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Overview of European innovation activities in marine energy technology

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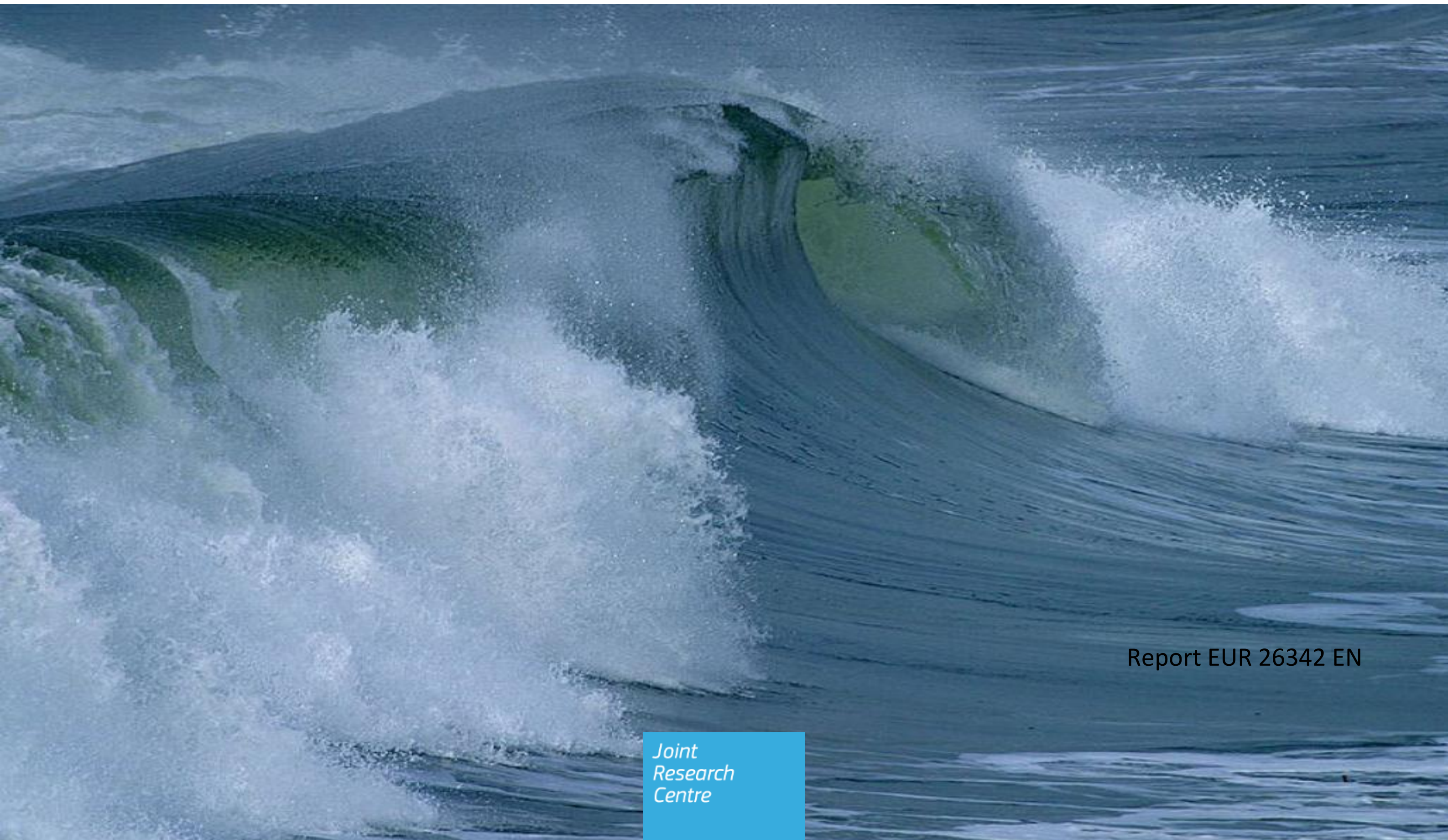

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Summary

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List of acronyms

€ Euro
bn billion
DoE Department of Energy (USA)
EC European Commission
EII European Industrial Initiative
EIB European Investment Bank
ERBD European Bank for Reconstruction and Development
EPO European Patent Office
EU or EU-27 European Union
FP Framework Programme
FiT/FiP Feed in tariffs/ Feed in premiums
GDP Gross Domestic Product
IEA International Energy Agency
IEE Intelligent Energy Europe
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
n.a. Not available
NACE Statistical Classification of Economic Activities
OECD Organisation for Economic Co-operation and Development
R&D Research and Development
RD&D Research, Development and Demonstration
TRL Technology Readiness Level
SETIS Strategic Energy Technology Plan Information System
SET-Plan (European) Strategic Energy Technology Plan
WIPO World Intellectual Patent Organization
WEC Wave Energy converters
WP Working Papers

1. Introduction and overall assessment

Marine energy, also sometimes encountered as ocean energy, has enormous potential for development: theoretically, global resources are estimated to be over 30,000TWh/year[1], a net potential greater than that of wind and solar. 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 provide high accuracy in prediction compared to those of wind.
- Seasonal availability of resource: 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 Atlantic Arc of the continent have high potential for the development of the marine energy technology: the United Kingdom, France, Portugal, Ireland, Spain, Denmark and Norway. 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 resource available in the United Kingdom alone has been estimated at 220TWh/yr, with a further 50TWh/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 generation. The largest amount of wave and tidal energy in 2020 will be generated in the United Kingdom (3950 GWh) and in France (1150 GWh). In addition, the Netherlands, Italy and Sweden have possibility to exploit localized resources.

Many studies report the potential of the technology, whereas fewer reports assess the state of the sector at a European scale. Usually, countries such as Norway, Sweden and Finland make less the objective of marine energy evaluation, as no future national targets are formulated in their national plans and, hence, no particular immediate constraints exist in the medium term for their development and their integration into national renewable energy mix.

In an alternative approach, the present report contributes to the overall evaluation of marine energy activities in Europe taking into account investments in knowledge creation, diffusion and commercialization of marine energy technology as a proxy for their commitment to the development of the technology. Particular attention is given to the national innovation system of 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 energy technologies. Other marine energy technologies such as salinity gradient are not fully developed yet, whilst

[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] Offshore Renewables – Unlocking the Potential, ICE, March 2010

Ocean thermal energy technology implementation in Europe is limited due to low temperature gradients in European waters.

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

The difficulty of 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 the marine energy technology; however, key features remain unquestionable.

Ocean energy technology is still not marketable, despite advanced levels of technology readiness (TRL) achieved by some developers. There are many aspects that still need to be addressed before commercialization. One of the most important constraints is the cost of marine energy farms. Complete costs for wave and tidal have been estimated in France 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 remain to be done in order 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 smaller. To surpass the cost constraint, ongoing research to commercialization proposes optimization and design of *arrays of turbines* able to increase the power produced (Giles et al 2011, Myers et al 2011). To include the first commercial-scale arrays of wave and tidal devices into the energy mix, important investments in subsea transmission systems and grid connections are needed (Beale, 2011).

Important research efforts are mobilized to bring technology closer to market. A cross-country exploration at European level of their intensity in different stages of technology life cycle could point out barriers to overcome on the way to preparing the technology to the market. Key results are summarised below:

- *The Knowledge diffusion* takes 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.
- *The Commercialization*, assessed by the markets in which developers search for protection through patents, is more important for the United Kingdom. French applicants find most attractive the national market for patent protection, whereas

[3] Some of the countries such as Netherlands have not been included due to data availability foe all the aspects that treated within the analysis.

[4] Source Source: Platts, European power exchanges , Quaterly 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

British technology developers aim for both national and international protection, in particular in North America and East Asia.

- *The Financial mobilization of resources*, in the fiscal year 2011, gathered approximately € 0.125 bn (EU-FP7, corporate and public R&D) for research activities in marine energy technologies. The distribution is not uniform across countries, with a 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 engineering knowledge of academic spin-offs and start-ups, does play an important role in technology development, contributing to more than 60 % of overall research investment. Moreover, public funding has been effective in the mobilization of efforts towards the demonstration of marine applications. For one euro invested by the European funding (FP7 or INTERREG) almost € 0.6 of national money is mobilized. The support incentive remains fairly the same at the country level, where national money are able to lever € 0.80 of private money (United Kingdom and France), with a higher mobilization observed in the case of France.
- *The Human resources* are relatively scarce: approximately 2400 persons were active within marine energy sector in 2011: 1000 persons were employed within the industry, whereas 700 people within research organizations. Compared to 35000 employed in the offshore wind[5] the industry is still in infant phase. Public support of the infant industry can be assured through domestic production subsidies, tariffs, or quotas, but the level of protection should depend on the industry's learning potential (Melitz 2005).
- Finally, a last 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 with respect to their *stringency in* encouraging innovation activities and *stability in assuring* investors the necessary planning horizon to undertake risky investments in innovation. Ireland displays a high stability of targets aiming not to discourage business opportunities for this sector. Oppositely, the United Kingdom, even though committed to the development of the offshore wind technology, does not present stringent and stable targets for wave and tidal technology.

The present assessment has identified that research activities display a relative specialization 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 commercialization 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). Knowledge diffusion involves a higher participation of countries such as

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

Ireland, Denmark and Norway and, therefore, an increase of synergies between countries could endorse even further the development of the technology.
This report contributes to assessment of recent evolution of marine energy technology, trying to identify factors or barriers to a conducive environment, favoring the emergence of innovation activities in marine energy technology.

2. Methodology and data considerations

The present analysis seeks to explore development of marine energy technologies in terms of interaction between nursery markets, technology developers and policy makers during the different stages of the process of knowledge development and diffusion. The final goal of the present analysis is to identify factors / causes that hamper the functioning of the marine energy innovation system. Based on the 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 analyze the formation and evolution of marine energy innovation activities, based on the methodology presented by Johnson and Jacobsson (2001), Bergek and Jacobsson (2003), Jacobsson and Bergek (2004). Such approach has been 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 through a functional assessment, designed to identify bottlenecks in mobilization of public and private innovation efforts by 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 aim to examine how the interaction between entrepreneurial initiatives and policy makers create opportunities or block the development of the innovation system. Such interdependencies are crucial especially for technologies for which market mechanism is weak, for which the state creates nursing markets.
By taking into account the level of risk induced by unexpected changes in the public polices, the report accounts for building system activities "should be directed towards increasing the strength of inducement mechanisms and reducing the power of various blocking mechanisms" (Johnson and Jacobsson, 2001). Moreover, the exploration of interaction between entrepreneurs, network and policies could provide useful insights upon the level of risk that is faced by the industry and technology.

Box 1. Function of 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 peculiar and non peculiar externalities.

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

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

Function 5: Market formation. In the case that markets do not yet exist it refers to protected spaces, such as "nursing markets" (Erickson and Maitland, 1989)

Function 6: Resource mobilization, 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 from A Bergek, M 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.

2.2. Data considerations

The present analysis, taking into account the availability of data of the various aspects investigated, is limited to a sample of 10 countries: the United Kingdom, France, Portugal, Ireland, Spain, Denmark, Norway, Italy and Sweden. Additional information is provided when relevant or available.

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 of national applicants to the 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
	Commercialization network: patent applications filled 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 centers-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 mobilization	Financial resources: Public RD&D data and European funding Human resources: Co-authors in 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 account for the patent family.

[7] up to 10 PhD programs were identified in 2013 as directly involved in the development of skills/knowledge relevant to the marine energy in 2013. These programs reflect the fragmented feature of marine energy knowledge

[8] 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 the description of the pattern of research activities within universities and research centres. Additionally, 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 the marine energy topic mainly reflects the participation of the scientific community to the development of the sector, accounted through the intensity of scientific interactions and knowledge dissemination. This exploration allows pointing out the main directions of research in the different technologies involved and indicating whether basic research also evolved towards bringing the technology closer to market. The main sources for this function are scientific articles collected from the ISI (see table 1) and EWTEC[11] proceeding 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. This research has been framed up to year 2011. Thus, journal papers reflect efforts undertaken before 2011, whilst conference publications highlight academic work up to 2011.

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 that seek production of 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 in 2011 a comparable production level with working papers (WP) presented at EWTEC. The convergence in production levels is also facilitated by the appearance of topic-specific journals dedicated to the generation of electricity from the ocean.

[11] European Wave and Tidal Energy Conference

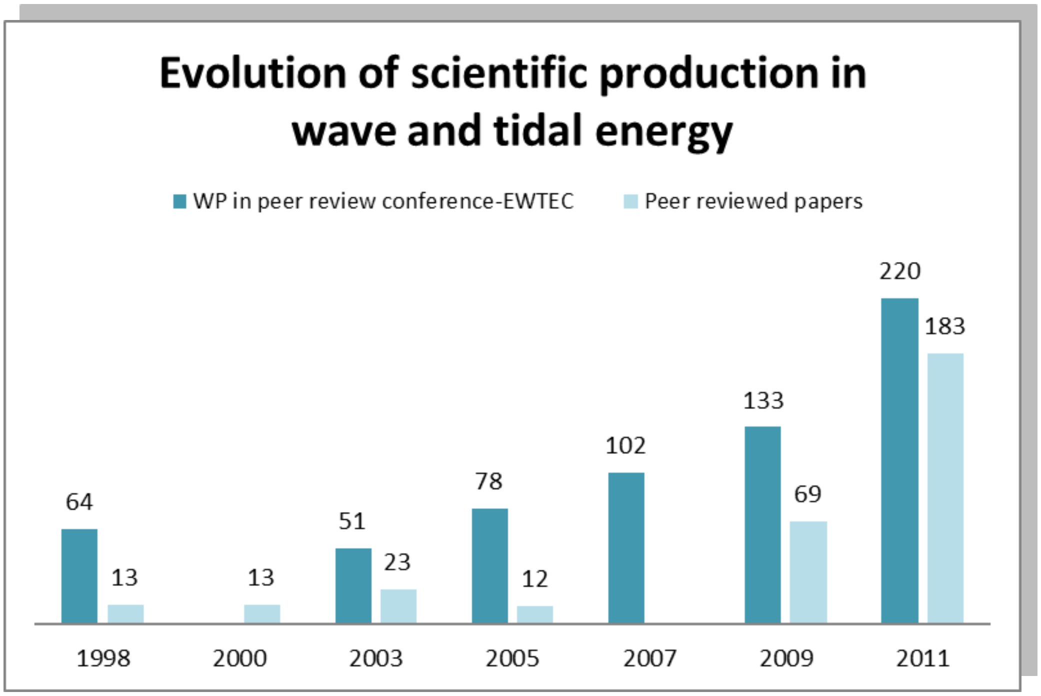


Figure 1 Recent evolution of academic knowledge production on wave and tidal energy topic.

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

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

During EWTEC 2007, wave energy constitutes the main core of research activities presented, with 51% of all papers focusing on wave energy related topics. The topic of *wave arrays* is 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 reflects the intense commitment and support from both academia and industry (EWTEC 2011). Key topics addressed at the conference include: environmental and economic assessment, real-sea testing of concepts, and in particular grid-integration. Synergies between actors increase significantly with the effort to get the technology to the market: increase in the size of teams co-authoring papers is observed for themes such as

[12] Technologies such as *SPERBOUY*, *Poseidon's Organ*, the *Wave Dragon*, *Point Absorber*, *The Rock OWC* and *The FROG* present their latest development and model testing.

Deployment, maintenance, and mooring for WEC*.* In terms of knowledge diffusion, the proceeding of EWTEC 2011 exerts outstanding influence over the scientific community (Table 2).

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*

An important step forward is seen in term on number of publications tackling issues and constraints such as *commercial development of the marine energy sector* and *cost optimization issues.* In the latter case, particular interest is given to *clustering of devices (sharing of infrastructure to decrease cost)* and in increasing energy yield through the use of artificial structures. Other topics include the study of *power transmission systems, design challenges for highly energetic seas, interconnection and use of innovative materials*.

In the context of knowledge diffusion, scientific papers act as an indicator of the scientific interactions and intensity of research on a national/international way. This information was extracted and used to assess F1 – Knowledge diffusion and creation.

3.1.1.2. Knowledge institutes: fundamental research in marine energy topics

Over 280 European knowledge institutes have been identified to be involved in knowledge creation, development and commercialization of marine energy related activities. The most important contributors are presented in table 3 which presents: (i) the total number of knowledge institutes per country, (ii) the total number of publications per analyzed country (fractual account - see methodology), and (iii) the top organizations publishing in the field per country including the number of publications per institute and the national percentage.

A joint exploration of these indicators allows us to describe a first set of findings related to the organization of research in marine energy topics: first mover countries (the UK) and late movers (Italy and Germany) show a widely scattered scientific network. Oppositely, Nordic countries concentrate their local research initiatives and provide knowledge spillovers to

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

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

other countries (table 3). Likewise, Ireland and Portugal exhibit a concentrated organization of research in marine energy topics.

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

Country	Organizations	Publications	Most important organizations (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 énergies, Le gaz intégral (each 2, 5%)
Spain	30	23.81	Tecnalia-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 Bernhard (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 & 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%), Wave Star A/S (3 - 10%), Dexawave Energy ApS, Spok ApS (each 2-7%)
Sweden	8	9.33	Division of 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 topic is large (91) and 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 present work cannot identify the resources availability as an important constraint for basic research activities.

Research activities in the UK are widely scattered, with a range of Universities involved in research activities. The commitment for the development of these diversified initiatives is greatly endorsed by public grants, such as Supergen Marine [13], explaining the scattered distribution of British research on this topic. Compared to other countries, United Kingdom institutions have an active role in the commercialization of the technologies developed within their departments (Robert and Malone 1996), with an higher rate of university spin-offs and start-ups that make use of universities' intellectual property (Lawton-Smith and Ho, 2006). However, despite the scattering of research across the country, it has to be noted that research activities in marine energy within display specializations of the institutes: *Plymouth University* focuses on costal/environmental studies, whereas *University of Edinburgh*, *University of Exeter* and *University of Strathclyde* focus on ocean engineering. *Southampton* and *Oxford* focus on tidal energy conversion, whilst *Belfast* focuses mainly on wave energy. Private organizations and consultancy firms Gharrad Hassan, Black&Veatch, ITPower, Qinetic, are also involved in knowledge creation.

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

On the other hand, in Scandinavian countries fundamental research tends to be concentrated in few institutes: Denmark displays 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, Dexawave Energy ApS, also have important research initiatives. In other countries, concentrated national research is seen in Sweden with Uppsala University leading marine energy research; and the Norwegian University of Science & Technology leads the way for Norway. Norway, Sweden and Denmark have also been actively involved in the testing and validation of the technology in recent years, and their institutes provide significant contribution in terms of international scientific collaboration.

Countries such as France, Italy and Germany, displayed a spread of research initiatives within many institutes. Their initiatives gather also the ones of the industry, whose commitment has lately pushed the development of marine energy initiatives. However, the publishing activity is to a large extent dominated public research institutes. Ecole central de Nantes is present with a long tradition of marine energy engineering and is involved with the development of French wave energy test centres. Italy is represented by institutes working on environmental assessments, but also show entrepreneurial initiatives.

Scattered organization of research activities in France, Italy and Germany.

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

EERA states that around ten universities and important research centers are involved in the development of the sector.

Ireland and Portugal show a concentrated allocation of marine energy resources. Irish research activity is highly concentrated around University College Cork. A similar case is seen in Portugal where the Instituto Superior Técnico is the hub of many research initiates. Such countries provide the appropriate logistics for devices to be tested and room for improvements to be created.

In Spain, private institutes are dominant in the creation of knowledge/ validation of the technology (Tecnalia); additionally, 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 programs for future researchers

Several technology skills, as well as interdisciplinary approaches, are needed to develop the necessary expertise needed to tackle marine energy challenges. Although the engineering formation (in particular electrical engineering and mechanical engineering) is vital for the human capital creation in marine energy, other skills may be required; an example of Phd topics on marine energy technologies is hereafter presented.

- 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 Modeling and Analysis
- Structural Reliability
- Stochastic Methods Applied in Nonlinear 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
- Modeling 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, wave scientist”[14]. The potential benefits for the development of offshore sector have triggered additional investment in higher education initiatives. Among the most noticeable, we find the € 7.8 million in the United Kingdom allocated to engineering education.

United Kingdom

The public organizations in the United Kingdom offer a significant range of doctoral programs[15] that develop skills/knowledge relevant to the marine energy sector. Key examples are the

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

[15] Phd database, around 10 Phd programs in 2013

Industrial Doctorate Centre for Offshore Renewable Energy (IDCORE) programme run jointly by University of Edinburgh , Exeter and Strathclyde aimed at developing specialized scientists.

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

Another example is the EPRSC-funded program 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 targeted master courses: Plymouth University offers an M.Sc program specifically in Marine Renewable Energies since 2011.

Ireland

Among the institutions involved in forming skills in marine energy, the most relevant are University of College Cork, University of Limerick, National University of Ireland Maynooth and University College Dublin. University of College Cork, with its Hydraulic and Maritime Research Centre, is a partner of the maritime and energy research cluster at Ringaskiddy and leads the FP7 project Marinet which devotes parts of its funds to training activities for young researchers.

France

A limited number of doctoral and master courses for marine energy are provided in France. Notable for its reputation in the research in marine engineering is *École Centrale de Nantes*[16]. Their research team enjoys a wide background that ranges between *Mechanical engineering*, *Applied Mechanics* and *Fluid Mechanics*. *Ecole Central de Nantes* has been directly involved in the development of a French-design 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. An important research centre, based in the north of France, IFREMER, is highly involved in marine energy offering test facilities as well support for researchers. The recent interest on marine energy topics has allowed many universities to develop ad-hoc course in marine energy technologies and related subjects.

Other countries

In Denmark strong doctoral specialization in marine energy is provided since 1995, mainly at Aalborg University. Aalborg University was selected as an advisory body for the *Danish Wave Energy programme* and has developed testing programmes of wave energy converters at laboratory scale since then. A large variety of Danish-designed WECs were tested at its facilities, including Wave Dragon, Wave Star, Wave Piston, WEPTO and Waveplane to name a few. A large array of educational offers is provided by Norwegian university of science and technology Trondheim (Norway). In Germany, Aachen University offers courses on development of power

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

take off systems, whereas Fraunhofer Institutes devote activities in developing skills for techno-economic assessment of marine energy.

Educational offers for marine energy in Italy are limited, aiming mainly to facilitate student exchanges between the University of Naples Bologna with Aalborg University, Southampton and Plymouth University, which have taken place over the years with a cross-university course organized in Naples[17].

Portuguese educational training in this field reveals significant initiatives, with many activities taking place at IST Lisbon and University of Porto. A collaboration between IST and Wavec (formerly Wave Energy Centre), has helped in providing ad-hoc an doctoral course in offshore renewables, in the fields of device modelling, power generation for OWC, cost-analysis of wave energy and related environmental impacts.

The diversity of programs that are offered across countries points out to the importance and the commitment that each of the country develops with respect to these technologies. A cross-sector and cross-country initiative has been established by doctoral research based in Europe to provide training and exchange possibilities for young researchers to wide their knowledge and expertise (Figure 2).

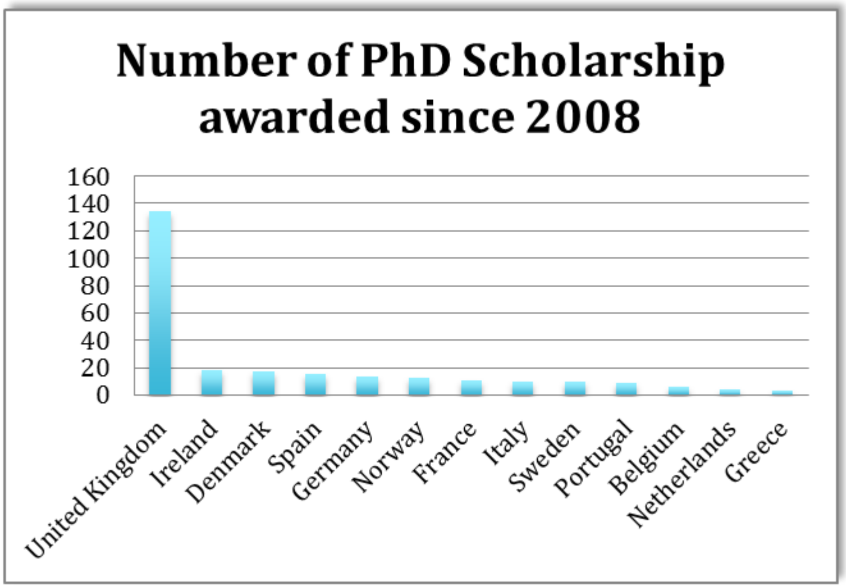


Figure 2 - Number of Ph.D. Scholarships awarded at EU institutions since 2008 (INORE)

The cross country distribution of human capital in marine energy is here above exemplified (Figure 2), using the information upon Network of Offshore Renewable Energies, which was established by students of NTNU, Edinburgh University and Wavec.

3.1.2. Applied research in the field of marine energy technology

The exploration of patent applications provides a comprehensive picture of applied research in wave & tidal energy technology (Figure 3). Two sources were used to collect data on patent applications WIPO and European Patent Office *EPO - Patstat*. The information is crucial to

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

determine the intensity of the knowledge transfer between applicants' home country and the different markets chosen for patent protection.

The analysis of patents allows quantifying the investment efforts of private and public entities. The volume of patenting activities has doubled from 2001 (117 applications) to 2010 (266) whilst it declined in 2011 (93 applications). The biggest increase is observed in the 4 year period from 2007 to 2011 with an average of 30 applications per year per country. Outside these years, the average is 15. Countries such as France, Ireland, Spain and Sweden present an average intensity of 15 applications from 2001 to 2011, whereas Norway patents almost double (26) and the United Kingdom patents are 4 times more (69).

The United Kingdom succeeds to mobilize in commercialization of the technologies important knowledge creation institutes, with many applications filed by academic spin-offs. Additionally, applications are filed by traditional wave and tidal developers such as Trident Energy Limited (24), Marine Current Turbines Limited (25), Aquamarine Power Limited (21), Rolls-Royce Plc[18] (previous owner of Tidal Generation Limited, 21) and Tidal Generation Limited (14).

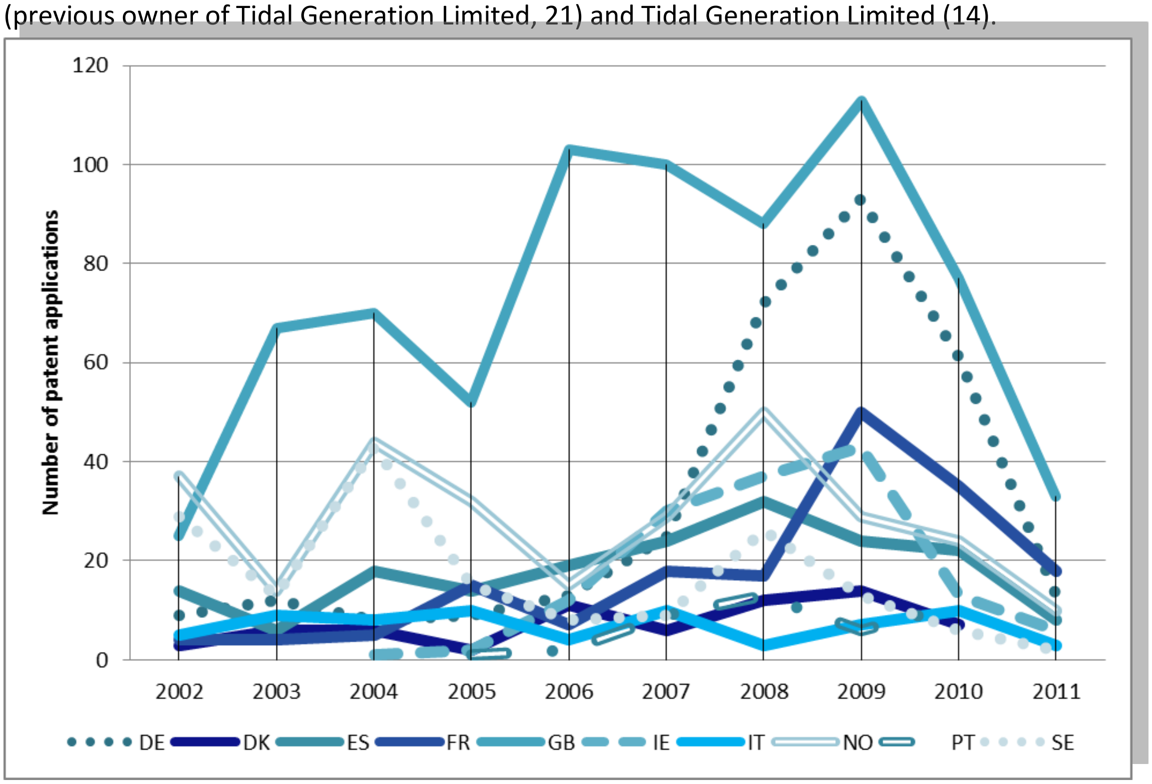


Figure 3 Evolution of patent applications between 2002 and 2011 for wave and tidal energy technology for sampled European Member States (Patstat database)

Norwegian actors include among investors marine energy technology companies such as Fobox AS (20 applications), Hammerfest Strom As (11 applications), Straumekraft AS (22 applications), Wave Energy AS (11 applications), Havkraft AS (4 applications) and others. An increasing trend in patenting is observed in Germany, the patenting activity of which registers significant levels,

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

outmatched only by United Kingdom, displaying the involvement of well-known private companies, such as *Robert Bosch Gmbh* and *Voith Patent Gmbh* (71 applications).

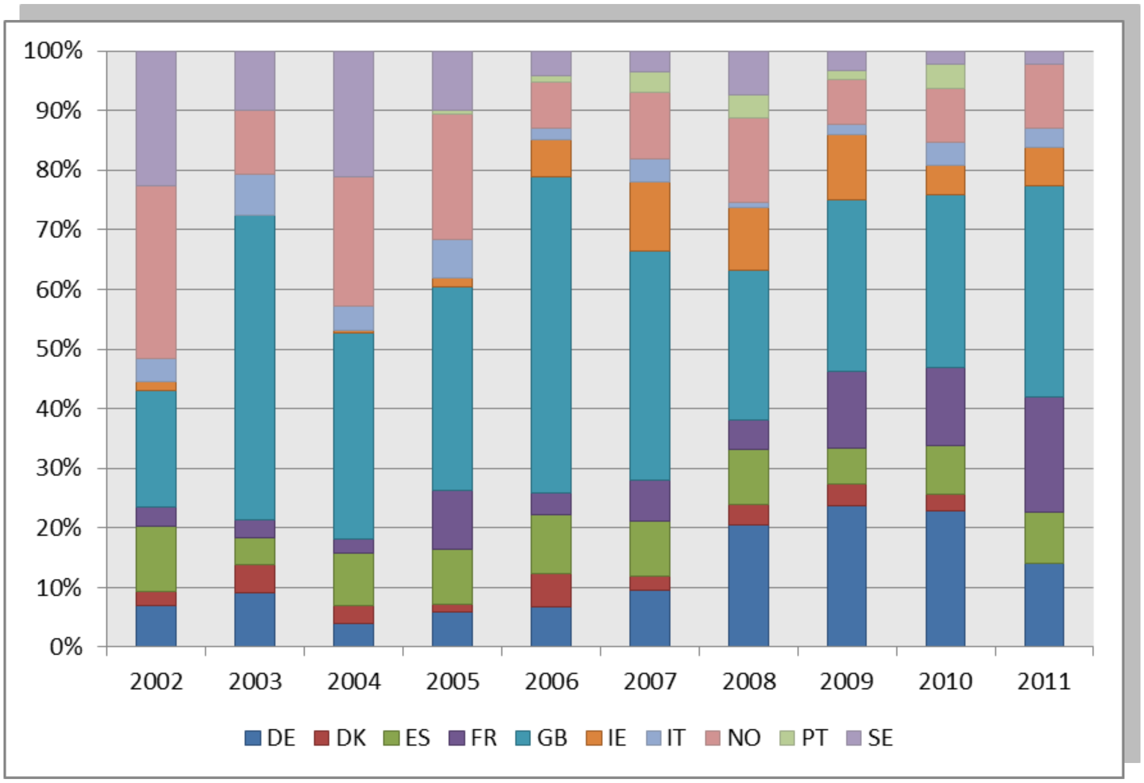


Figure 4 Intensity of patent applications for wave and tidal energy technology for sampled European Member States between 2001 and 2011

The French initiatives present a significant increase at national level in particular in the last years (Figure 4), with patent applications increasing from 4 in 2001 to 18 applications in 2011. The French patenting landscape mixes public and private initiatives. Among public initiatives *Centre National de la Recherche Scientifique* (CNRS) shows a significant activity (14 applications). The involvement of SBM in marine energy passes through participation to *S3 Innovative Wave Power Project*, which is developed in association with IFREMER and the Ecole Centrale de Nantes. The project was selected for public funding (Investments for the Future Program/ADEME)[19]. Other large companies such as naval engineering companies DCNS (8 applications) and EDF, but also small companies (TurbOcean SAS), indicating the increase interest for marine energy conversion. In the same time span, Ireland's share in patent applications decreases from 20 % to 6 % in 2011. The country shows a concentrated distribution of patenting activities with OpenHydro Group Limited filing for 62 applications.

Spain has a constant patenting activity, around 10% share of all countries considered with significant knowledge creation activities realized by public organizations. Significant activity is noted for a company resulting from an ex European project, *Pipo Systems, S.L.*

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

The Swedish applications show a research activity highly concentrated around the project of Seabased AB (98 applications). Other important innovating entities involve private companies, such as Ocean Harvesting Technologies AB (6 a), Current Power Sweden AB (12). Patent applications below average are seen in Denmark, Portugal and Italy. Activities in Denmark show a constant trend patenting behavior with the bulk of applications that is dominated by well-known wave energy firms: Wave Star Energy Aps (13), Wavepiston Aps (7), Oxydice A/S (8). In Portugal a mix of public and private efforts contribute to the technological development. Among the knowledge institutes, significant is the activity of *Instituto Superior Tecnico-Lisbon* (5). Among private companies Sea For Life, Lda, inventor of *Wave Energy Gravitational Absorber*, files for 4 applications. An examination of patent applications in Italy identifies wave product innovations of a small company Tecnomac S.R.L. (4), and of Italian universities involved in developing the marine energy such as Polytechnic of Turin (2).
As expected, the countries fostering the majority of innovations in the fields are associated with a diverse technology spectrum of wave and tidal applications. The bulk of patent applications blend public and private research efforts, with a higher commitment of private companies in countries such as Germany, Denmark Norway and Sweden. Spain and Portugal notably show higher implication of public institutes.

3.1.3. Evaluation of the knowledge creation function

The assessment of the function goes from general to specific themes: from knowledge creation (published papers and proceedings) to applied research (commercialization of technology) to patent applications. The potential capabilities in forming specialized labor pool are taken into account.
The United Kingdom shows a good performance in all the dimensions analyzed and potentially future synergies could be created to enable learning by doing activities. This in line with the activities and the role that the UK plays in developing marine energy technologies and the potential benefit the country could have by a specialized sector.
Countries such as France, Germany and Sweden display a similar pattern with an intense concern for the commercialization of the technology and lesser involvement in knowledge creation (Appendix 1). In France and Sweden public support is considerable, and enforcing private initiatives, whereas in Germany the road to commercialization is the result of diversification of technologies and risk 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 commercialization of marine energy.
Spain succeeds to provide a good knowledge offer, as well as to valorize its skills and knowledge through scientific publications. Initiatives for commercialization of the technology remain limited. Ireland, despite low commercialization activities, obtains a higher score thanks to scientific output and knowledge offer. Italy is performing the lowest in all the indicators, showing a limited public commitment to the development of the technologies and limited private initiatives, which are born thanks to knowledge collaboration networks as further on

described. However this reflect the potential benefit the country may obtain from investing in marine energy.

3.2. F2 – Knowledge diffusion and knowledge transfer

The intensity of collaborations in the sector is largely determined by the pre-commercial stage of the technology. Marine energy knowledge diffusion is mostly dominated by intra-institutional/intra-country partnerships, although inter-university collaborations and industry–academia partnerships are present in later stages of demonstration of marine applications.

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

A structural analysis of the marine energy scientific networks shows that the average size of collaborating entities is 1.65 authors per publication, but featuring intense collaborations and a denser network in specific themes such as *marine current resource and modeling*, *wave energy converter modeling*, *wave energy converter power take off systems*, *marine current energy converter testing*. Intensification of scientific collaborations has been encouraged by national targets that identify *wave and tidal device modeling* tools as top priority for the industry (UK), with a framework of six years for its completion (Topper and Ingram 2011, UKERC/ETI Marine Energy Technology Roadmap).

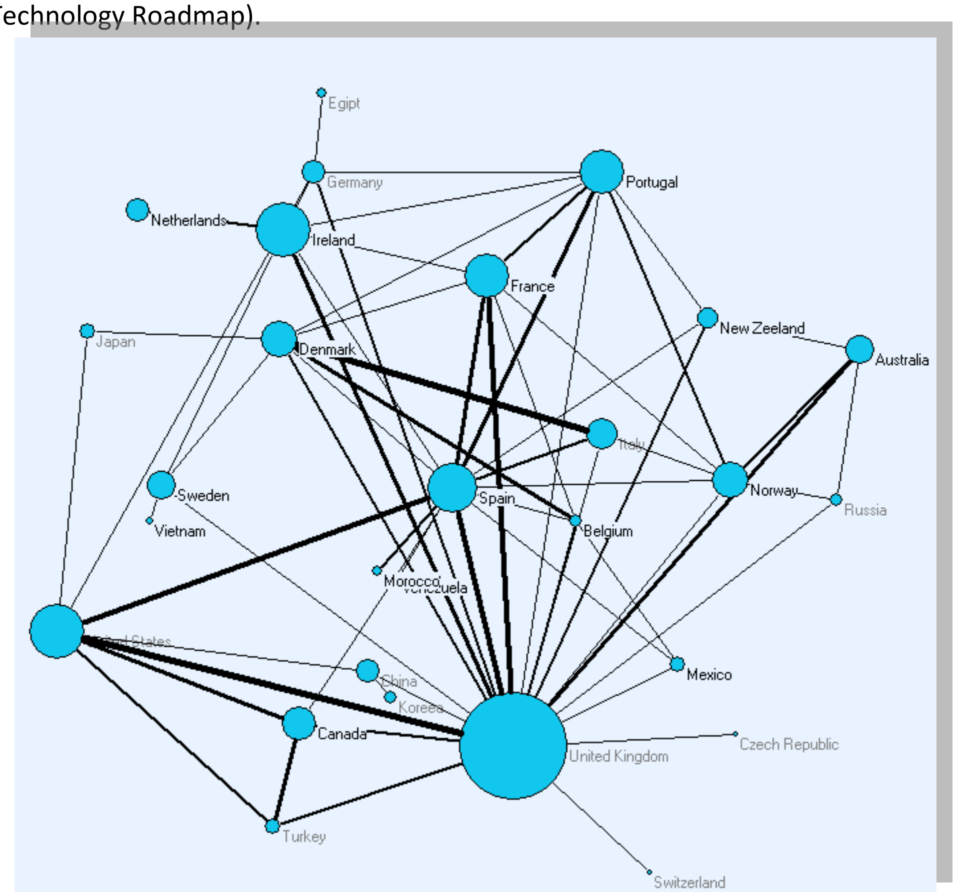


Figure 5 Network representation of academic collaboration of organisations publishing on marine energy topics aggregated at country level. Size is adjusted for occurrence in scientific publications; the width of each line represents the intensity of collaboration between countries.

A large bulk of scientific discoveries is developed by relatively small industrial players, which are spinoffs /start-ups of universities or research centers. Modeling of WEC/TEC, 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 centers or even large industrial players into the creation of tacit knowledge. Hence, scientific collaboration increases when the physical and financial needs addressed.

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

Limited within-country institutional collaboration is observed in Norway and Denmark, which show extensive international collaborations, especially with institutions from late movers in marine energy sectors such as Italy and Germany (Figure 5). For example, scientific interactions are cultivated between Denmark and Italy, in particular through doctoral programs allowing to overcome the spatially bounded feature of knowledge diffusion. Furthermore, the FP7 projects have helped in fostering academic cross-country collaborations; under the umbrella of European projects, the project entities succeed to set 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 flows of utilization of knowledge developed towards future scientific work related to marine energy technology. This can be measured by assessing the number of publications produced and of sub-consequent citations. The density of the network, together with the scientific recognition of the publications (measured through papers citations) can give an indication of the average scientific productivity by country.

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

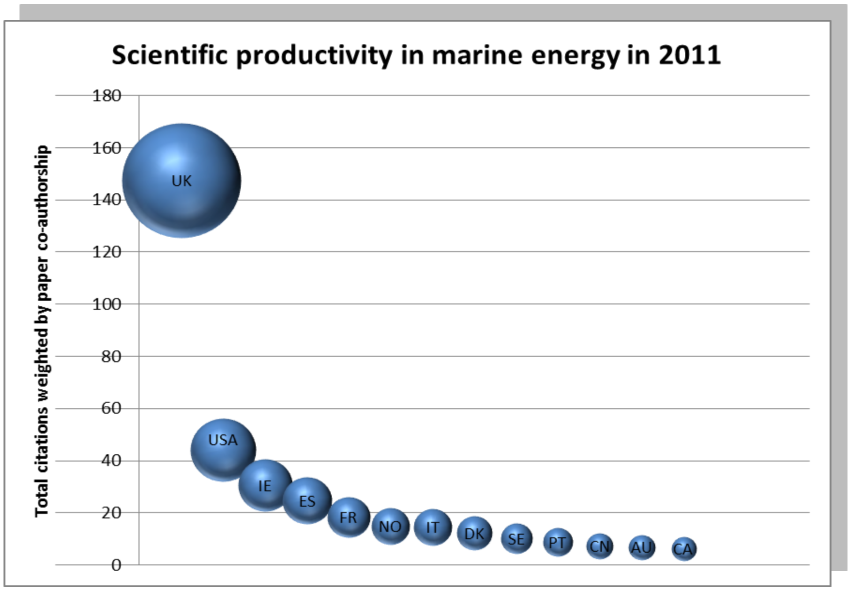


Figure 6 Contribution of countries to knowledge diffusion process measured by their scientific productivity in marine energy publications. The indicator was obtain by dividing the number of citations received by paper by the number of co-authors and finally aggregated at country level

Specific themes such as wave energy converter modelling and wave energy power take off are more cited 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, in the sense that a denser network would likely attract higher citations.

3.2.3. Spatial knowledge diffusion of private research

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

Figure 7 points out again the importance of European countries to knowledge diffusion. At 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 for international market is demonstrated by the company *Seabased*, who applied for intellectual protection at patent offices in different countries.

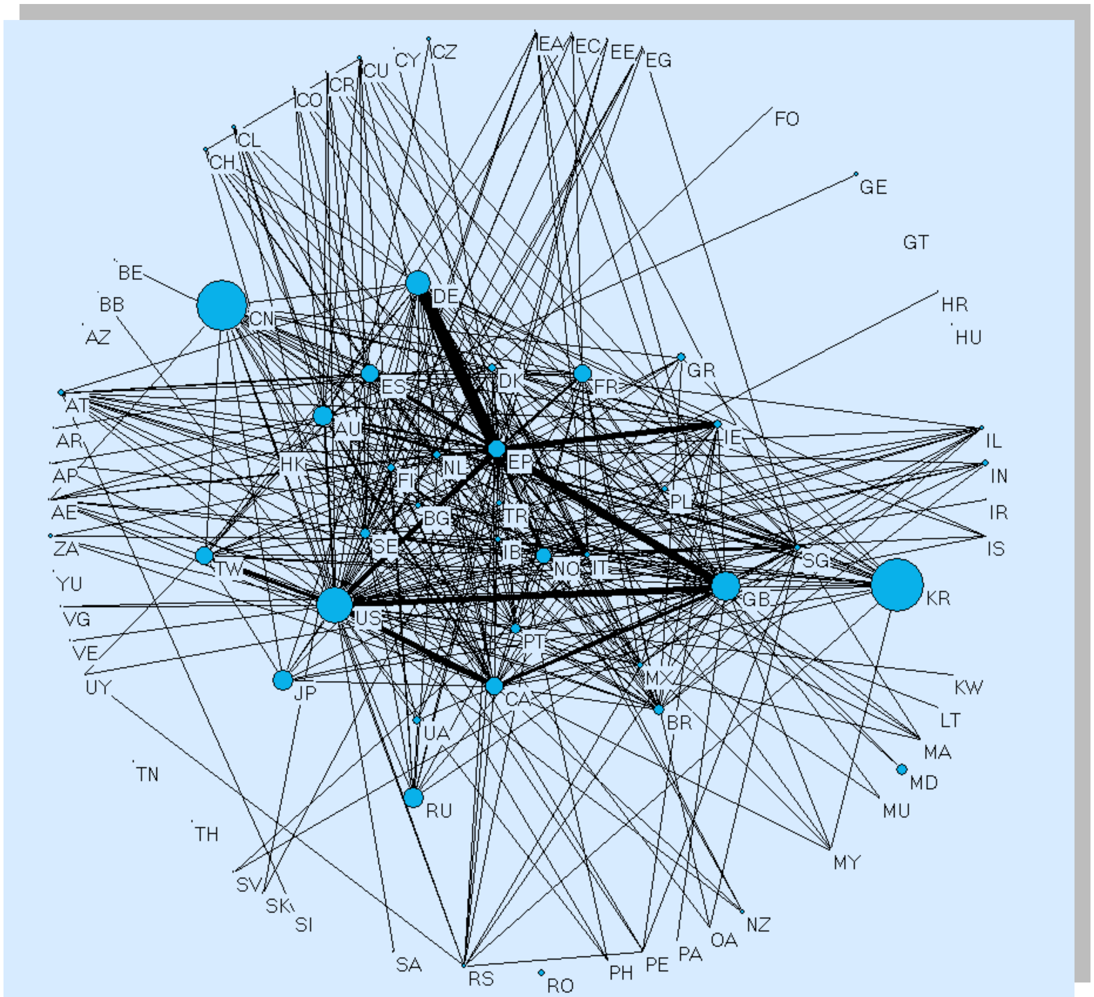


Figure 7 Network representation of commercial interests of public and private entities patenting in marine energy applications between 2001 and 2011 by country and patent office. The width of lines represents the intensity of collaboration between countries. The size of the bubbles indicates the number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

Knowledge outflow is typically higher than knowledge inflows in countries such as Ireland, United Kingdom and Norway. Also the public research is committed to international commercialization 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 present a more substantial involvement by industry. An examination of the partners participating in EU funded projects offers an additional take on the investment in emerging marine energy technology (Figure 8). United Kingdom, France and Spain play a central role in the European collaboration network. An important role is played by French organizations, which are closely cooperating with British counter-parts in developing infrastructures and logistics needed by the development of the sector. Projects such as *Marinet (Marine Renewable Infrastructure Network)* and Marina Platform (*Marine renewable integrated application platform)* succeed to gather initiatives from all European countries. Targeted projects such as

Standardization of Point Absorber Wave Energy Convertors by Demonstration and Surge Simple underwater generation of renewable energy gather a limited number of participants and of countries.

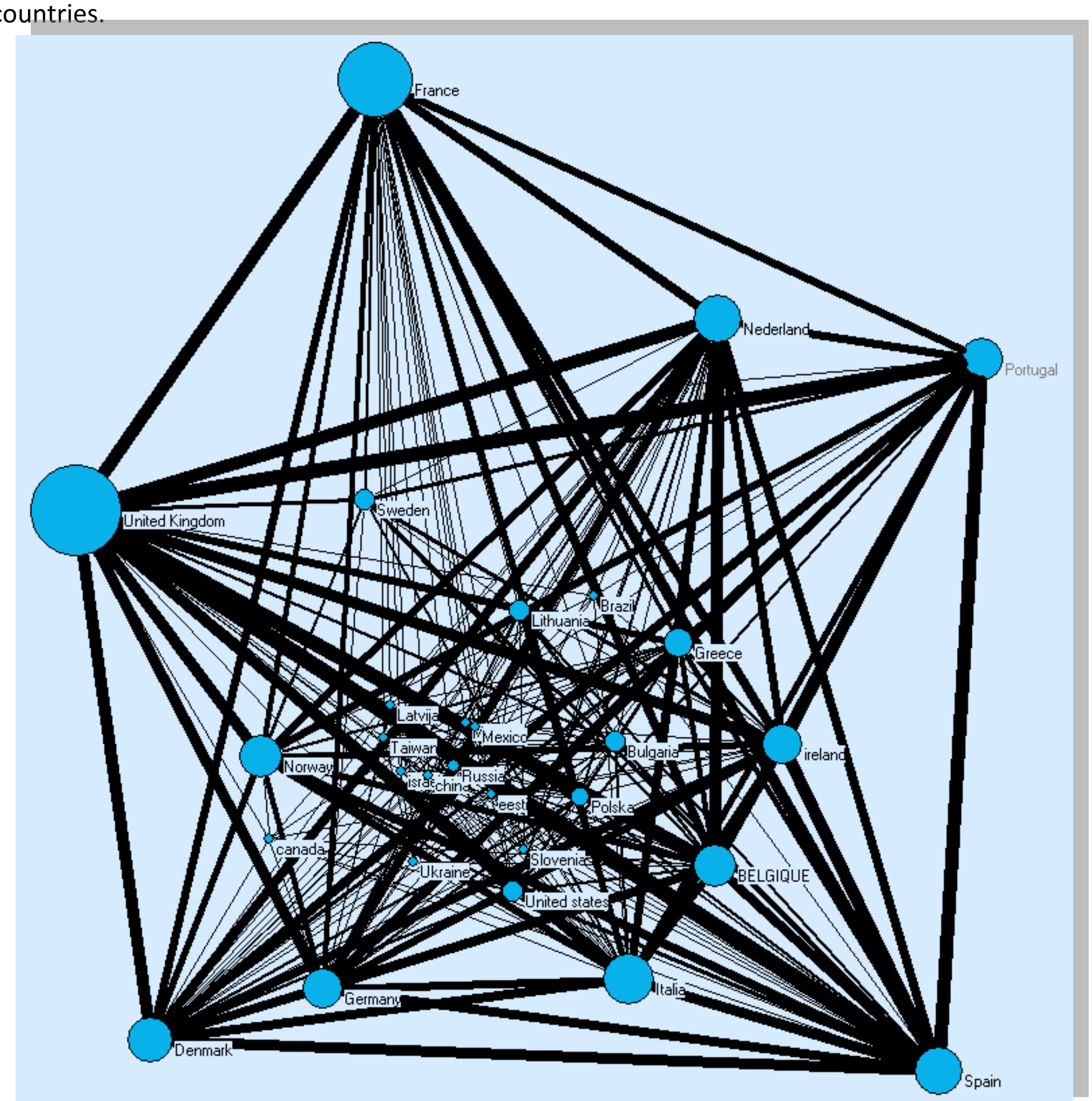


Figure 8 Network representation of public-private partnerships of entities participating in projects listed in CORDIS, related to marine energy topics. The width of lines represents the intensity of collaboration between countries; organisations are aggregated on country level. The size of the bubbles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

3.2.5 Evaluation of knowledge diffusion for main European countries

The fundamental knowledge expressed in terms of scientific publications and citations of scientific works exerts an important weight in evaluating the knowledge diffusion function (Appendix 1). In terms of scientific impact, the most important is the contribution of the British and Irish researchers. Also France features higher scientific recognition than other countries; and is comparable to the Spanish one. In terms knowledge diffusion through network collaboration, the Irish institutions register similar contribution to French and Spanish counterparts. The German, Norwegian and Spanish developers show interest towards foreign market, such as Korean, Canadian and American markets. The country most participating in the knowledge diffusion process is the United Kingdom, which organizes scientific events and searches the commercialization of the technology through both public and private initiatives.

3.3. F3 - Knowledge commercialization: entrepreneurs and venture capital

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

3.3.1. The academia spin-offs and new start-ups

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

Table 4 Examples of marine energy academia 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 S.r.l,	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*
Keppler Energy	University of Oxford	*United Kingdom*
Manchester Bobber	University of Manchester	*United Kingdom*
Nautricity Ltd	University of Strathclyde's	*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*

UK universities are very active in the commercialization of marine energy technologies; however, commercialization activities also take place in other European countries.

Vital support for new technology ventures is provided by public organizations, 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 displayed in Figure 9.

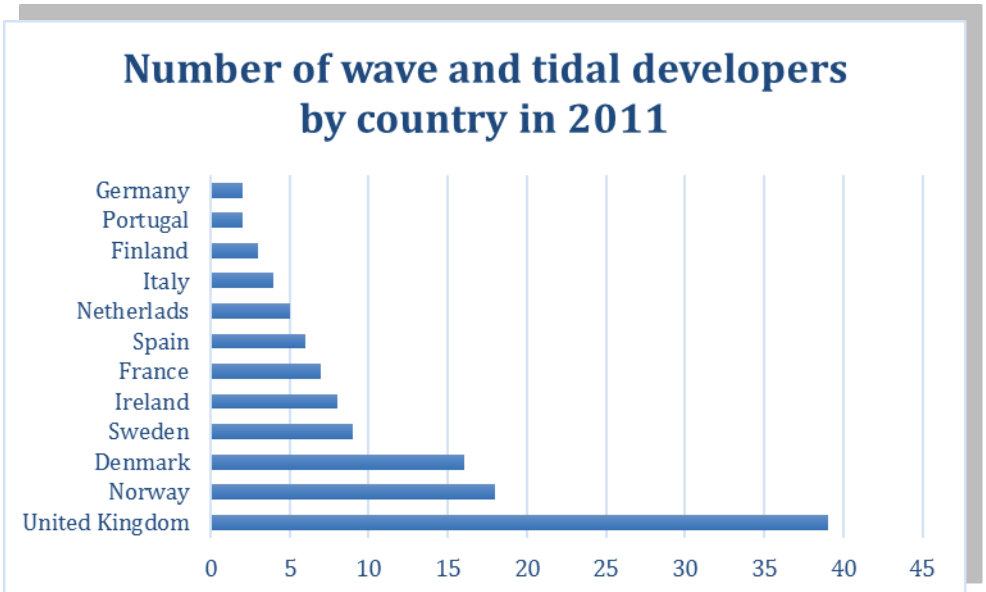


Figure 9 Number of marine energy technology developers by country in 2011

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 needed to increase assurance that marine energy system will be deployed (see box 2). Even not as spectacularly as for other energy technologies, marine energy technology developers have succeeded to attract investment funds needed for testing their applications. Incumbent energy companies (see box 2) have increased their participation in the development of the sector with important efforts made by countries such as France, the United Kingdom, Germany, Norway and Sweden.

Box 2. The case of **French** companies. In 2011, *Alstom* buys 40 % shares of the British AWS Ocean Energy and 2 year later acquires Tidal Generation for around € 57 million. *DCNS* acquires Open hydro and starts operations in the north western part of France. *Actimar*, active in marine energy technology, is currently owned by the group Suez.

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

Norwegian tidal-turbine maker, Hammerfest Stroem SA, succeeded to raise € 14.5 million through equity raising. Fortum is a major shareholder of Aqua Energy Solutions AS, in AW-Energy Oy and since 2010 is involved in a demonstration project with Seabased AB.

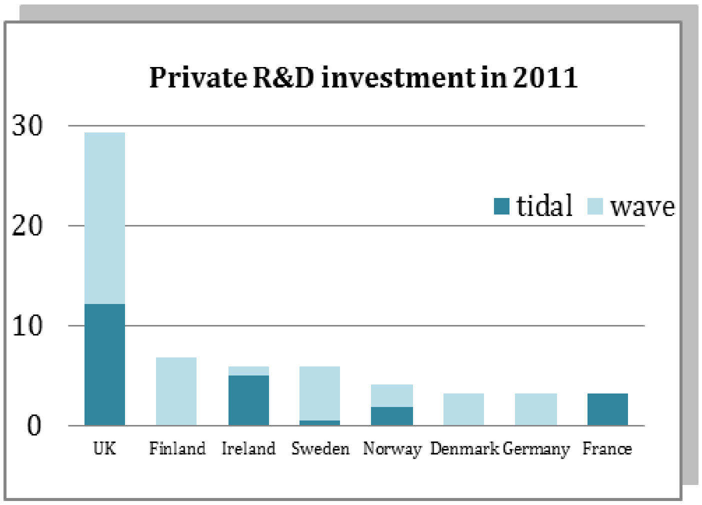
German energy companies are also involved in demonstration projects: *Siemens AG*, acquired up to 45 % of shares of tidal technology developer *Marine Current Turbines Ltd*; *Schottel GmbH*, a marine propulsion specialist, is a major shareholder in *TidalStream*; *Voith Hydro Ocean Current Technologies*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

Among **Swedish** companies, ABB contributes to the development of the marine technology acting as shareholder in SEEWEC Consortium, a major shareholder in Aquamarine Power in 2007.

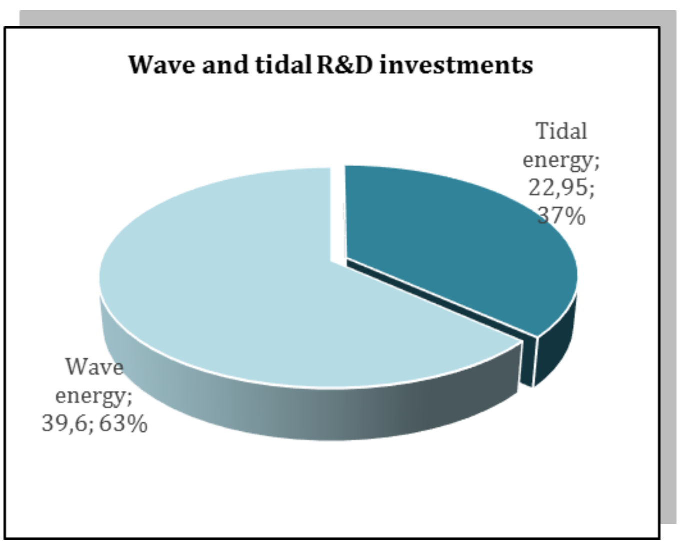
Spanish companies *Iberdrola* and *Acciona* are also involved in marine energy projects. *Iberdrola* invests in *Oceantec Energias Marinas S.L. Abengoa* is attracted by *Wavebob* project; the project however fails to raise the necessary demonstration funding (€10 million) and was forced recently to shut down.

3.3.3. Diversification of research activities for wave and tidal developers

By country, the R&D investments point out the UK as the main investor in wave and tidal technologies. The breakdown of investment by type of marine energy technology is shown in Figures 10, 11 and 12. The assessment relies on patent applications of wave and tidal developers to which an average intensity of R&D per patent of € 0.9 million was allocated. The intensity might change with future calculations.



10 a Estimation of research investments (in millions of euros and in percentage) of private developers by marine energy technology and by country in 2011



10 b Distribution of research investments by marine energy technology in 2011

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

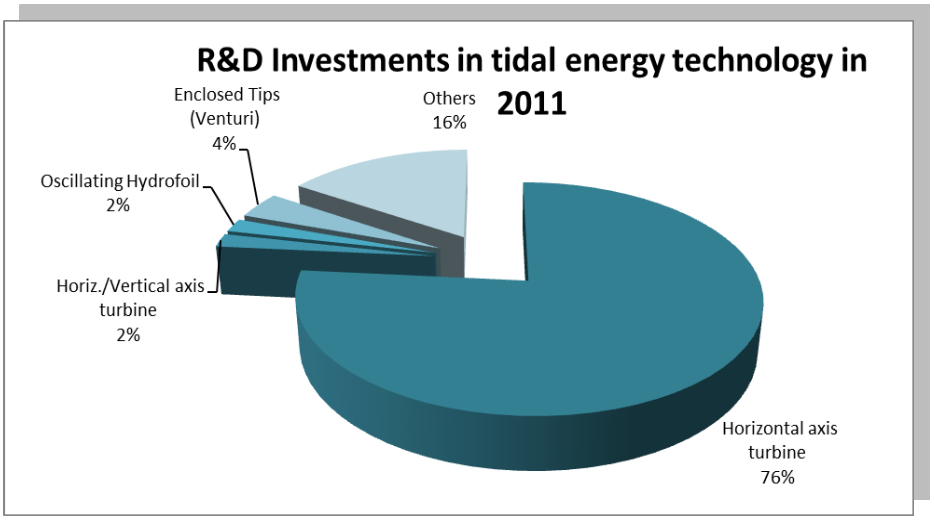


Figure 11 Estimation of research investments (in percentage) of tidal energy developers by main concepts represented on EMEC website. The assessment relies on patent applications of tidal developers

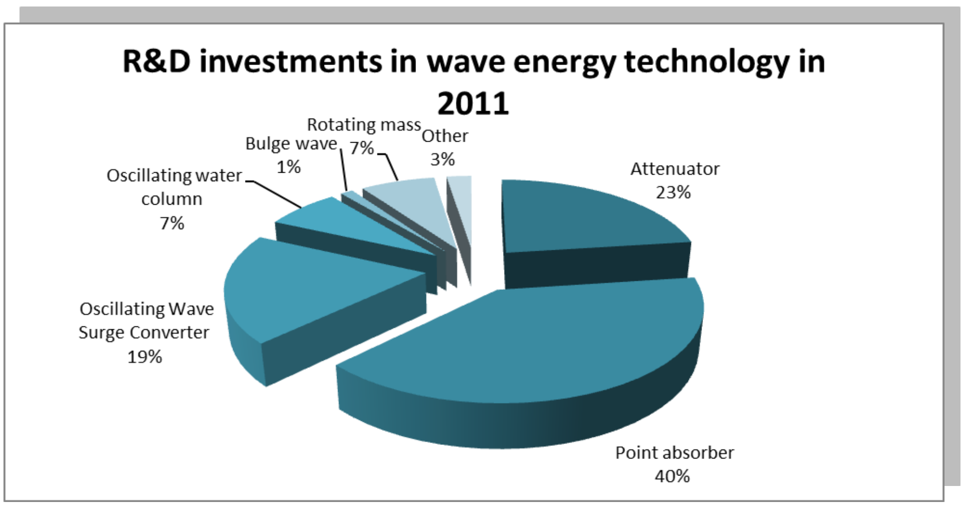


Figure 12 Estimation of research investments (in percentage) of wave energy developers by main concepts represented on EMEC website. The assessment relies on patent applications of wave developers

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

It has been shown that higher chances for technologies to surpass the commercialization valley of death are related with a wide diversity of concepts. The more diverse the portfolio of wave and tidal technologies, the lower the investors' 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 indicate a higher diversity for the United Kingdom and Norway and lower 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 valorizing business opportunities given by the marine energy.

3.4. F4 – Guidance for research

Guidance for research activities are provided by public support to wave and tidal energy deployment*. Targeted policies* such as public subsidies for deployment (*Feed-in-Tariffs*, *Quota System*) are needed by marine energy developers to efficiently plan their investment. The present section refers to the level of public instruments, as potential enablers of innovation activities.

3.4.1. Deployment subsidies

Besides targeted policies for deployment, such as *feed-in-tariffs* and *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 UK seem to have high levels of policy effectiveness. Table 5 presents main support for deployment of marine energy projects.

Table 5 Support schemes across European member states.

	Fit/FIP (€ct /kWh) -wave and tidal	Fit/FIP (€ct /kWh) -wind	Quota system
Denmark	5-8	1.3	
France	15[20]	Onshore: 2.8 – 8.2 Offshore: 3 – 13	
Germany	3.4-12.7	Onshore: 4.87 – 8.93 Offshore: 3.5 – 19	
Ireland	22	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)*
Norway			0.049 (2013) *
UK			0.050-0.104**

[20] 173 €/MWh and €200M of capital support, 133 ro France Energies Marines

* Quota obligation per MWh of electricity sold or consumed;** Nb of roc/MWh; it doubles for installations >10MW

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, high 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 compared to the UK; however, the French authorities offer capital support grants of up to €200M to reduce risk for investors.
- ***Investments:*** The Irish government has set in place a financial package for marine energy [21] covering the support for device developers, the development and enhancement of grid-connected test facilities, such as the Atlantic Marine Energy Test Site in Bellmullet and the Galway Bay test site.
- ***Infrastructure:*** Portugal initiates first steps for the development of the Wave Energy Pilot Zone and creates a dedicated subsidiary of the National Energy Networks.
- ***Targets*:** New Spanish targets seek installing first 10 MW by 2016 and new planning occurs in Germany ("National Master Plan Maritime Technologies").
- ***Licensing***: Norway sets up a 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 an one-stop shop for licensing wave and tidal energy projects that helps developers in deploying their technologies.

For countries such as Denmark and Portugal, the level of feed in tariffs and premiums is more than double for marine energy rather than for other renewables energy technologies (i.e offshore wind), thus showing the interest in developing 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 notice 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 allow the development of technology-producing companies.

In summary, *targeted policies* in some countries would further promote marine energy technology development, although the risk of policy spillovers is difficult to occur in the absence of a commercially mature technology.

3.4.2. NER 300

"NER300" is the name given to a financing instrument managed jointly by the European Commission, European Investment Bank and Member States. This name is derived from Article 10(a) 8 of the revised Emissions Trading Directive (2009/29/EC) which contains 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).

[21] administered by a new marine Energy Development Unit (OEDU) based within the Sustainable Energy Authority of Ireland (SEAI),

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

- Wave energy devices with nominal capacity 5 MW;
- Marine/tidal currents energy devices with nominal capacity 5 MW; and
- Ocean thermal energy conversion (OTEC) with nominal capacity 10 MW

Three wave and tidal projects, to be developed in the UK and in Ireland, have been selected for NER 300 funding, out of the five submitted from the first Call (table 6).

Table 6. Wave and tidal energy projects funded through NER 300

Status	Project	Countries	Fund rate €/kwh	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

The selected wave and tidal projects feature a funding rate that is 5 times greater than the one awarded to wind technology and two times greater than offshore wind projects. Cumulatively, the financed projects aim at installing around 24 MW wave and tidal energy capacity, which represents a tenfold increase with respect to the 2011 level. The ambitious entrepreneurial initiatives are sustained by public intervention for the case of the United Kingdom (tidal energy) and 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 with one of more wave technology that have reached TRL9. The projected installed capacity of the array is of 5 MW.
- Four tidal energy twin rotor turbines each rated at nominal 2 MWE will be installed in the Ocean Kyle Rhea project (8 MW).
- 3-bladed, seabed mounted tidal turbines will be installed in waters between the islands of Islay And Jura off the west coast of Scotland (10 MWE), Meygen project.

Non-selected projects were submitted by Portuguese (5 MWe) and French (10 MWe) bidders. The Portuguese project proposed the implementation of an array of 10 surging wave energy converters (nominal capacity 500 kW each). The French initiative, to be developed in the island of Reunion, presented a novel and ambitious technology: Ocean Thermal Energy Conversion. OTEC has been identified has a technology where EU state may have a technical advantage, but of difficult implementation in EU waters due to low temperature gradient differences.

3.4.3. Evaluation of the public support for the development of the technology

The potential of publicly induced innovation as a function of deployment support instruments points out Ireland as the country offering the highest guidance for research (Appendix 1). Compared to offshore wind energy technologies, countries such as Denmark and Ireland offer a

higher subsidization (in terms of feed in tariffs and premiums) for the development of marine projects. In absolute terms, the level of Feed in tariffs/premium Italy, Portugal, is higher than in other countries potentially exert significant inducement over innovation activities in marine energy technologies. However, It has to be noted that the wave and tidal resources available in Denmark and in Italy are lower compared to those of other EU countries and thus these countries may have opt to obtain technology advantages rather than deployment advantages.
In the aggregate, Ireland offers the highest public support for the deployment of the technology followed by the United Kingdom, Denmark and Italy.

3. 5. F5 – Market formation

The sector has an expectation to reach commercialization in the next decades, going up to 30-40 years for wave energy (Pound et al 2011). The nascent state of the industry is graphically represented by different stages of development of the on-going projects in 2011 (Figure 13).

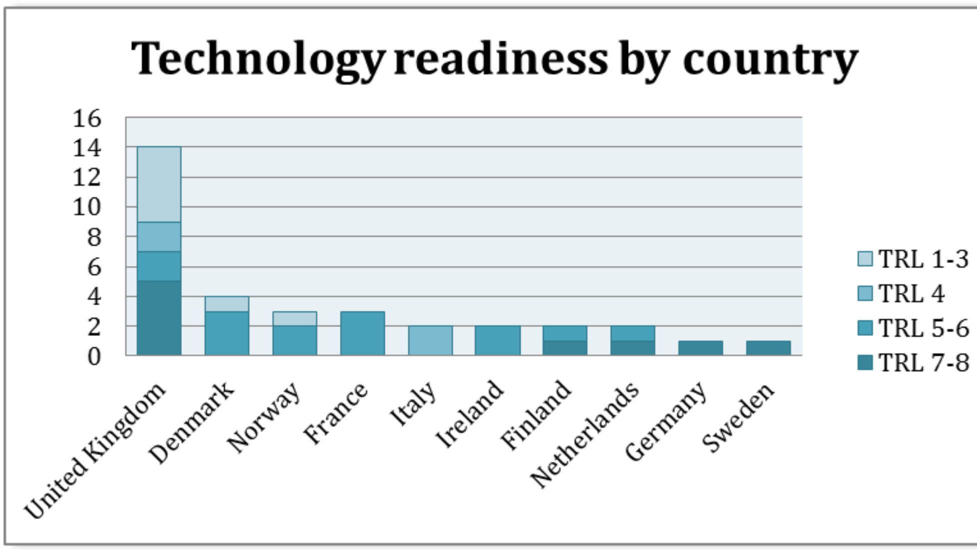


Figure 13 – Technology readiness level of wave and tidal technologies by European country

Within all the marine energy projects deployed in Europe, only 22% of them are partially/totally commissioned. As seen in Figure 14, 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 project reflecting early stages of development: Announced / planning begun or Financing secured / under construction.

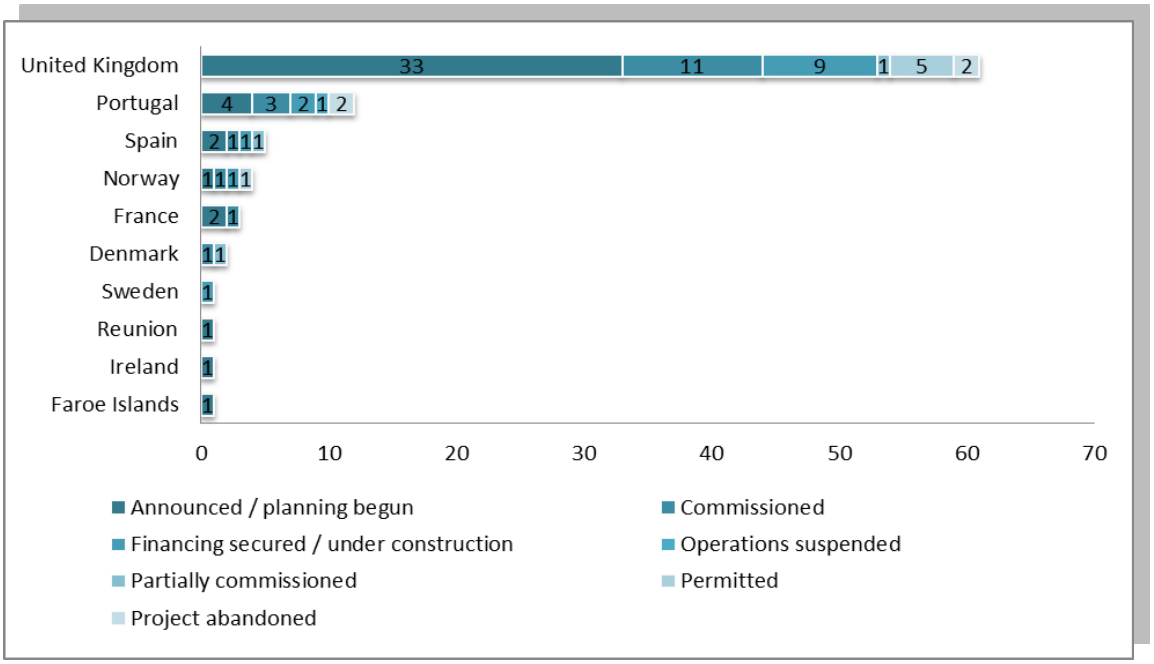


Figure 14 Wave and tidal projects by stage of development across European countries. Bloomberg energy database

The successful completion of marine energy projects involve 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 the understanding the state of marine energy supply chains.

3.5.1. Physical infrastructures-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 necessity of infrastructure for testing of devices and for the deployment of early arrays and demonstration projects is of primary importance. This often relates to the availability of sites for reliability testing of device, provision of cables, grid connection and infrastructure. So far, mainly due to the early stage of technology, little capacity has been installed in Europe, with many single devices in the range 0.2-1.MW deployed.

The nascent status of marine energy technologies is highlighted by the limited number of sites commissioned and builds around Europe. Currently, including the La Rance barrage (France), 260MW have been installed. However, a number of infrastructure sites available for development and demonstration of the technology and in particular small to large scale testing is available at University and Research Centres. A number of European facilities have been made available to developers at different stage through the FP7 funded Marinet Project. The list of the facilities available in Europe is presented in Table 7. In addition, other EU and national funded projects have provided access to marine energy testing; such are the FP7 Hydralab, which provides access among others to 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 dedicate tidal and wave energy facilities, of which EMEC is the leading example comprising grid connected tidal and wave energy sites. Figure 15 present the real-sea infrastructure developed and underdeveloped in Europe for the testing and demonstration of wave energy devices.

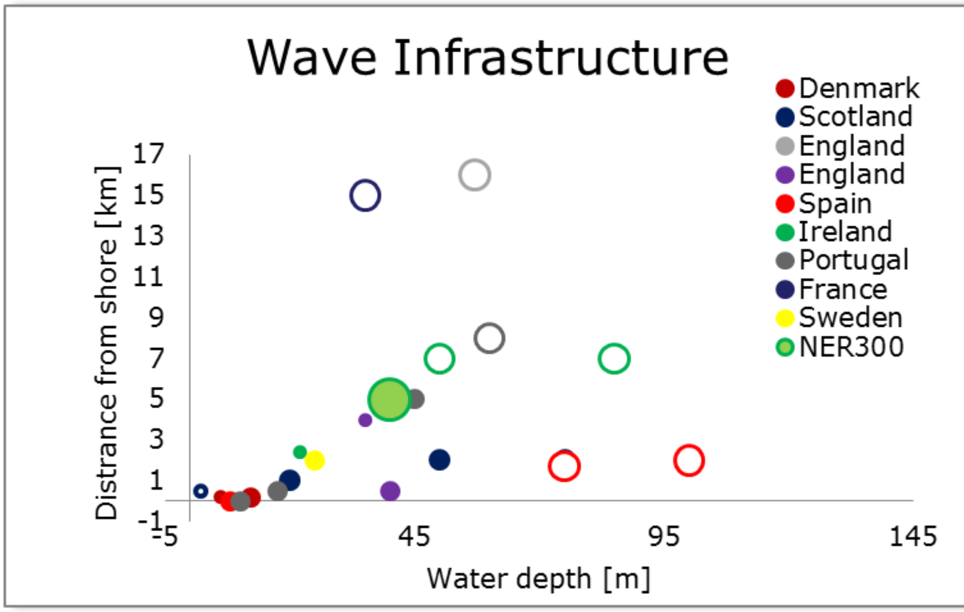


Figure 15 – Real sea demonstration facilities in Europe for wave energy testing. Hollow cycles indicate planned projects.

Table 7 - List of wave energy test centres and of the 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
WaveHub	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
OceanPlug	Portugal	Array	No	2007	Yes	No
SEMREV	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

The development of wave energy test and demonstration sites is an indicator of the progress and of the constraint that the sector has faced over the past few years. The EMEC test site is operational since 2003, whilst Wave Hub, developed for array testing, has been ready since 2010 but yet no installation has taken place. On the other hand, towards the end of 2000's, nursery test sites to help with the structural design of wave energy converters have been developed. This highlights the technical difficulties encountered in the development and deployment of reliable offshore device (Table 8).

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 technology, tidal farms have been proposed and are currently going through licensing and commissioning. The need for testing and furthering the application of the technology has in recent years seen the call for 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 from the Isle of Wight. An overview of the tidal facilities developed in Europe is presented in Figure 16 and Table 9.

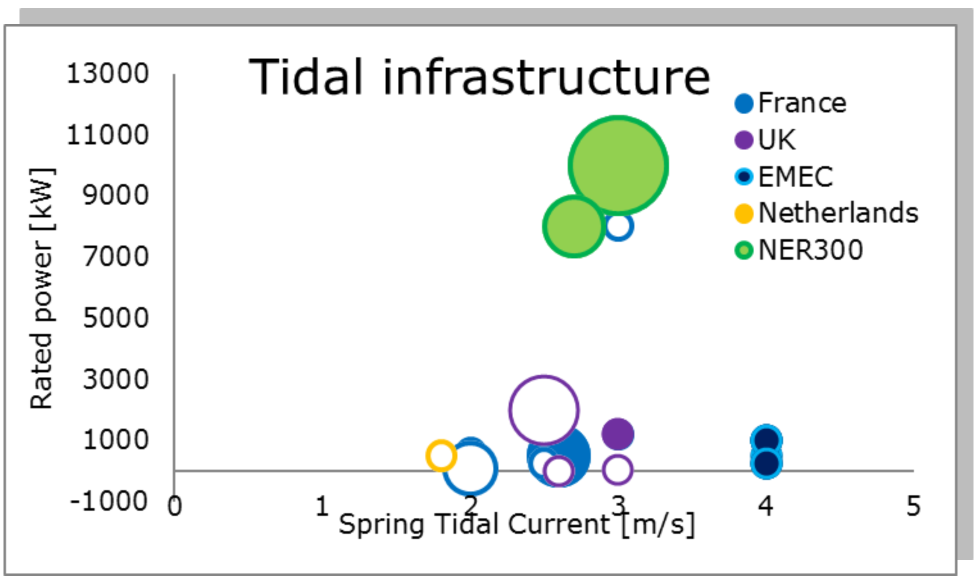


Figure 16 - Real sea demonstration facilities in Europe for tidal energy testing

Table 8 - List of tidal energy facilities and of 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	1/4 scale mono-turbine demonstrator	2013
Sanda Sound, Scotland	UK	1/4 scale twin-turbine demonstrator	2014
Strangford Lough, Ireland	UK	Pre-commercial (Testing)	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
Strangford Lough, Ireland	UK	1/4 scale demonstrator	2012
Montrose Bridge, Scotland	UK	Commercial	2015
EMEC	UK	Test Centre	2008
Kyle Rhea, 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 WaveHub and SEM-REV account respectively for a 25km and 24km of length. Critical to the laying and installation of cables is the use of specialized equipment (e.g. telecom vessels).

The cost of installation is high, ranging from € 4-20 million per MW installed, with a cost of submarine cable per kilometer which is rated at a minimum of € 0.5 million (ADEME, 2009). Typical cost of repairs is in the range of € 0.7 -1.4 millions including the cost of repair joints and spare cable (James 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 of the sector, it is likely that issues related to the development of substation and increased need for stable grid infrastructure will be considered in the future. These items have already been accounted as future bottlenecks for the sector; however, it is likely that an integrated approach and cross-industrial approach as envisaged for the offshore wind energy sector will be required to overcome such barriers. Funds made available in the UK by the Crown Estate require developers to have already in place an application for grid access[22], although issue in the development of the required grid infrastructure in Scotland have already arisen, with no expansion forecast until 2017[23]. The OES implementation of IEA has started a programme led by Tecnalia in Spain to assess the capability for grid integration and transmission for 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, however, 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, Scotish 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 harbor for maintenance. Device developers have worked in closed collaboration with vessel manufacturers in order to develop specific installation and operation vessels[24]. However, it is likely that no convergence on vessel design will be achieved 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 harbor, thus offering access to 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 not encouraged yet the development of ports aimed to serve the marine energy sector. Development in the field are already seen in Orkney, where funds for 9.5M€ were provided to expand harbour facilities due to increase of marine-energy related traffic[25]. These funds appear to be low compared to those made available for the development of wind energy adapted harbours in the UK (70M€);

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

[23] http://www.bbc.co.uk/news/uk-scotland-20816349

[24] http://www.openhydro.com/news/OpenHydroPR-010911.pdf

[25] http://www.bbc.co.uk/news/uk-scotland-scotland-business-22358818

however, they should be considered as substantial given they are direct to implement facilities in one location.

3.5.2. Nursery markets

The development of nursing markets represents potentially, the most important public support for the development of pre-commercial stage technologies. The availability of pre-facilities represents the infrastructure needed by infant projects to connect at sea and thus 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 reminded hereafter:

- the WaveHub, which offers facility for testing arrays of wave energy devices with a total capacity of 20 MW;
- the AMETS, which offers berth for the testing of WECs;
- the Pico OWC, which is operational in Portugal since the late nineties (although it has sustained periods of abandonment);
- the DanWEC -part of Hanstholm harbor[26]- which has seen the trials of wave energy projects led by WaveStar, Waveplane and Dexa .
- the Lysekil test center(Sweden), which since 2002 is actively supporting the wave power research, being able to host ten WECs, thirty biological buoys, one substation, on observation tower and one subsea power cable to shore until the end of 2013 (Lejerskog et al 2011). It is considered by 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 of the selected countries is hereafter presented within four stages:

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

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

The construction phase includes installation contractors, component manufacturers (nacelle, gravity base 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, consultancy firms.

The following section does not intend to present an exhaustive description, but rather an identification of the mix of national or international efforts committed to the demonstration and

[26] Margeritini et al 2011

implementation of marine energy projects. Additionally, it points out the extent to which the development of the sector involves traditional oil and gas companies.

Ireland

At national level, a significant support for Irish marine energy supply chain was the creation in 2012 of the SmartBay platform. Under the umbrella of a private organization, 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[27]". Further transparency and support is offered by a publicly available database offering useful information upon Irish marine energy supply chain[28] (Figure 17). Sustainable Energy Authority of Ireland points out the 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.

Figure 17 Representation of public and private entities participating in Irish supply chain

[27] http://www.smartbay.ie/AboutUs.aspx

[28]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

However, the same report[29] points out 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 OE projects. Despite significant offshore capacities that are/can be mobilized around this technology, the marine energy companies struggle hard to raise necessary capital for testing their devices (i.e. WaveBob Limited).

Denmark

First mover into the sector, Denmark presents only three marine projects (including in Faroe Island-see figure 18). The marine energy supply chain reveals opposing situations, with projects run by the mobilization of national partners (Wavestar) or projects involving international partners (Wave Dragon). The WaveDragon technology displays a mix of local and international efforts: German, Swedish and British suppliers work together for the validation of the technology[30],[31]. The international cooperation in developing the prototype WaveDragon is reflected within the history of testing: first tested at the Danish Wave energy test centre at Nissum Bredning, a multi-MW device pilot further approved, but yet not installed in Wales. Further testing for validation of the technology takes place through the participation in many European co-operation projects. Oppositely, another project developed at the Nissum centre, the Wavestar, presents a supply chain which is national dominated (Blandt, Sauer Danfoss) with a nationally testing of the prototype at Aalborg University (2004-2005, Scale: 1/40) at Nissum Bredning (2006-2010, Scale: 1/10) and at Roshage[32].

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[29] [29] 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

[30] http://www.spok.dk/consult/wavedragon_e.shtml

[31] 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

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

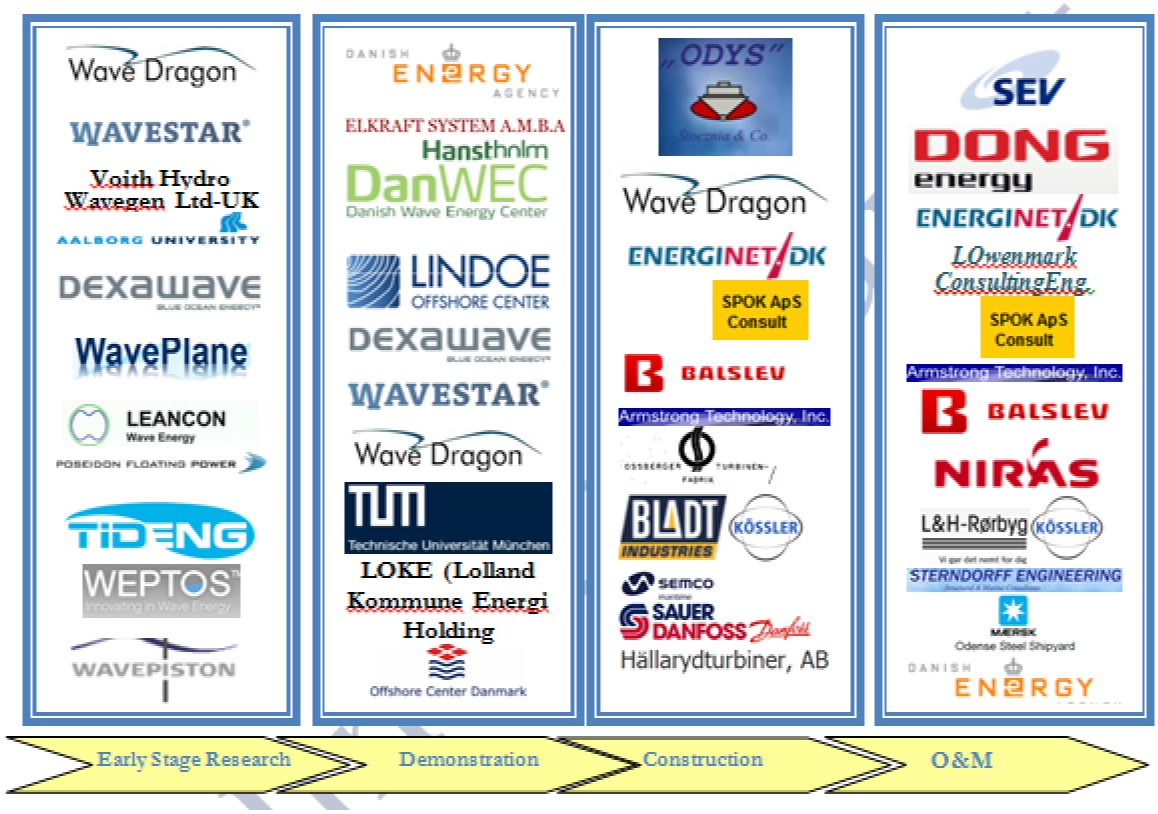

Figure 18 Representation of public and private entities participating in Danish supply chain

Nationally, both technologies enjoy the strong offshore expertise present in Denmark with further potential synergies between wind and wave energy able to ensure a sharing of the infrastructure costs as well as O&M facilities (figure 20). For example, a future collaboration of Wavestar with *Dong Energy* and *Energinet* plan the installation of a 600 kW WEC to a wind power plant (owned by Dong) at Horns Rev 2, western cost of Denmark[33].

France

Until recently only a limited number of projects was 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 developed under the national incubators or research centers (Ecole Centrale De Nantes).

33 L. Marquis , Morten Kramer, J. Kringelum, Julia Fernandez Chozas, N.E. Helstrup Introduction Of Wavestar Wave Energy Converters At The Danish Offshore Wind Power Plant Horns Rev 2http://www.icoe2012dublin.com/ICOE_2012/papers.html

Figure 19 Representation of public and private entities participating in tidal and wave French supply chain

The involvement in tidal energy technology has as key partners *Gas de France (GDF Suez)* and DCNS (Figure 19). National utility company, *Gas de France* develops two projects in locations that cover 80% of the marine current energy potential in France. One project involves the demonstration of the Canadian technology, Sabella, whose devices of 0.5 MW are planned for demonstration in winter 2013/2014 at *Fromveur Passage* (South Brittany). The total project cost is estimated to be around € 10 millions, out of which the public support of the French Environment and Energy Management Agency is around one third. GDF is also involved in another project where HyTide turbines of 3-12 MW (*Voyth Hydro,* Norway) are expected to be tested at *Raz Blanchant*. The installation and construction operations are realized in the nearby port of Cherbourg where national partners (Cofely Endel, ACE and CMN) could provide their expertise in the development of the project.

Another tidal project involves DCNS, a large group specialized in services for shipyards, naval bases, submarines and surface ships and systems and associated infrastructure. DCNS commitment to energy solutions is reflected on its investment in civil nuclear engineering and marine renewable energy (MRE), the latter reflected in acquisition of *OpenHydro*, an Irish tidal energy company. Experimentation of MRE devices[34] of 2 MW takes place at *Plateau de la Horaine* since 2011 (plan 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 mobilizes € 40 million and engages *Alstom* as a key partner in the

[34] Hauteur : 21 m, Diamètre : 16 m, evidées leur centre pour le passage de la faune. Poids avec le support : 500t,Tournent 70% du temps,vitesse moyenne 3,5tr/min

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 mobilizes research efforts of almost 20 technology

Figure 20 Representation of public and private entities participating in Norwegian supply chain

developers. Marine energy initiatives are harvested inside 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 most relevant is the initiative of Statkraft. Innovative initiatives in the Norwegian supply chain (figure 20) feature turbine blades of laminated wood planned to be used in Morild projects, funded under Renegi programme[35] and developed within initiatives of organizations such as NTNU, CFD Norway, NTI and Moelven Limtre.

Spain

Many of the partners included in the graphical representation (figure 21) refer to the project sponsored by the Spanish government, *LÍDeres en Energías Renovables* Oceánicas[36].

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[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

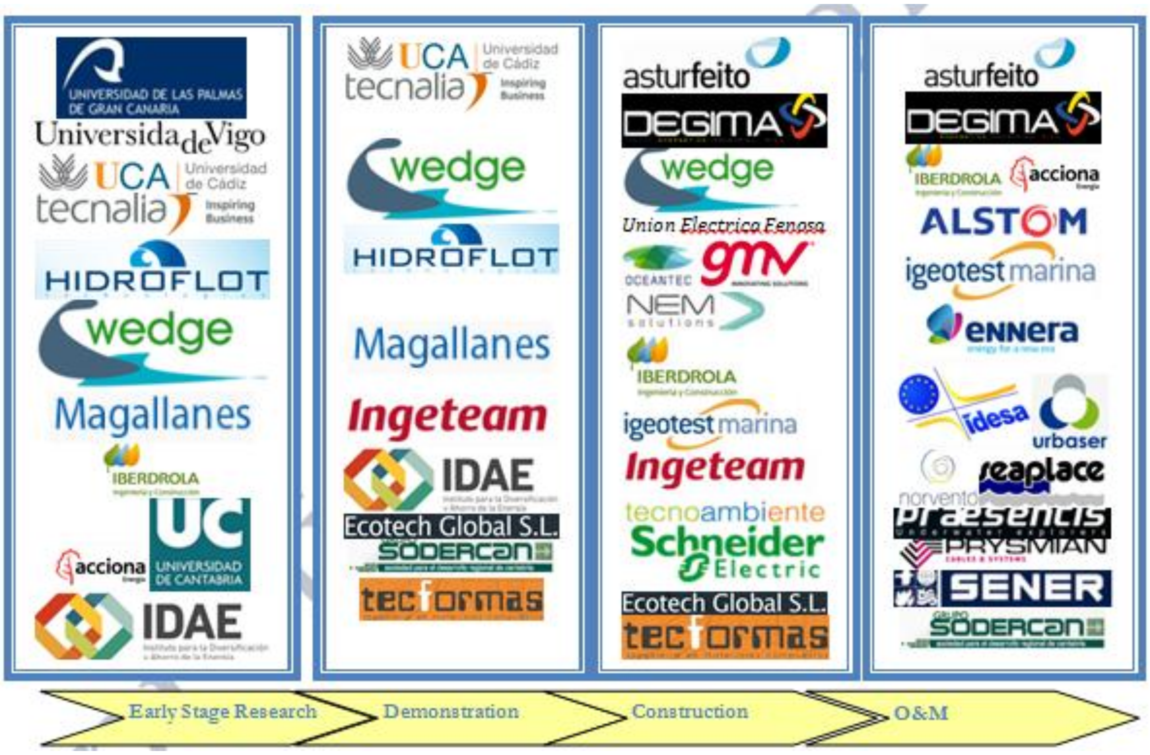

Figure 21 Representation of public and private entities participating in Spanish supply chain

Aside from the LIDER project, three small technology developers (*Hidroflot*[37], *Wedge SL* and *Magallanes Renovables*[38]) raised the interest of established marine suppliers (such as *Asturfeito*, *Sodercan*, *Ecotech Global* or *Tecformas)* in the demonstration of marine energy pilots. Small-scale demonstration is realized with the help of the expertise of research centers, public institutions, as well as private funding (i.e. Energy Equity Partners and Urbaser).

Portugal

Portugal has different ongoing projects and gathers only few technology developers. Key participants in the Portuguese marine energy supply are presented in Figure 22.

Kymaner Energetic Technologies is testing the stress in the structure under the wave climate at the southern part of Portugal (Algarve). Innovative technology is being developed by Sea For Life, able of harnessing energy from waves by making the most of the laws of gravity (Wave Energy Gravitational Absorber).

Despite its potential, few national technology developments are initiated, whereas Wavec plays a key role in developing an international network of experts in offshore energy projects (SOWFIA, Si Ocean, Atlantic PC, DT-Ocean, Equimar, Marinet).

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

[38] http://www.magallanesrenovables.com/

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

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 a wave energy industry generating € 28 billion/annum and employing up to 48,000 people. Most of the job creation in wave energy can be expected from 2030 onward with a majority of jobs within the export business (Pound et al 2011). The UK has a very rich supply chain that spans the different stages of development of the technologies; the participation of key companies is illustrated in Figure 23. The UK through EMEC and Wave Hub has seen the highest number of device developed and it is currently the leader actor in deployment, testing and retrieving 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 consenting process.

Figure 23 Overview of the UK supply chain (key players)

3.5.3. Market formation assessment

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

On the other hand, the UK, 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 mobilize in building the marine energy sector.

3.6. F6 – Mobilization of resources

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

An appropriate guidance for research and suitable public support create a conducive environment able to enhance the mobilization of financial and human resources. In 2011 the mobilization of *financial resources* for wave and tidal sector remained relatively limited: annual research investments amount to € 100 million at European level, the equivalent of less than 10% of what was invested in the mature wind energy technology. The mobilization of *human resources* is even more limited: the size of the labour pool for pre-commercial wave and tidal industry accounts for approximately 2400 people, nearly 6% of the jobs in offshore wind in 2011. An increased demand for jobs, related to the operation and maintenance services, is expected to occur with the deployment of arrays of marine energy devices.

3.6.1. Mobilization of financial resources within European countries

A global picture of the financial distribution of resources among the public and private investors is summarized in Figure 24.

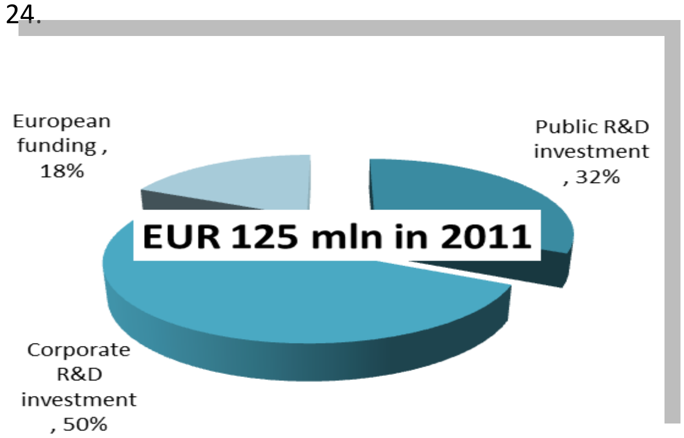

Figure 24 a Total RD&D investment in wave and tidal energy projects

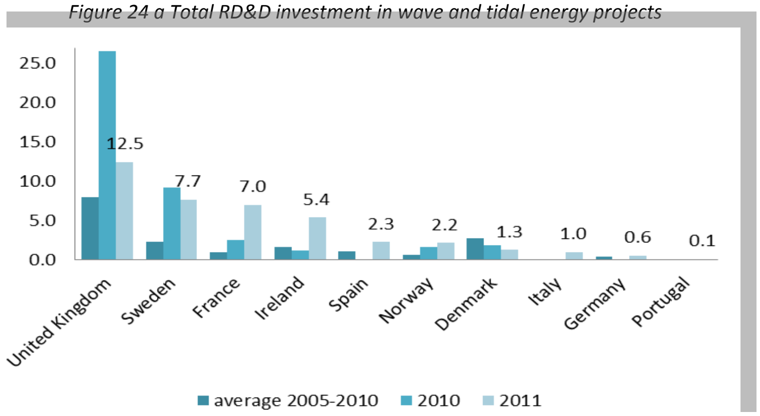

Figure 24 b The evolution of the public RD&D investment by country.

Figure 24 a and b. Total RD&D investment in wave and tidal energy projects by European country for the year 2011. The assessment of corporate investment relies on patent applications of wave and tidal developers to which was allocated an average intensity of R&D per patent of € 0.9 million. The intensity might change with future calculations.

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

The geographical distribution of corporate research is less concentrated than the public R&D investments, being mostly made in the United Kingdom (31%) and Germany (23%). Oppositely, highly concentrated in Europe, 82 % of the public R&D investments in wave and tidal are carried out by four countries: the United Kingdom, Sweden, France and Ireland (Figure 24). Reflecting an increased commitment to the development of the technology, the 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 occurs in the last three years and mirrors a mix of prior involvements (taking place in the United Kingdom and Norway), as well as new entries in the industry such as the novel projects developed in France and Sweden. For instance, the United Kingdom, among first movers in the industry, has seen a yearly increase of RD&D investments of € 3.3 million during the period 2001 to 2010 (Figure 24 b).
The Sotenas project, under development in Sweden, is encouraged by public funding (€16.11 million) as a part of the Swedish Energy Agency initiative to facilitate the demonstration and commercialization of new technologies. Table 9 presents additional national funding schemes that are introduced to support the development and demonstration of innovative, new technologies, products and processes in the areas of marine energy, such as Scottish Government Waters Fund (the UK) or Marine Energy Accelerator Grant Programme (the 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 (the UK).

Box 3 Marine Renewables Proving Fund

Funding of tidal companies **Atlantis Resources Corporation** (€ 2.21M), **Hammerfest Strom** (€ 5.12 M), **Voith Hydro** (€ 2.28 M) and Marine **Current Turbines** (€ 2.57 M) aim the amelioration of 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 Strom**.
- The drive train and control systems, design and fabrication of next generation blades including blade root interface and funding of the operation of SeaGen (1.2MW twin nacelle tidal device) by MCT.
- The design and construction of the 1MW EMEC tidal device- Voyth Hydro.

Funding of wave energy companies **Aquamarine power** (€ 5.58 M) . Pelamis (€ 5.86 M) 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 connected device by Pelamis.

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

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		

Among the different programs that are displayed 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 (Box 3). These demonstration programs are also seeking to reinforce the low private initiatives of major companies, as within the intentions of the funders was a scaling up demonstration programs 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 3). Some of the national programs are seeking to encourage pure research such as Carbon Trust Marine Energy Accelerator (in the UK). Other programs seek to encourage product development.

A description of the research priorities in marine energies for main European countries is provided in Figure 25.

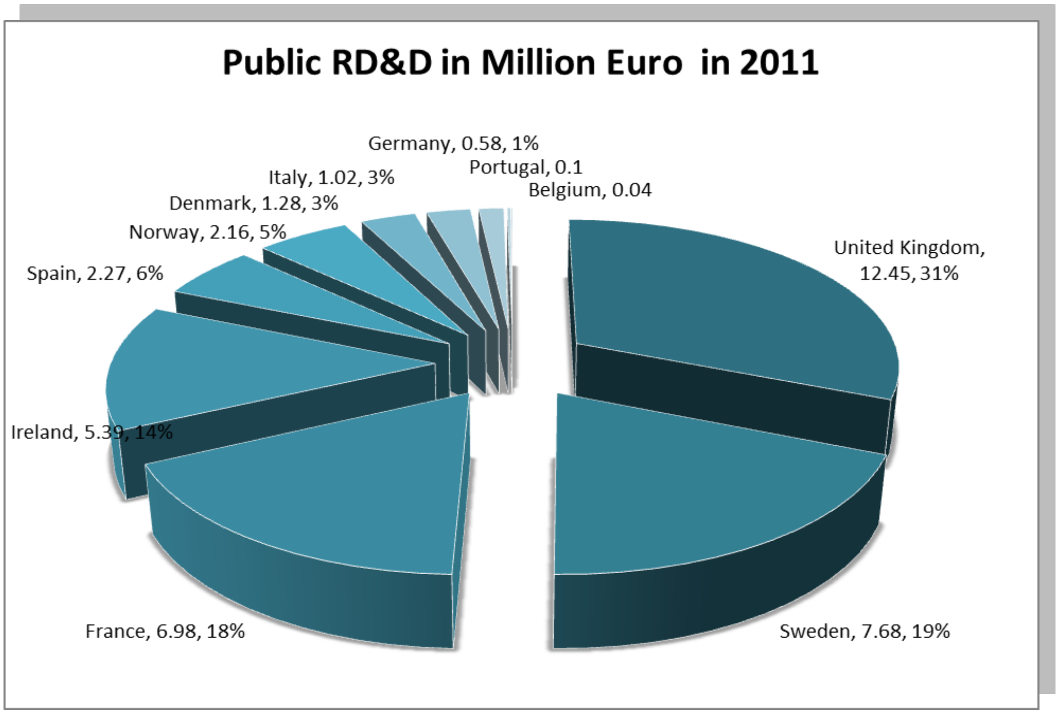

Figure 25 Public RD&D investment in millions of euro and in percentage for wave and marine energy technology across European countries in 2011

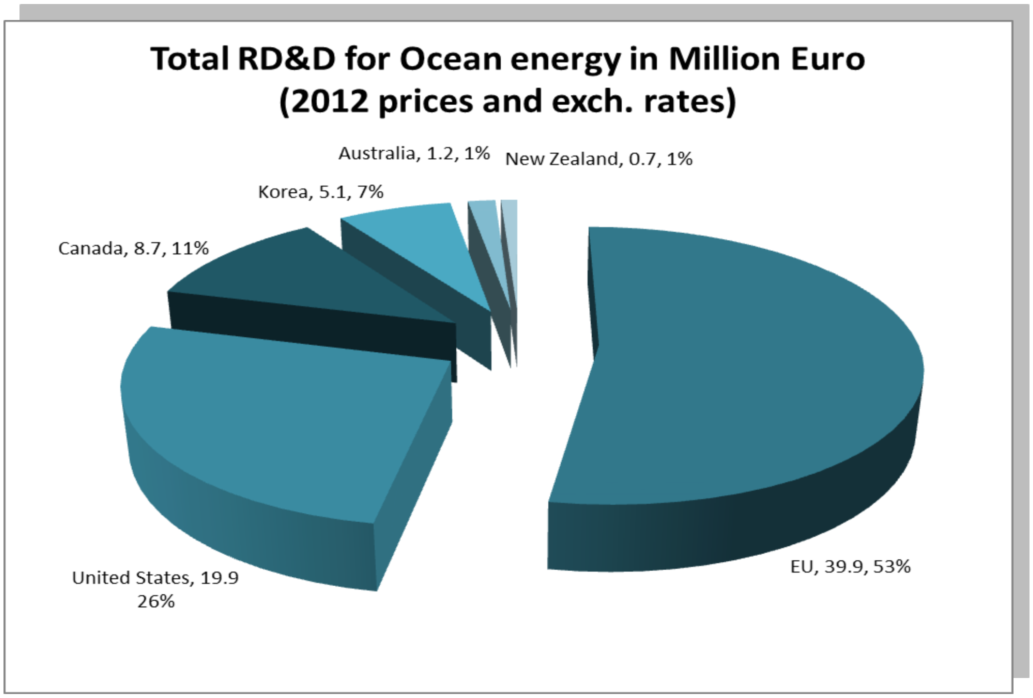

Figure 26 International comparison of public RD&D investement in marine energy technology in 2011

Total public RD&D investment in 2011 amounted to € 40 million with the United Kingdom, accounting for one third of the European investment, with most of funds devoted to fundamental research, rather than demonstration (Figure 27). In Sweden, most investments to demonstration projects (Figure 27).

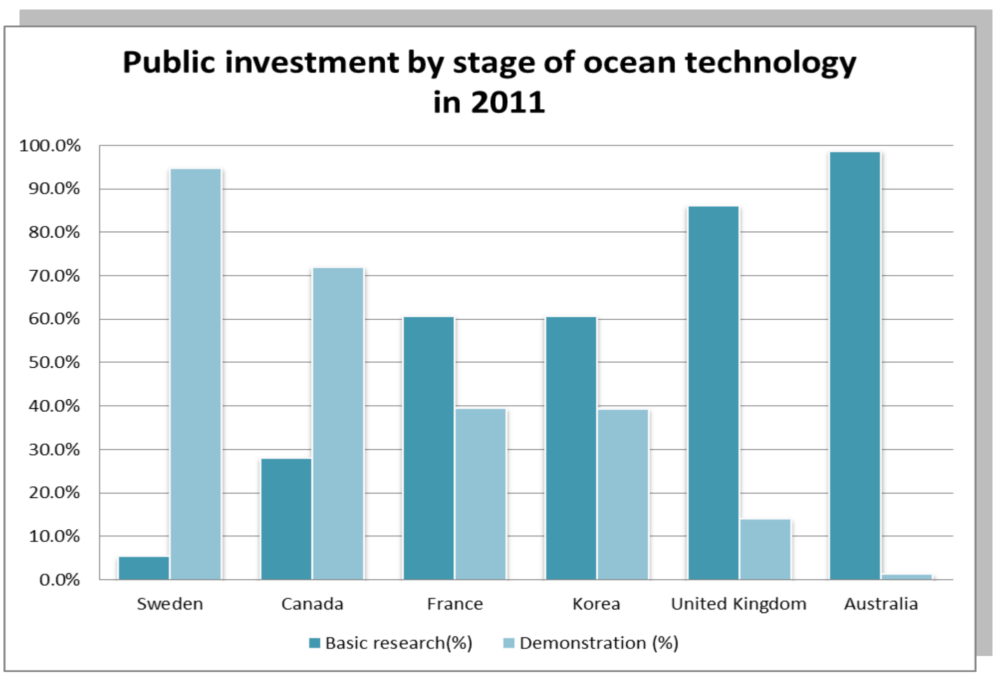

Figure 27 Intensity of basic research versus demonstration project in total R&D investment for key country investors in marine energy technology in 2011

An international comparison of public RD&D investments reveals that Europe holds 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 of 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 higher intensity of investments in demonstration projects is seen in Sweden (95%) and Canada (72%). Even though such a statement does not point out to the country which have brought the technology most closely to the market, it anticipates the potential deployment of the technology within countries: most likely, France, Korea and Sweden intensify their efforts as they possibly envisage a 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 induce. Private investment induced by public support can be examined through leverage ratios (Box 4).

Policy significance reflects the extent to which the 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 displayed in table 10, the United Kingdom and Denmark seem to exhibit seemingly leverage ratios, with one euro of public money raising 80 private eurocents. Norway also shows a higher power of raising private money, as one 1 euro spent raises 1.12 euros of private money.

Box 4 Mobilization of financial resources

Leverage can be defined as the private investment induced by national subsides to research. Additionally, the ratio should take into account that certain research projects could have been developed independent of the availability of available 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 casual impact: some of the private investment would have happened independent of the level of public intervention.

[40] We leave aside projects in which the state had assured the whole financial support

Table 10 Leverage ratios for sampled marine projects

Country	Number of projects retrieved	Funds mobilized (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

3.6.3. Mobilization of financial resources at European level

The main European bodies involved in the financing low-carbon energy technologies and hence in related RD&D activities are the European Commission, the European Investment Bank and European Bank for Reconstruction and Development. The 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).

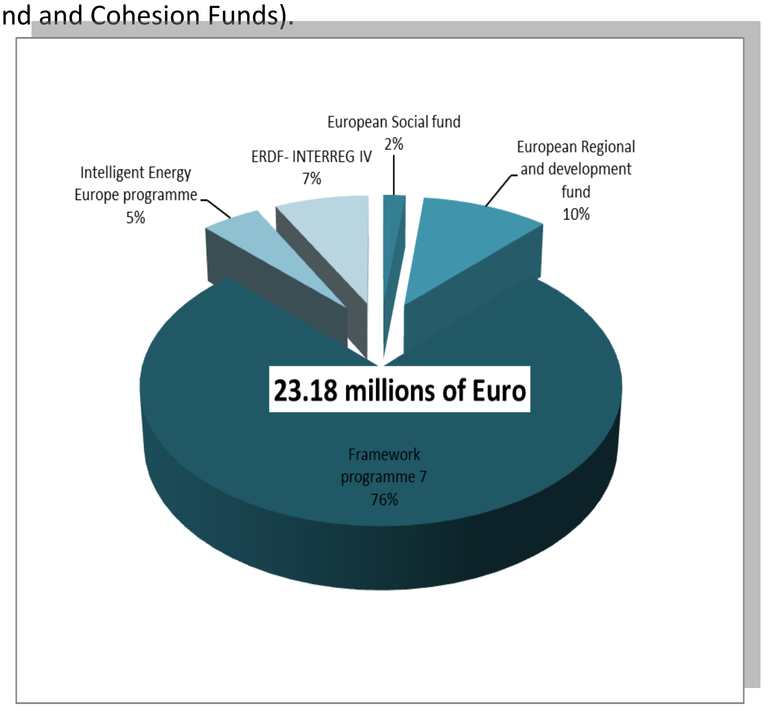

Figure 28 The European financial contribution by funding programme for the development of marine energy projects in 2011

In 2011, a relative high interest is found at the European level for the development of the technology and noticeable efforts into bring it to the market. € 23 million are allocated through European funding for marine energy technology (Figure 28). The majority was allocated through the FP7, whose level is comparable with the European R&D investments in the electricity grids.
The mobilization of resources occurring through European funding points out to a leverage ratio of 1.6 for research framework programs FP7 and regional initiatives such as ERDF. Accordingly, for every euro allocated through ERDF/FP7 funding, approximately additional 60 cents are invested by national public and private organizations into marine energy projects. Almost 70 % of European funding (figure 29) is directed towards the development of the wave and tidal energy technology. Relatively higher priority in the EU funding is given to the development of the wave energy technology (45% of total funding), which could benefit a large number countries.

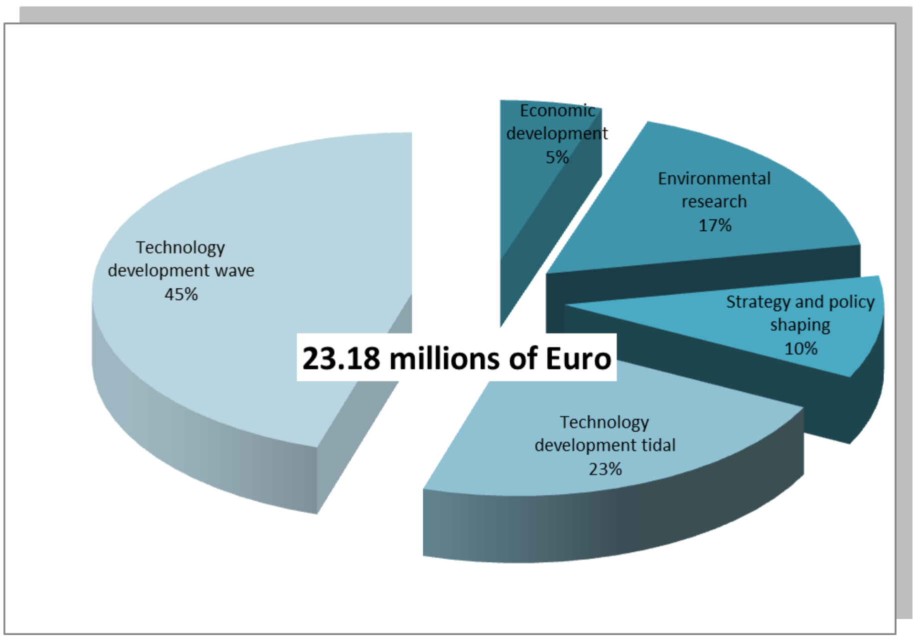

Figure 29 Research themes financed by European funding in 2011

Among the significant projects in the ***creation and diffusion of knowledge*** of wave and tidal technology, MaRINET, ties together collaborations of 28 partners spread across 11 European countries and Brazil. Significant European funding is directed towards bringing the technology closer to the market, through the Marina platform. Additionally, important potential benefits are foreseen for the harbours if the marine energy technology becomes ***commercially viable,*** such as the project *Ports adapting to change* (PATCH). The project is considered 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].

[41] "Blue Growth Final Report Scenarios and drivers for Sustainable Growth from the Oceans, Seas and Coasts", Scenarios and drivers for Sustainable Growth from the Oceans, Seas and Coasts".

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

3.6.4. Human capital and skills

The marine energy sector is expected to grow significantly over the next 20-40 years' time horizon. By 2020, the European Ocean Energy association (EU-OEA)[42] estimates 26000 direct jobs (or 40000 direct and indirect jobs), whereas by 2050, the employment in wave and tidal energy sector should be around 310000 direct jobs (or 470000 direct and indirect jobs). At a 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 out the will for the development of the industry: by 2035, 19500 jobs are expected to be created in the United Kingdom (RenewableUK), whereas 1329 jobs in Ireland[44] .

The current situation of the marine energy sector is estimated through data available on research, and private investment and presented in Table 11.

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

[43] and saved nearly 1.0 billion tonnes of CO2 emissions

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	Nb. Researchers Publishing/ Presenting WP[45]	Nb. FTE in Technology spin-offs, start-ups[46]	Approximation of direct and indirect jobs 2011[47]	Range of jobs[48]
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

Consequently, the size of human resources allocated in the sector is estimated to a range of 2000-2800 persons. One third is directly involved in basic research, working within universities or collaborating with them. This distribution also describe British marine portfolio in which 1/3 of the funding is allocated for postgraduate training in 2011. However, the UK shows a good distribution in private sector employment. Norway and Denmark are more active in the commercialization of the technology than in the knowledge creation, with potential of entrepreneurial resources 3 times bigger than the academic ones. Oppositely, Italy and Portugal feature a greater academic involvement in the development of the technology and lesser market experimentation. France succeeds to direct the venture capital initiatives into the demonstration initiatives and faster brig to market of the technology.

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

46 The number of jobs triggered by commercialization of the technology approximated using the average size of start-up /spin off companies of 1-10 employees. Some of the companies are registered on International B2B Meetings in the field of Marine Renewable Energies

47 to account also for indirect jobs in ocean energy, the number of direct FTE is multiplicated with a multiplicator (for indirect jobs) which was calculated for the case of Ireland47. 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 might change the presented information.

48 Finally, 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 that is available for the companies working within the sector. The least well represented country was Germany, for which in the commercialization activities we accounted as only Siemens with its two acquisitions in the wave and 2 new 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 other 15 companies identified as technology developers.

3.6.5. Evaluation of the mobilization of resources across countries

Spain, France and the United Kingdom have a higher labour pool than other countries and also mobilize 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 creation for innovation in marine technologies

This function refers to concerted actions aimed at developing and affirming the sector. Public acceptance for wave and tidal technology seems relatively high. The legitimation of the technology is lobbied through political and industrial networks. On one hand, the offshore wind industry has the same interest as wave and tidal industry in the reduction of the operation and maintenance costs. On the other hand, the level and the changes in the wave and energy targets express the level of risk that decision makers induce/ block in the development of marine energy industry. The long term stability of public support schemes should assure 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 needed to justify project expenditures[53]. The following exploration seeks to evaluate how strong the institutions are, or respectively how strong the lobby of the industry is, in acquiring the legitimation of the new technology.

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

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 Spain	250 100	300 600	250 100
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

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

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

1. Are the public commitments *sufficiently stable?*

Many changes have taken place from the time that governments had formulated goals for marine energy until present. These might 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 uncertain signals, investors postponed the risky investments which lead to innovation and deployment of marine technology. Such uncertain signals have also been testified to play 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 away the private investments.

2. Are the 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 of the Member states is met by 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 has little contribution to the national energy mix. Ambitious targets with respect to incipient stage of the technology development are set by the energy white papers and later in the NREAP of each of the countries. Such ambitious targets have allowed for community acceptance with a greater involvement of stakeholders and residents in the implementation of renewable energy projects. European countries do not show a stringent commitment to marine energy, whereas many are affected by different constraints such as the recent economic crisis, or the delay in reaching the bounding 2020 targets. Only few countries succeed to encourage entrepreneurial marine energy initiatives and attract investments for long term development of the technology.
Norway and Sweden are not far in their targets in their energy mix and compared to the other countries could potentially stimulate more activities targeting the development of the technology. Additionally, Ireland displays a high stability aiming not to discourage business opportunities for this sector. The evolution of support to marine electricity production could indicate how strong the public institutions are, whereas the evolution of instruments would relate also to the lobbying power of the industry.

4. Discussion and conclusion

Marine energy industry 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. Most of the European countries display a high involvement in this step of the process; certain countries with a higher intensity than others (United Kingdom, Ireland and

Norway). Following the demonstration of prototypes, operational improvements are proposed in order to increase its viability. Once the market is created and well defined, one prototype standardized process innovation could occur and, with time, also learning effects.

The passage through different phases of the technology development is associated with a specific level of risk associated with the technology or with the business. In the early stage of *Tank Testing* phase, the level of risk associated is characterized as low for both business and technology[54]. Most of the countries engage in this phase of research activities and some of them succeed even to export their knowledge such as Denmark, Ireland and Norway, whereas the environment is not under control, the *Sea Trials* assessed as high risk for technology derived from a higher of complexity of the technology related to power performance, deployment technology, survivability, manufacturing and commissioning procedures, degradation mechanisms and aspects affecting availability can be investigated[55]. In this stage, few countries besides the UK are making considerable efforts in valorizing new business opportunities, such as France, Sweden, Norway and Germany. The stage Multi-Device Arrays deals with important risks for business and lesser for the technology[56]. The NER 300 funding is tackling these risks as novel projects will be deployed in UK and Ireland.

Along these stages of technological development, additional uncertainty might be induced by unexpected variation of the 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 allow an identification of failures: technology legitimation and public guidance for support. Many countries, even though committed to the development of the offshore wind technology, do not formulate stringent and stable targets able to reinforce innovation activities for wave and tidal energy technologies.

Overall, the mobilization of financial resources for wave and tidal energy gathers only 10 % of the aggregated (public and private) investment in mature technology (wind technology). The human resources of the sector gather less than 6% of the ones of young technologies (offshore wind energy technology). Although the mobilization of resources is relatively low (comparative to other technologies), public money are effective in mobilizing funding for innovation activities in marine energy technology: one euro of national public money raises additional 80 private eurocents, whereas with one euro of European public money raise additional 60 national eurocents.

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

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APPENDIX

Appendix 1 Methodological considerations

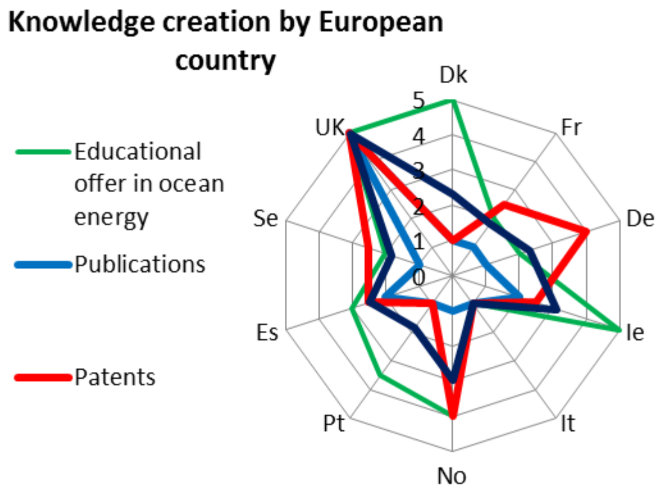
A functional approach to innovation systems (Johnson and Jacobsson, 2001; Bergek and Jacobsson, 2003; Jacobsson and Bergek, 2004) is proposed in order to analyze the formation and evolution of technological innovation systems. The innovation system is divided into 7 functions:

- 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 mobilization.
- Function 7: Legitimation

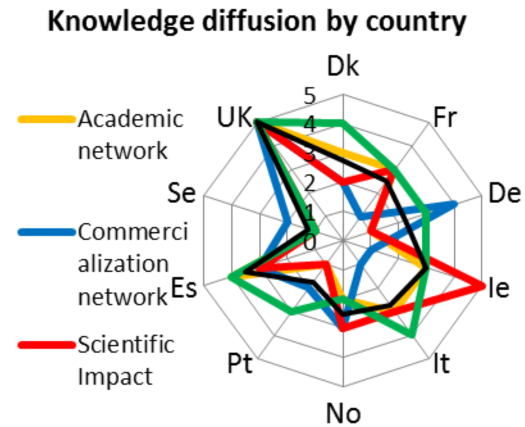
Each of the functions is evaluated through specific indicators, such as the ones described in box 1. Each indicator is divided into quintiles and each country receives an evaluation, a score from 1 to 5 based on its performances: 1- 1st quintile, 2nd –second quintile and so on. A final aggregated score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

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

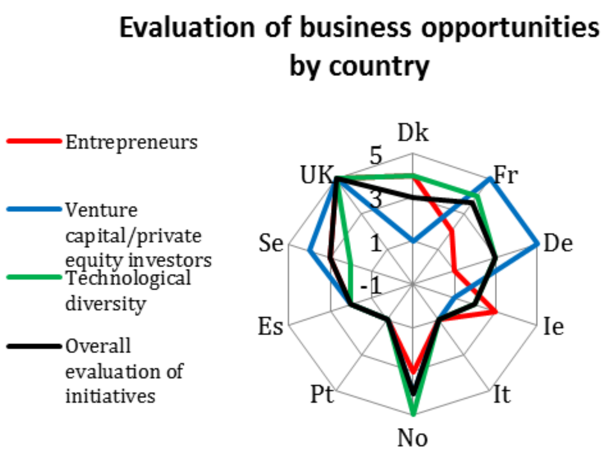
An illustration of each function of the marine energy innovation system is provided hereafter.



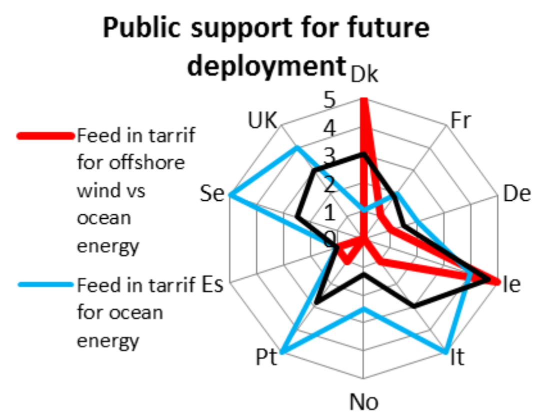
Function 1: Knowledge development



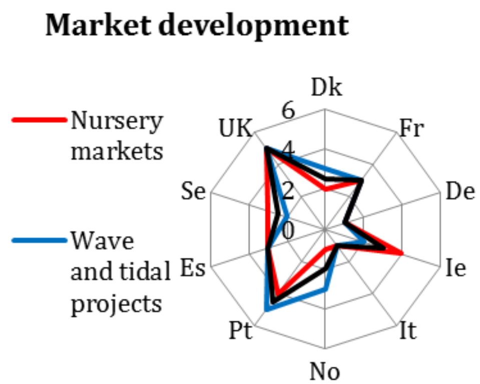
Function 2: Knowledge diffusion



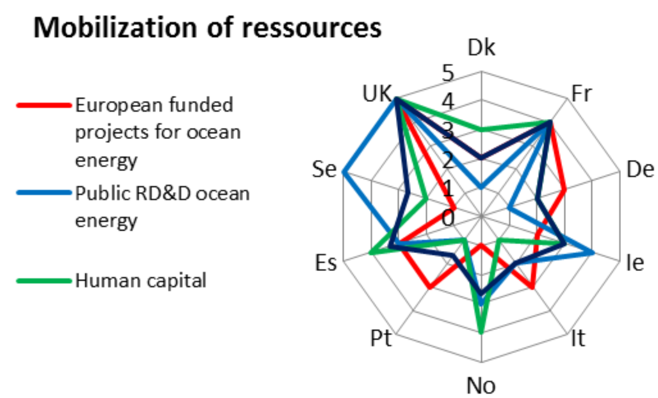
Function 3: Entrepreneurial experimentation.



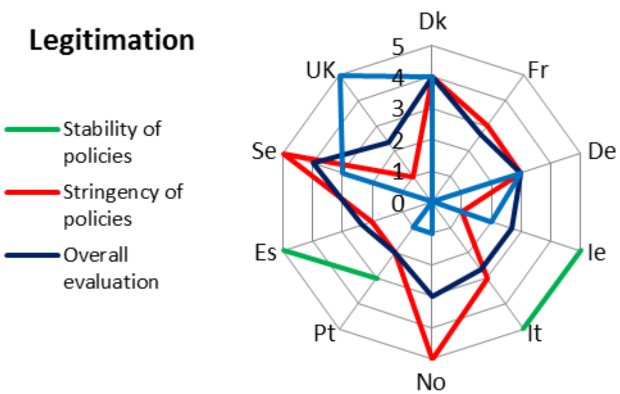
Function 4: Influence on the direction of search.



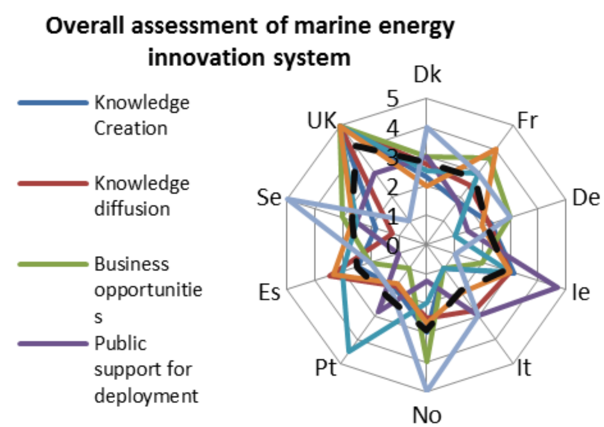
Function 5: Market formation.



Function 6: Resource mobilization.



Function 7: Legitimation



Marine energy innovation system by European country in 2011

Appendix 2 Wave and Tidal Test facilities available in Europe thorough FP7 funding.

Owner	Country	*Name of Facility*	Scale of Facility	Type of facility technology
Aaalborg Univesitet	DK	*Deep water wave basin*	Small lab	Wave
Aaalborg Univesitet	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 Energia)	ES	*Mutriku OWC plant*	Large-scale site	Cross-Cutting
EVE (Ente Vasco 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 Center	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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Abstract
This report aims at providing an overview of the research capabilities for innovation activities in marine energy within Europe in 2011. The sector features intense product innovation, embodied by development of diverse marine energy devices, which is dominant in the early stages, when the market is not yet well defined. Overall, the mobilization of financial resources for wave and tidal energy gathers only 10 % of the aggregated (public and private) investment in mature technology (wind technology). The human resources of the sector gather less than 6% of the ones mobilized by young technologies (offshore wind energy technology). Although the intensity of mobilization is relatively low, public money are effective in mobilizing funding for marine energy innovation activities. Additional constraints for technology are induced by unexpected variations in policy support for the technology and influence subsequently 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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