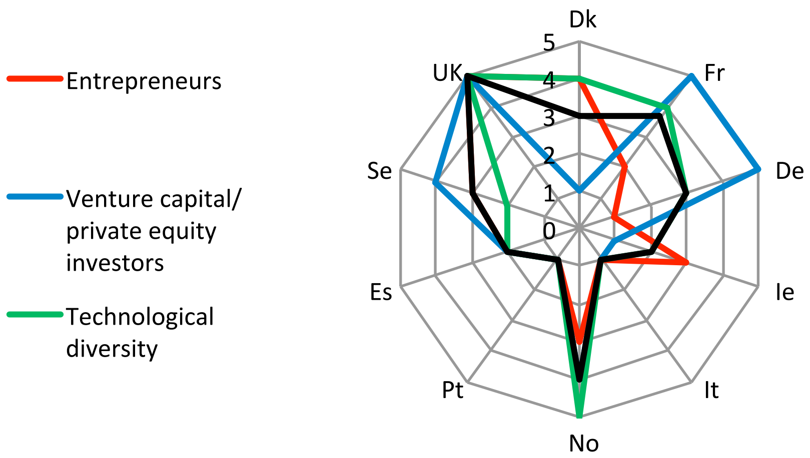
Ocean energy knowledge diffusion by country

Function 2:
Knowledge diffusion

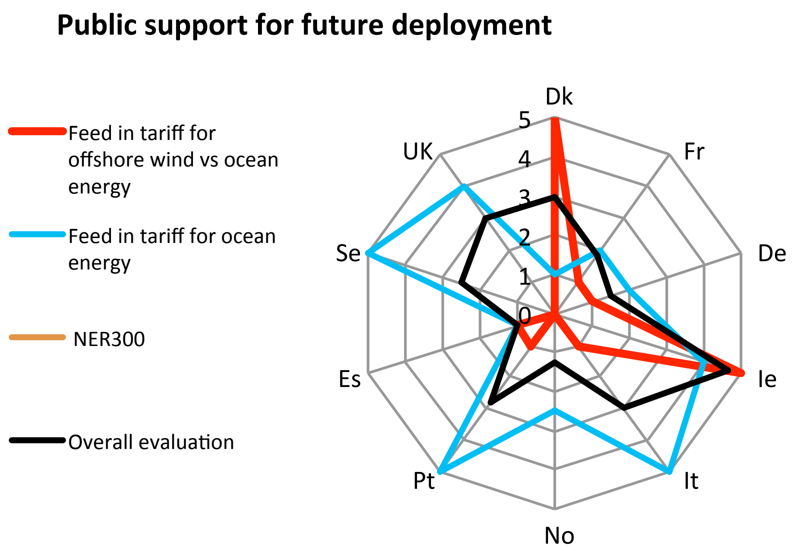


Evaluation of business opportunities by country

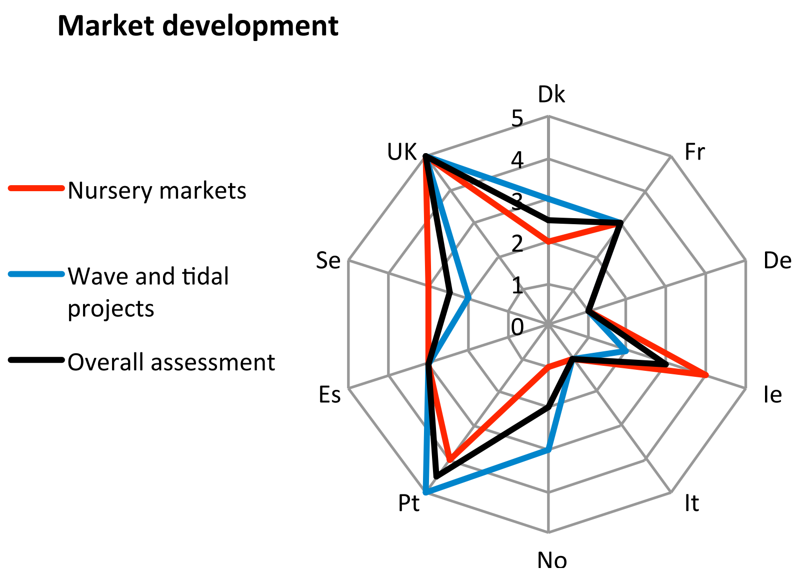
Function 3:
Entrepreneurial experimentation



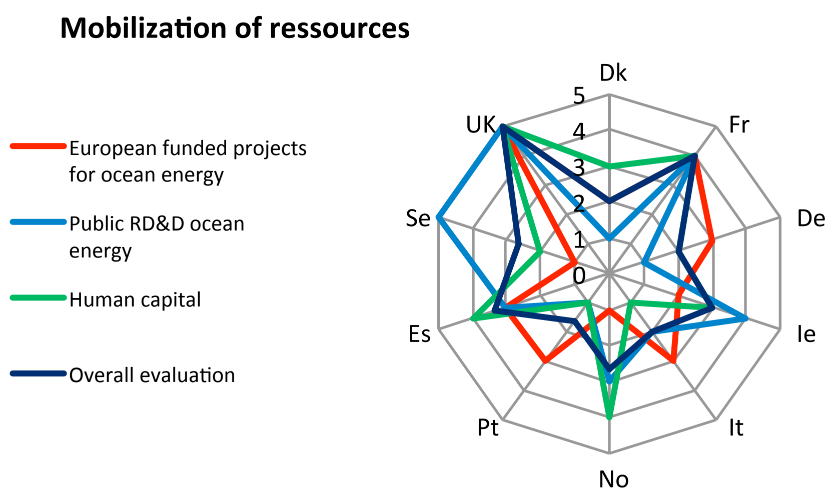
Function 4:
Influence on the direction of search



Function 5:
Market formation

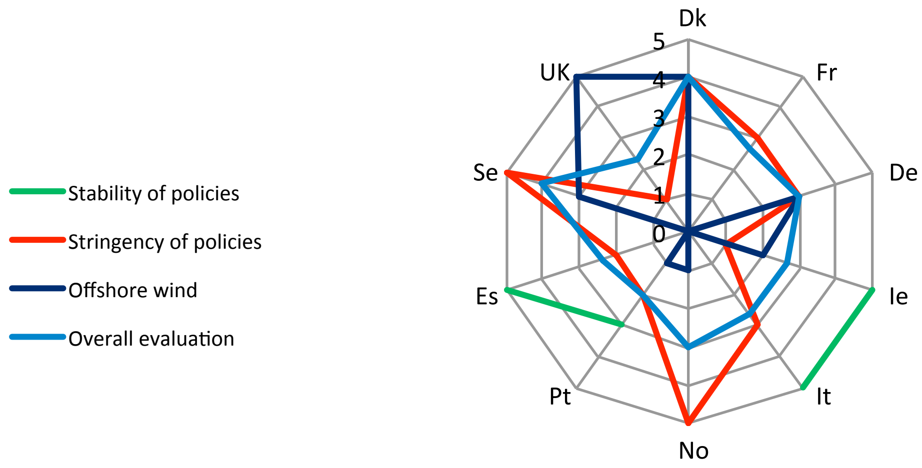


Function 6:
Resource mobilisation



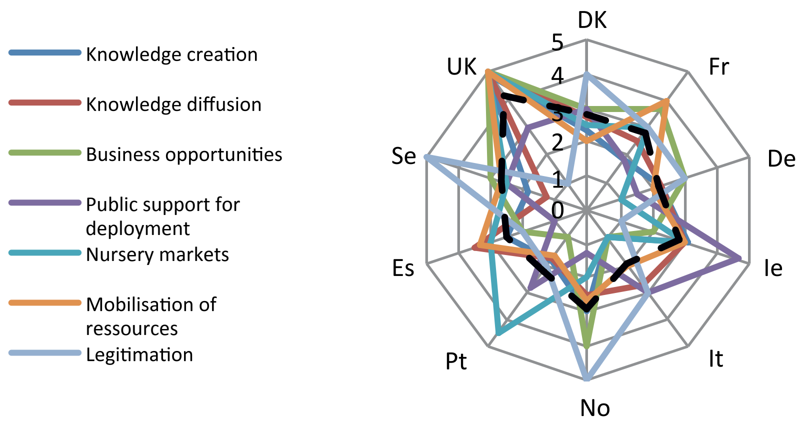
Function 7:
Legitimation

Legitimation



Marine energy innovation system by European country in 2011

Overall assessment of ocean energy innovation system



Appendix 2: Wave and tidal test facilities available in Europe through FP7 funding

Owner	Country	Name of facility	Scale of Facility	Type of facility technology
Aalborg Universitet	DK	*Deep water wave basin*	Small lab	Wave
Aalborg Universitet	DK	*Nissum Bredning Test Site*	Small lab	Wave
Centro Nazionale Ricerca	IT	*Circulating Water Channel*	Large lab	Tidal
Centro Nazionale Ricerca	IT	*Wave Tank*	Large lab	Wave
Danmarks Tekniske Universitet	DK	*Current Flume with a Carriage*	Small lab	Tidal
Danmarks Tekniske Universitet	DK	*PowerLabDK*	Large lab	Cross-cutting
Danmarks Tekniske Universitet	DK	*Mechanical test facilities*	Large lab	Cross-cutting
Ecole Central de Nantes	FR	*Hydrodynamic and marine Engineering Tank*	Large lab	Wave
European Marine Energy Centre	UK	*Real Sea Test Sites, Orkney*	Medium-scale site	Wave, Tidal
EVE (Ente Vasco de la Energia)	ES	*Mutriku OWC plant*	Large-scale site	Cross-cutting
EVE (Ente Vasco de la Energia)	ES	*Biscay Marine Energy Platform - BIMEP*	Large-scale site	Wave
Fraunhofer Institute	DE	*Offshore Field Test Facilities*	Large-scale site	Cross-cutting
IFREMER	FR	*Materials in Marine Environment Laboratory*	Large lab	Cross-cutting
IFREMER	FR	*Deep Seawater Wave Tank*	Large lab	Wave
IFREMER	FR	*Wave/Current Circulation Tank*	Large lab	Wave, Tidal
Narec	UK	*CPTC Energy Link Labs*	Large lab	Cross-cutting
Narec	UK	*Nautilus Rotary Test Rig*	Large lab	Cross-cutting
Narec	UK	*Large Scale Wave Flume*	Large lab	Wave
Narec	UK	*South West Mooring Test Facility*	Medium-scale site	Cross-cutting
Plymouth University	UK	*Coastal marine and Sediment Transport Laboratories*	Large lab	Wave, Tidal
Queen's University Belfast	UK	*Shallow Water Wave Tank*	Small lab	Wave
Queen's University Belfast	UK	*Portaferry Tidal Test Centre*	Medium-scale site	Tidal

Wave and Tidal Test facilities available in Europe thorough FP7 funding (continuation)

Owner	Country	Name of facility	Scale of facility	Type of facility technology
Sintef	NO	*Renewable Energy Lab - SmartGrids*	Small lab	Cross-cutting
Strathclyde University	UK	*Kelvin Hydrodynamics Laboratory*	Small lab	Wave, Tidal
Sustainable Energy Authority of Ireland	IE	*Galway Bay 1/4 Scale Wave Energy Test Site*	Medium-scale site	Wave
Sustainable Energy Authority of Ireland	IE	*Wave Energy Test Site, Belmullet*	Large-scale site	Wave
Tecnalia	ES	*Electrical PTO lab*	Small lab	Cross-cutting
Tidal Test Centre	NL	*Tidal Testing Centre Den Oever*	Medium-scale site	Tidal
University College Cork	IE	*Beaufort marine Wave Basin*	Small lab	Wave
University College Cork	IE	*Beaufort Rotating Test Rig*	Small lab	Cross-cutting
Universita di Firenze	IT	*Boundary Layer Wind Tunnel*	Small lab	Tidal
Universita di Firenze	IT	*Wave/Current Flume*	Small lab	Wave, Tidal
Universität Stuttgart	DE	*Turbine Test rigs*	Small lab	Cross-cutting
Universität Stuttgart	DE	*Laminar Wind Tunnel*	Small lab	Tidal
University of Edinburgh	UK	*Curved Wave tank*	Small lab	Wave
University of Edinburgh	UK	*FloWave*	Large lab	Wave, Tidal
University of Exeter	UK	*Dynamic Marine Component Test Facility*	Small lab	Cross-cutting
WAVEC	PT	*WAVEC OWC Pico*	Large-scale site	Cross-cutting

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This report aims to provide an overview of the research capabilities for innovation activities in marine energy within Europe in 2011. The sector features intense product innovation, embodied by the development of diverse marine- energy devices, which is dominant in the early stages, when the market is not yet well defined. Overall, the mobilisation of financial resources for wave and tidal energy gathers only 10 % of the aggregated (public and private) investment in mature technology (wind technology). Human resources in the sector account for less than 6 % of those mobilised by young technologies (offshore-wind-energy technology). Although the intensity of mobilisation is relatively low, public money is effective in mobilising funding for marine energy innovation activities. Additional constraints for technology are induced by unexpected variations in policy support for the technology and subsequently influence the future development of the technology. Finally, Europe has great potential in the development of the technology if more active policy coordination and synergies are exploited.

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