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Increasing synergies between institutions and technology developers: Lessons from marine energy

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HIGHLIGHTS

- Intense knowledge creation takes place in the UK and in Nordic countries.
- European research network facilitates knowledge diffusion between first and late movers.
- Business opportunities are intensified by French, German and Swedish participants.
- Public funding complements private research initiatives, especially in UK, Norway, Denmark and France.
- Policy variations induce new risks on marine energy finance.

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ABSTRACT

This paper describes innovation activities in the marine energy sector across ten European countries in 2011. *Intense knowledge creation* occurred in the UK and northern European countries, while European research networks encouraged public–private partnerships facilitating *knowledge diffusion*. An analysis based on a technological innovation system (TIS) has identified challenges for the system to evolve from one phase of development to another, i.e. from pre-development to take-off phase. In order for marine energy to pass successfully through the commercialisation 'valley of death', entrepreneurial experimentation and production is crucial. Entrepreneurial initiatives were developed mainly in the United Kingdom, Denmark, Norway and Ireland, whereas France, Germany and Sweden were active through venture capital initiatives. Additional system-builders, such as the authorities in charge of energy policies, could offer guidance for research, ensure legitimacy and effectively mobilise resources for system development. Although public support was efficient in stimulating private investment, national targets seemed less efficient in creating a long time horizon for private investors, due to consecutive, unexpected changes. In contrast, positive interactions between technology developers and policy-makers could empower *market formation*. Ultimately, the creation of a policy community, also involving local communities, could foster a positive environment for the development of innovation activities.

1. Introduction

Global resources for marine energy were estimated to have a net potential greater than that of wind and solar (32,000 GW). Additional key features make them good candidates for covering the renewable energy mix of European countries: although wave and tidal energy still face the ***intermittency*** problem, the tidal resource is ***predictable*** (Corsatea and Magagna, 2013); moreover, 'wave is more predictable than wind, and outputs are not subject to short-term swings' (Gross, 2004). Given their potential, national targets were formulated within European countries' national plans, and by 2020 the projected installed capacity (43 GW in Europe) should generate 3% of total electricity consumption (European Commission, 2014). However, these targets did not mirror immediate action plans for medium-term sector development and integration into national renewable energy mixes. In other words, public support for marine energy deployment remained unclear; conversely, public funding for research, development and demonstration activities succeeded in enhancing private initiatives in the early stages of the innovation process (Corsatea and Magagna, 2013), the latter facing suboptimal levels due to uncertainty in the market potential of the technology (Arrow, 1962).

The level of uncertainty associated with the technology and the business varies along the life cycle of marine energy technology. Low levels of risk for both business and technology are attributed

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to early-stage research (i.e., *tank testing*), whereas higher technology risks are associated with *sea trial* demonstrations, mainly deriving from power performance, deployment technology, survivability, manufacturing and commissioning procedures and degradation mechanisms (Flinn et al., 2011). In contrast, even if an entity had recently enjoyed NER 300 funding, the subsequent *multi-device arrays stage* faces significant business risks. Alongside these stages of development, additional uncertainty might be induced by unexpected variation in public support for the development of the technology. The present analysis includes an external, policy-induced risk to the technology (or business), which is measured through features of public policies, such as their stringency and stability. Accounting for the latter, the technological innovation system (TIS) approach makes explicit the relationships between innovation dynamics and policy (Bergek and Jacobsson, 2003; Hekkert et al., 2007; Bergek et al., 2008). This approach introduces two institution-related dimensions, legitimation and public guidance for research, which allow for the identification of policy-induced *failures* within marine energy innovation systems. This analysis adds to previous studies that have identified system failures that prevent successful marine energy commercialisation in the UK, despite the introduction of public incentives aimed at inducing innovation activities (Foxon et al., 2005).

Another added value of the present study relates to a framework of analysis which extends from one country – the United Kingdom – to several European countries involved in marine energy innovation activities; the present work considers countries' investments in knowledge creation, diffusion and demonstration as a proxy for their commitment to the development of the technology. Novel data on marine energy innovation activities were collected and constructed, for the latest available year (2011). The marine energy innovation system was described across ten European countries: Denmark, France, Germany, Ireland, Italy, Norway, Portugal, Spain, Sweden and the United Kingdom. Interactions between technology developers and policy makers in the early stages of the research of marine energy knowledge development and diffusion were explored. Finally, proposals were made to increase synergies between public and private activities, enabling future development of marine energy innovation systems.

The paper is structured as follows. Section 2 presents studies relevant to the present analysis. Section 3 presents the data and the methodology used to assess marine energy innovation systems. Section 4 provides an overview of the marine energy activities across the countries selected for the study, and Section 5 maps the results according to the TIS approach. Section 6 discusses the results and policy applications according to different functions of the marine energy innovation systems, and Section 7 concludes the paper.

2. Review of the literature

At country level, a variety of marine energy studies have identified both barriers and opportunities for the development of the sector (Gross, 2004; Foxon et al., 2005, Winskel et al., 2006; Vantoch-Wood and Connor, 2013; Kerr et al. 2014). Many of them acknowledged the opportunities that were created by the availability of public funding for the marine energy sector (Winskel, 2007; Jeffrey et al., 2013,). Along with opportunities, a series of difficulties were encountered for marine energy innovation. Some authors suggest that institutional and organisational inertia favours short-term market efficiency rather than long-term innovation: in such an environment the innovative entities, mainly represented by small private firms, 'operate in an investment climate intolerant of technical risk, yet which imposes high short-term expectations' (Winskel, 2007). Lack of public-sector coordination and lack of transparency were invoked as additional factors diminishing investor and stakeholder legitimacy (Vantoch-Wood and Connor, 2013). On the basis of all the difficulties identified in the process, an agenda was sketched, putting forward key topics for helping the development of the marine energy sector. First, current research should be oriented towards the investigation of economic impacts, wealth distribution and the community benefits of marine energy deployment. Secondly, new ways of enhancing communication/knowledge flows and facilitating the consultation and planning processes should be identified. Finally, ways of dealing with uncertainty should be traced, whilst taking account of public attitudes (Kerr et al., 2014).

Thus, specific proposals are needed to deal with economic difficulties, technical challenges, supply-chain bottlenecks and the complexity of the marine energy sector. However, suggestions for the development of the sector could take inspiration from the path followed by other young technologies, e.g., offshore wind. The development of the offshore wind energy system in the UK has followed a path marked by several features, such as the 'recognition of an exceptional resource and relative ease of exploitation; government commitment and policy geared to controlled growth and strategic oversight, adequate economic support and start-up investment; and growing scale, confidence and organisation on the part of the industry' (Jay, 2011). The above quotation includes key aspects of the functional innovation system approach (TIS) which could also be replicated in the marine energy sector's take-off.

A functional approach to innovation systems was previously used in the literature, with the aim of analysing the formation of TISs (Johnson and Jacobsson, 2001; Bergek and Jacobsson, 2003; Jacobsson and Bergek, 2004; Hekkert et al., 2007,). The merit of the TIS approach lies in its capacity to account for the involvement of the institutional framework in the development of the sector. The ability of environmental policies to facilitate the diffusion and technological development of renewable technologies has been extensively examined (Soderhölm and Klaassen, 2007; Johnstone et al., 2010a, 2010b; Popp et al., 2011). These studies estimated unidirectional relationships in which private research efforts respond to policy changes, leaving aside subsequent variation in public policies responding to changes in private initiatives. The circular causality could be addressed through functional analysis via the introduction of a supplementary dimension, i.e., the level of risk induced by changing policies. Decision-makers can influence the level of uncertainty of the development of the technology. For example, a government policy targeting the increased deployment of a specific technology reduces the level of risk associated with that technology (Oxera, 2011). The extent to which public policies reduce risk and induce innovation can be accounted for by a functional analysis, introducing institution-related dimensions, such as *legitimation* and *influence on the direction of research* (Johnson and Jacobsson, 2001; Bergek et al., 2006). These dimensions are used to describe how interaction between entrepreneurial initiatives and policy-makers creates opportunities or blocks the development of the innovation system. Accounting for the level of risk induced by unexpected changes in public policies, the present study evaluates the extent to which system activities are directed towards increasing the strength of inducement mechanisms, or conversely towards reducing the power of various blocking mechanisms (Johnson and Jacobsson, 2001). A functional approach was also used in identifying bottlenecks for offshore wind innovation systems (Wieczorek et al., 2013), for the development of which a systemic policy instrument is recommended, to meet the challenges in terms of infrastructure, institutional alignment and connectivity of actors. In line with previous findings on technological innovation systems (Raven, 2005;

Hekkert et al., 2007; Wieczorek et al. 2013), the authors' intuition is that coordinated interactions of public and private actors could act as a factor of success for the governance of the development stage of the technology. Increased synergies between public and private actors could make possible a stable funding horizon for risky technologies, which would in turn enhance the future development of marine innovation systems. For instance, entrepreneurs could have little capacity to build the innovation system and attract resources for research (Section 6) in the context in which they operate, in an investment climate intolerant to technical risk and within a short time horizon experiencing unexpected variation of targets (Winskel, 2007). On the other hand, in a positive environment, decision-makers and industry representatives could contribute to the formation of a policy community for renewable sources, mobilising resources around marine energies at European level. To the best of knowledge, the present analysis presents the latest data on the process of marine energy technology development. The exploration of interaction between participants in a technological innovation system could provide useful insights regarding the level of risk faced by industry and technology.

3. Material and methods

Several studies have investigated marine energy technology at one-country level, namely for the UK (Gross, 2004; Foxon et al., 2005; Vantoch-Wood and Connor, 2013; Jeffrey et al., 2013), whereas fewer assessments have presented the sector on a European scale (Corsatea and Magagna, 2013). Policy documents (SI Ocean, 2013) have considered, for evaluation, only countries formulating future national targets in their national plans (i.e., Denmark, France, Ireland, Portugal, Spain and the UK). Technology assessment studies have illustrated, in a fragmented way, developments in other countries, such as Norway and Sweden (SI Ocean, 2012). In an alternative approach, the present work has broadened the spectrum of countries, taking into account the participation of both technology developers and decision-makers in the creation of a national marine energy innovation system. Consequently, countries' efforts, both public and private, in knowledge creation and demonstration are considered as a proxy for their commitment to the development of the technology. As a result, particular attention was paid to national innovation systems in ten European countries: Denmark, France, Germany, Ireland, Italy, Norway, Portugal, Spain, Sweden and the UK. Data on the most technologically advanced marine energy technologies, wave and tidal energy technology, are considered for the latest available year, 2011.

3.1. Methodology

The analysis took a functional approach: a division of the innovation systems into functions aimed at identifying bottlenecks in the mobilisation of public and private innovation efforts at various stages in the technology life-cycle. First, a knowledge development process was described in terms of *knowledge creation* activities (*Function 1*), involving public and private actors. Further reinforced and locked in through pecuniary and non-pecuniary externalities, further sector development was illustrated by k*nowledge diffusion activities* (*Function 2*). Thirdly, marine business opportunities were reflected through *entrepreneurial* initiatives (*Function 3*), transforming the new knowledge into concrete actions (Schumpeter, 1929). However, renewable energy investments and *entrepreneurial initiatives* might be induced by a higher opportunity cost for using natural resources and by the introduction of taxes/subsidies modifying relative input prices. By encouraging firms to economise on a resource that has become more expensive, decision-makers could *influence the direction of research* and induce innovation in marine energy technology systems (*Function 4*). Because the technology is far from commercialisation, *market formation* (*Function 5*) *was reflected* through marine energy initiatives and specific protected spaces, i.e., 'nursing markets' (Ericsson and Maitland, 1989). Additional *financial mobilisation*, such as research subsidies, contributes to the development of the TIS (*Function 6*). However, the level of innovation inducement also depends on the actions of advocacy coalitions (Suchman, 1995), either represented by industry (i.e., marine energy or offshore wind) or policy-induced (Jänicke, 1997, 2005). These coalitions can create *legitimacy* (*Function 7*) and a positive environment, crucial for the development of any RES technology, which will initially be rather costly (Breukers and Wolsink, 2007).

Following the description of the system in terms of the functions enumerated above, barriers and opportunities are identified at the level of each function. Such barriers/enablers further describe the interactions among entrepreneurs, network and policies that make the development of the marine energy sector possible (see Section 6).

3.2. Data consideration

In accordance with the methodology, the data were collected in order to illustrate interactions among both public and private participants in marine energy TISs. By TIS functions, their participation provided information on barriers to innovation activities and to the future development of the sector.

Marine energy *knowledge creation* was measured in terms of scientific and working papers. The main source for scientific articles was the *ISI Web of Science* and *Science Direct*. A keyword search on relevant topics such as 'wave energy converters' and 'tidal energy' provided a first set of information for the present analysis.[1] The data were supplemented by working papers presented to the EWTEC peer review conference.[2] Working papers and publications were counted as *fractions*, meaning that the weight of the publication was 1 and if *n* countries participated, each country received 1/*n*. Co-authoring per publication allowed to gauge the intensity of inter-institutional and international collaboration. Also, the publication data made it possible to count the number of researchers active in publishing/presenting peer review papers.

The entrepreneurial initiatives accounted for the knowledge transformed into concrete projects and taking advantage of new business opportunities in the marine energy sector. The entrepreneurial initiatives of the sector included information on marine energy technology developers collected from the EMEC website, marine patent applications, marine energy conferences (Southampton, UK, 2011; Brest, France, 2013) and the Nordic green website.[3] The intensity of their commercialisation initiatives was measured by their patent applications at the World Intellectual Property Office (WIPO) and the European Patent Office (EPO – Patstat database). The use of Patstat made it possible to distinguish patent applications filed at patent offices other than those of the country of the applicant. That information made it possible to determine the volume of *knowledge transfer* between applicants'

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[1] A keyword research on relevant topics such as 'wave energy converters' and 'tidal energy' has provided a first set of information to rely on. For example, in 2011 a keyword search produced around 7 000 publications that were screened out; we finally retained only 183 documents.

[2] The working papers reflect the basic research efforts in academia at the time in 2011, while the peer-reviewed publications should reflect the research efforts in 2010 or 2009.

[3] Data is available upon request. The Nordic green website provides information on green technologies, start-ups, innovators and investors in the Nordic, Baltic and Arctic regions.

home countries and the different markets chosen for patent protection.

The amount invested by private companies in marine energy technology was computed by the method described below (Wiesenthal et al., 2012; Corsatea et al., 2014). First, it was assumed that the proportion of marine energy patents among the total patent applications of a company constitutes a proxy for its intensity in R&D expenditure.[4] Secondly, that proportion was multiplied by the overall R&D budget of the corporation; a lag structure of one year was used to take into account the delay between the point at which private research occurs and the point at which it impacts on innovation. Large companies, listed on stock exchanges, reveal their overall R&D budgets, whereas small companies could opt not to reveal their research expenditure. In order to deal with that limitation, for smaller companies, the level of R&D investment was approximated using an average R&D investment per marine energy patent,[5] previously computed for large companies that publish their overall R&D expenditure (Corsatea and Magagna, 2013).

To estimate total direct and indirect jobs in the marine energy sector, an output multiplier of 1.78 was used to account also for the number of indirect jobs[6] (Morrissey, 2010). Direct jobs included the number of active researchers and medium-sized start-ups per country. Academia had an important role in the development of the marine energy industry, as many of the marine companies were university spin-offs and start-ups; acknowledging its important role, British public funding allocated a third of its total marine portfolio to postgraduate training.[7] The number of researchers by country was estimated on the basis of the number of papers authors submitted to peer-reviewed journals and peer-reviewed conferences (EWTEC). The number of jobs triggered by the commercialisation of the technology was approximated using the average size of start-ups/spin-off companies with 1–10 employees. Finally, taking the case of Ireland as representative[8], the range of marine energy jobs was estimated across selected countries.

Apart from mobilisation of private resources, public support complemented and stimulated investment in the development of the technology. Pre-permitted infrastructures, such as marine energy centres, represented one of the most significant supports for sectoral development. Information on *wave energy centres* and the number of projects initiated was collected from the SOWFIA project and the Bloomberg energy database. Additional public financial support targeted the enhancement of R&D and/or demonstration activities. Data pertaining to national R&D funding were collected from the International Energy Agency (IEA) RD&D statistics database.[9] European financial support for R&D investment mainly reflected the contribution of the 7th Research Framework Programme (FP7–80% of total EU contribution). Other energy-related EU funding schemes were mobilised to support wave and tidal technologies (e.g., the Intelligent Energy Europe (IEE) programme). Most of the EU-funded projects were multi-annual; an annual estimate was obtained by an even division of project budgets by the number of project years. Each project execution year shares an equal amount of funds, irrespective of the start and end months of the project. Additional European support through NER 300[10] provided useful insights for future technology development. Data sources are presented in Table 1.

Certain public policies can offer guidance for research directions and offer further legitimation for the technology to develop. Such data was collected from Res-legal and Si Ocean; public support for deployment was reflected by the level of feed-in tariffs for production of electricity for marine energy sources. The data on levels and changes in marine energy targets were collected from national renewable energy plans (NREAPs), the Renewable Energy Directive relating to national targets for 2020, SOWFIA and SI Ocean.

4. European marine energy context

Marine energy could make a significant contribution to global energy needs (IEA, 2007). In view of its potential, marine energy was targeted as one of the activities that made the European Blue growth strategy possible (European Commission, 2012). Despite that potential, in the form of wave and tidal energy, the sector appeared to be at an infant stage. In 2011 the technology was still not marketable, despite the advanced levels of technology readiness (TRL) achieved by some developers. Approximately 10 MW of wave and tidal stream capacity was installed in 2012, mainly located in the UK, Spain, Sweden and Denmark (European Commission, 2014). The sector presented a scarcity of human resources, less than 6% of those mobilised by other young technologies, such as offshore wind energy (Corsatea and Magagna, 2013). In addition, the sector invested barely 10% of the amount allocated for R&D activities by the mature wind energy sector. Mobilisation of public and private resources for the marine energy sector in 2011 is presented below.

4.1. Illustration of public research activities

Reflecting a wide range of specialised knowledge relating to marine energy, 281 European knowledge institutes were involved in knowledge creation, development and commercialisation in marine energy areas in 2011 (Appendix A). The total number of British knowledge institutes was relatively large (91), three times greater than in France (31), Spain (30) and four times greater than in Ireland (22). The high level of commitment for the development of British marine initiatives was backed up to a great extent by public grants. British institutions specialise in certain fields: Plymouth University focuses on environmental studies, while the Universities of Edinburgh, Exeter and Strathclyde focus on marine engineering. Nordic countries such as Denmark, Sweden and Norway were actively involved in the testing and validation of the technology; important research initiatives were undertaken by Uppsala University, the Norwegian University of Science & Technology and the Technical University of Lisbon. The French research institutes involved in marine energy have long histories in aeronautics (Nantes) or in marine research (IFREMER, Brest). Italian participation was significant as regards environmental assessments (FP7 projects), while German research, besides its involvement in commercialisation processes (EON), also participated in technology development (University of Siegen).

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[4] Ipc class codes considered for the assessment are those recovered from WIPO green inventory E02B9/08, F03B13/12, F03B13/14, F03B13/16, F03B13/18, F03B13/20, F03B13/22, F03B13/24, F03B13/26 and F03G7/05.

[5] The assessment relies on patent applications of wave and tidal developers to which was allocated an average intensity of R&D per patent of EUR 0.9 million. The intensity might change in future calculations.

[6] 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. Source: *The Downstream Impacts of OE in Ireland*, Dr. Karyn Morrissey, Economics of Ocean & Marine Energy Workshop, 21 April 2010, HMRC, UCC, Cork, http://www.academia.edu/Download.SEMRU, NUI Galway, *Ireland's Ocean Economy*, December 2010. This SEMRU report was prepared by Karyn Morrissey, Stephen Hynes, Michael Cuddy, Cathal O'Donoghue, *The downstream impacts of OE in Ireland*.

[7] British marine portfolio of GBP 18.5 million is distributed in targeted funding (GBP 10.9 million) and in postgraduate training (GBP 6.5 million); EERA presentation.

[8] A similar calculus was performed by Morissey et al. (2010). In fact, the present calculus is inspired by their work.

[9] International Energy Agency, R&D Statistics, http://wds.iea.org/WDS/Common/Login/login.aspx, accessed June 2013. The data was supplemented where possible with national reports, as in the case of Germany.

[10] http://www.ner300.com/.

Table 1
Data sources for innovation activities by knowledge system function.

	Dimension	Indicator	Source
Technology	**Knowledge development**	*Peer review conference/published papers* *Number of patent applications of national applicants to the National patent offices*	*ISI, Science Direct, EWTEC website* *Patstat, October edition 2011*[a], *WIPO (World Intellectual Property Office)*
	Knowledge diffusion	*Number of patent applications filled at foreign Patent offices*	*Patstat applications, October edition 2011*
	Entrepreneurial initiatives	*Spin offs and start-ups*	*EMEC, Patstat, EWTEC, Thetis EMR*[b] *and Nordic green website*[c]
Public support	**Influence on direction research**	*Deployment subsidies*	*Res-legal and SI-Ocean NER 300*[d]
	Legitimation	*Wave and tidal energy targets* *Offshore wind installed capacities*	*NREAP, 2009 European directive for the national targets for 2020, SOWFIA and SI-Ocean*
	Resource mobilization	• *Public RD&D data* • *European funding* • *Wave and tidal centres*	*IEA RD&D database, Cordis-FP7, Interreg, IEE funded projects, Bloomberg, Sowfia,*
Market formation	**Market formation**	*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*
		Human resources: scientists/ companies	*EWTEC, ISI, EMEC, SEAI, Renewable UK (2011)*

[a] The assessment does not account for the patent family.
[b] http://www.thetis-emr.com.
[c] http://www.nordicgreen.net/startups/wavehydro/aqua-energy-solutions.
[d] http://www.ner300.com/.

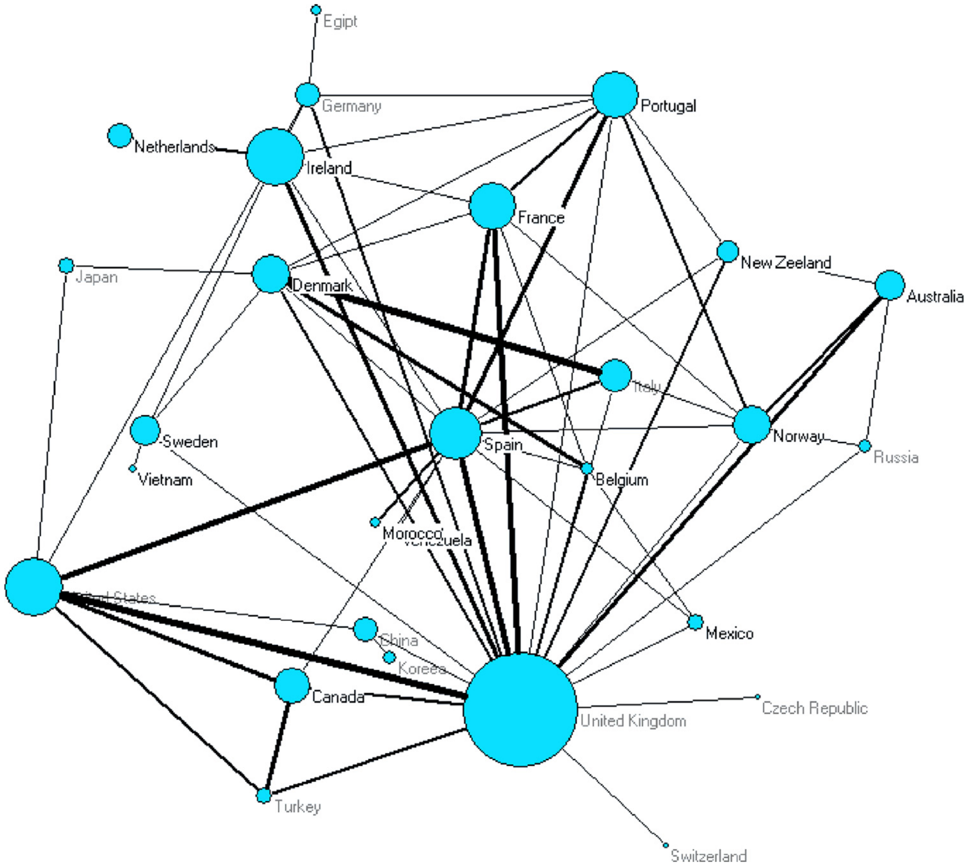

Fig. 1. Network representation of academic collaboration of organisations publishing on marine energy topics aggregated at country level. Size is adjusted for occurrence in scientific publications, width of line represent the intensity of collaboration between countries.

A cross-country exploration reflected an organisation of research activities in which first-mover countries (the UK) and late movers (Italy and Germany) presented a scattered academic network. In contrast, the Nordic countries, Ireland and Portugal concentrated research initiatives within a small number of institutions (Appendix A). Not surprisingly, scientific collaboration reflected intra-country efforts and was substantially dominated by the UK, followed by Spain, Ireland and Portugal. British academia served as a hub for international scientific collaborations with a central role in marine energy technology development (Fig. 1).

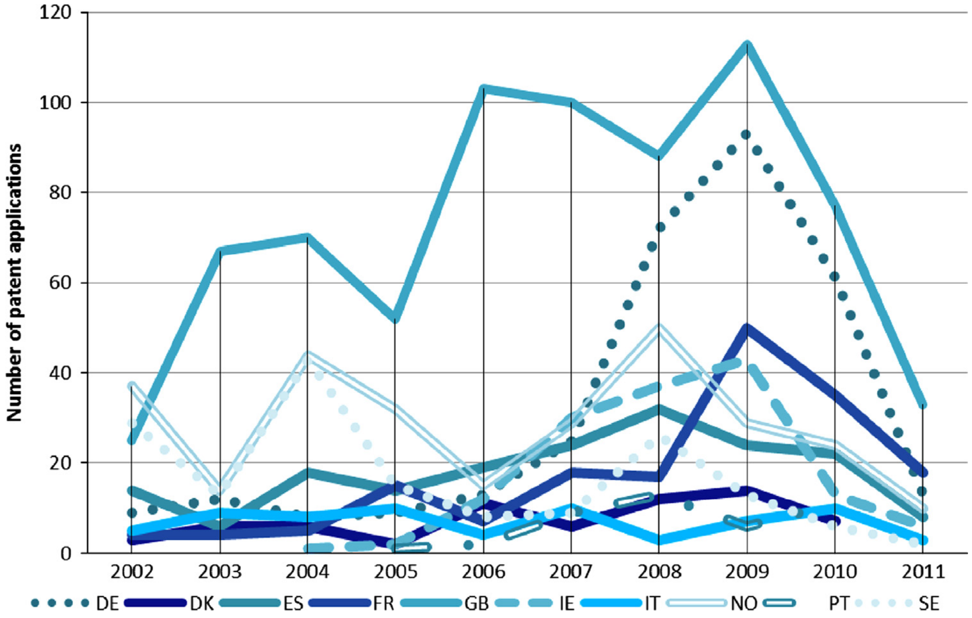

Fig. 2. Evolution of patent applications between 2002 and 2011 for wave and tidal energy technology across European Member States (Patstat database).

The scientific publishing network showed limited intra-country institutional collaboration in Norway and Denmark. These countries were extensively involved in international collaborations with countries such as Italy, Germany and France. Between Denmark and Italy, scientific interactions resulting from doctoral programmes made it possible to overcome the spatially bounded feature of knowledge diffusion.

4.2. *Private developers of marine energy technology*

In 2011, almost 33% of European marine energy developers were British, followed by Norwegian and Danish companies. France, Ireland, Spain and Sweden together accounted for almost 30% of the innovation entities. Most marine developers presented intense commercialisation activity, as measured by numbers of patent applications. Aggregated at country level, the volume of patenting activity doubled from 2001 to 2010 (Fig. 2). Countries such as France, Ireland, Spain and Sweden presented an average intensity of 15 applications from 2001 to 2011; Norway applied for almost twice that number of patents, the UK four times as many. Dominating in bulk of patent applications, the UK succeeded in mobilising the efforts of traditional wave and tidal developers (*Trident Energy Limited*, *Marine Current Turbines Limited*, *Aquamarine Power Limited*). Patenting activity by Norwegian firms decreased as a proportion of European patenting, whereas an upward trend was observed for Germany, whose patenting activity recently registered significant levels, outdone only by the UK (significant German applicants were *Robert Bosch GmbH* and *Voith Patent GmbH*). The French initiatives showed a significant increase at national level, in particular in the last few years (explained also *by Single Buoy Moorings Inc.*), whereas Ireland's share in European patent applications decreased during the period, from 20% to 6%.[11] Sweden showed research activity highly concentrated around *Seabased AB*. Spain and Portugal showed a constant level of patenting activity, with significant involvement of public organisations in knowledge-creation activities.

National markets were attractive for French and Swedish applicants. In these countries, knowledge inflow[12] was higher than knowledge transfer. In most patent applications there was a high degree of openness to international markets. Swedish technology developer, *Seabased AB*, sought intellectual property protection both within and outside the EU (i.e., United States, Korea, Canada, Mexico and Brazil). Knowledge outflow[13] was typically higher than knowledge inflows in countries such as Ireland, the UK and Norway. Companies such as *Havkraft AS* (Norway) and *Voith* (Germany) patented at the British patent office. British applicants mainly submitted their patent applications in the United States, Canada and Korea (*Isis Innovation Limited*, *Tidal Generation Limited*) or Canada and Norway (*Aquamarine Power Limited*, *C-Wave*). Three British technologies sought intellectual property protection targeting a wider commercialisation area: *Trident Energy Ltd.*,[14] *Marine Current Turbines Limited*[15] and *40 South Energy Ltd.*[16]

Summarising, six countries revealed a greater interest in the commercialisation of marine energy technology (i.e., the UK, Norway, France, Ireland, Spain and Sweden). A high level of commitment was shown by British developers and academia, whose international patent protection reflected different market niches.[17]

4.3. *Public support for the development of marine energy technology*

In 2011 the mobilisation of financial resources for wave and tidal sector remained relatively limited both in aggregate level (EUR 0.1 billion) and by source of funding (Fig. 3); corporate research investments in marine energy represented less than 10% of corporate R&D investments in wind energy.

Highly concentrated in Europe, 82% of public R&D investments in wave and tidal were carried out by four countries: the UK, Sweden, France and Ireland (Appendix B). Reflecting an increased commitment to the development of the technology, public

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[11] The country shows a concentrated distribution of patenting activities with OpenHydro Group Limited.

[12] Knowledge inflow is defined as patent filing by national and foreign applicants at national offices.

[13] Knowledge outflow is defined as patent filing by national inventors at foreign patent offices.

[14] Canada, Norway, Austria, Portugal, Brazil, Denmark, United States and Mexico.

[15] United States, Canada, China, Korea, Russia, Austria and Germany.

[16] Korea, Canada, Norway, Mexico, Slovenia and Brazil.

[17] For example, Robert Gordon University files patent applications in the United States, Austria, Germany and Denmark; the University of Strathclyde files applications in Korea, Norway and the United States, while the University of Manchester shows interest in the Canadian market.

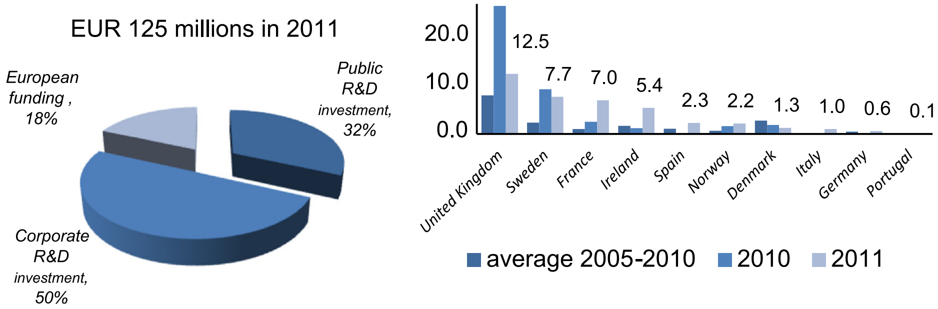

Fig. 3. Total RD&D investment in wave and tidal energy projects by European country for the year 2011. The right side chart presents the evolution of the public RD&D investment by country. The assessment of corporate investment relies on patent applications of wave and tidal developers to which was allocated an average intensity of R&D per patent of 0.9 mln of Euros. The assessment might change with future calculations.

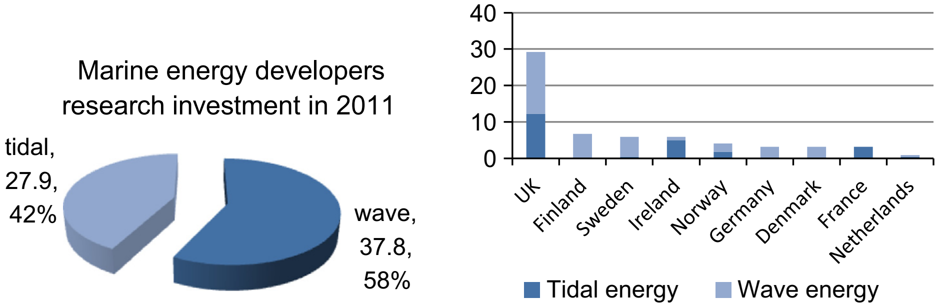

Fig. 4. Estimation of research investments (in millions of euros and in percentage) of private developers by marine energy technology and by country in 2011. The distinction between wave and tidal technologies takes into account the classification provided by the EMEC website. The assessment relies on patent applications of wave and tidal developers to which was allocated an average intensity of R&D per patent of 0.9 mln of Euros. This assessment might change with future calculations.

investment in wave- and tidal-related projects increased tenfold in ten years, from EUR 4.2 million in 2001 to EUR 40 million in 2011.[18] Most of that increase occurred in the last three years and reflected a mix of prior initiatives (mostly UK and Norway) and new projects developed in France and Sweden. Surprisingly, the latter countries allocated an important proportion of the investment to demonstration projects.

In 2011, almost 70% of European R&D investments was oriented towards the development of the marine energy technology, with higher priority given to wave technology[19] (45% of total funding). In addition, European funding gave significant priority to knowledge creation and diffusion. For example, an examination of Cordis projects revealed that certain countries (the UK, France and Spain) played central roles in the European collaboration network; although Spain participated in only half of the selected European projects, it succeeded in interacting with almost all selected countries. In addition, European collaborations reflected joint initiatives by British and French organisations focused on developing infrastructures and logistics needed for the development of the sector. Moreover, European investments contributed to creating conditions for market formation; certain projects focused on improving the quality of port management, maritime employment, improving cross-border connectivity and promoting cooperation between ports and the marine energy industry via transnational business events (Ports Adapting To Change).[20] In conclusion, European funding made a significant contribution in all the functions making up the sectoral innovation system of marine energy technology.

5. Results: mapping the marine energy innovation system across European countries

Knowledge creation and diffusion in marine energy technology exhibited fast development (*Functions 1 and 2*). Between 1998 and 2011, the number of working papers increased by 400%, while published papers increased 13-fold. Marine energy works exerted a strong influence on the scientific community, with an average of four citations per work. The content of the marine papers revealed increased efforts over recent years to get the technology ready for commercialisation. Whereas at the end of the 1990s, marine energy basic research was dedicated to improvements in air turbines, in the late 2000s significant attention was paid to the study of wave energy converters, hydrodynamic modelling and wave-converter arrays (EWTEC conference of 2007). In 2011, synergies between public and private actors were strengthened with respect to *deployment*, *maintenance*, *and mooring* for wave energy converters, and the size of the scientific teams increased to six authors per publication.

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[18] For instance, the United Kingdom, among the first movers in the industry, showed an annual average increase of EUR 3.3 million of RD&D investment in 2001-10 (Fig. 6). British government spending complements and reinforces private investment, with major infrastructure organisations (National Renewable Energy Centre, the European Marine Energy Centre, Wave Hub and QinetiQ) that endorse early technological stages such as first and next generation prototypes, up to 1 MW (Renewable UK 2010, *Channelling the Energy*: *A Way Forward for the UK Wave* & *Tidal Industry Towards 2020*, http://www.renewableuk.com/en/publications/reports.cfm/Wave-and-Tidal-Channelling-the-Energy).

[19] In the development of wave energy technology, project Marinet and Marine renewable integrated application platform succeed in gathering initiatives from all European countries.

[20] http://my-europa.eu/index.php?option=com_community&view=groups&task=viewgroup&groupid=192&Itemid=25.

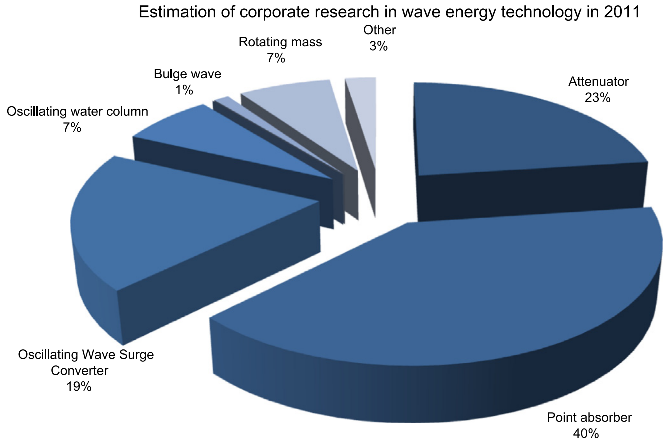

Fig. 5. Estimation of research investments (in percentage) of wave energy developers by main concepts following the classification provided by the EMEC website. The assessment relies on average patent applications of wave developers to which was allocated an average intensity of R&D per patent of 0.9 mln of Euros. This assessment might change with future calculations.

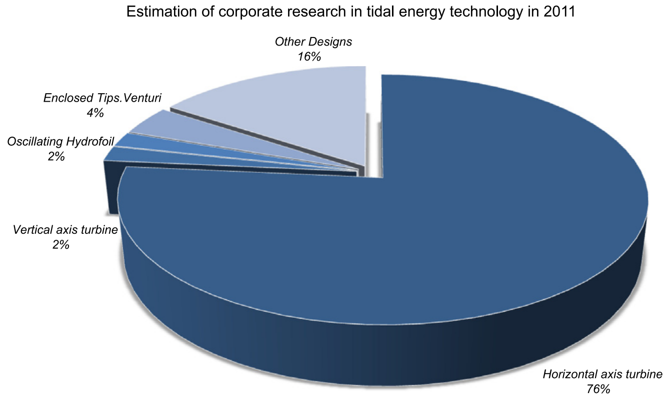

Fig. 6. Estimation of research investments (in percentage) of tidal energy developers by main concepts following the classification provided by the EMEC website. The assessment relies on patent applications of tidal developers to which was allocated an average intensity of R&D per patent of 0.9 mln of Euros. This assessment might change with future calculations.

Entrepreneurial experimentation (*Function 3*) and corporate investments were not evenly distributed across countries and technologies (Fig. 4). The UK was the only country investing comparable amounts in wave and tidal energy technologies. Finland, Sweden, Denmark and Germany reflected mostly research initiatives on wave energy devices. Among the types of devices, higher wave research investments were allocated in 2011 to the development of the *attenuator*, the *point absorber* and the *oscillating wave surge converter* (Fig. 5). The UK and Sweden invested more in the development of the *point absorber*, while the *attenuator* was mostly developed by Danish and British companies. Finland contributed to the diversification of the technology, with significant investments in the *oscillating wave surge converter* and the *rotating mass device*.

In 2011, 77% of the companies' research on tidal energy technology seemed oriented towards *horizontal axis* developments; half of that was invested in the UK and 25% in Ireland. France invested most in the horizontal axis, but also favoured research in *Enclosed Tips – Venturi.*[21] Complementing those research priorities, the development of the *oscillating hydrofoil* was mainly encouraged by the UK (Fig. 6).

To sum up, potential dominant prototypes struggled to emerge in the new market: *horizontal axis* for tidal technology, whereas wave technology mixed devices such as the *point absorber*, *attenuator* and *oscillating wave converter*. At this stage of development, diversification potentially allowed for a lowering of risks for investors investing in a portfolio of emerging technologies. To measure diversification, the Shannon index was computed[22] across different tidal and wave technologies (see Figs. 5 and 6).[23] The UK and Norway presented more diversity of concepts, whereas less fragmentation of knowledge was observed for Sweden and Spain. The technological diversification potentially allowed for a lowering of investor risk, and also increased the chances of the technology passing beyond the 'valley of death'.

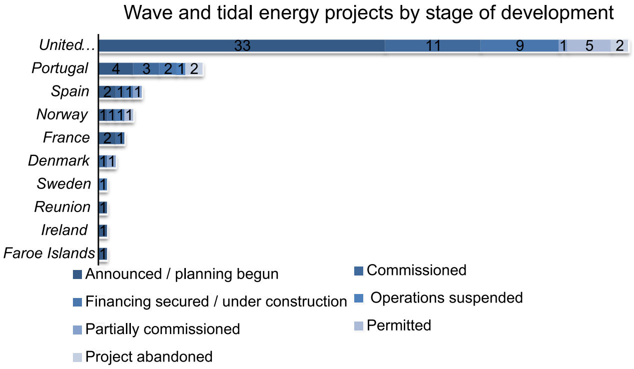

Fig. 7. Wave and tidal projects by stage of development across European Member States. Bloomberg energy database.

Market formation (*Function 5*) was publicly supported by pre-permitted infrastructures and deployment incentives, measured by the level of feed-in tariffs. The sector remained in a pre-commercial stage, with testing and demonstration of diverse concepts across European countries (Fig. 7). Of all the marine energy projects deployed in Europe, only 22% were partially/totally commissioned. Most of the successful projects were developed in the UK (12), approx. 50% of all the wave and tidal projects proposed/installed in Europe. France, Norway, Demark and Spain each accounted for one commissioned project. Portugal, Spain, Norway and France also showed commitment to developing marine energy projects; however, the majority of the projects were at early stages of development (*announced/planning begun* or *financing secured/under construction*). The cost of installation of wave and tidal farms was high, ranging from EUR 4 million to EUR 20 million per MW installed, with a cost of submarine cable per kilometre rated at a minimum of EUR 0.5 million. The typical cost of repairs was in the range of EUR 0.7 million to EUR 1.4 million, including the cost of repair joints and spare cable (Beale, 2011); the cost was higher in high-energy environments with swept, rocky and trenching seabed conditions.

The development of 'nursery markets' represented potentially the most significant public support for the development of pre-commercial-stage technologies. Such pre-permitted development facilities supplied the infrastructure needed by infant projects to connect at sea and to reduce overall marine energy project costs.

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[21] EMEC: Venturi Effect devices house the device in a duct which concentrates the tidal flow passing through the turbine. The funnel-like collecting device sits submerged in the tidal current. The flow of water can drive a turbine directly or the induced pressure differential in the system can drive an air turbine.

[22] The calculus is based on the number of developers by type of device and technology. The Shannon entropy quantifies the uncertainty associated with investments across technologies.

[23] $Shannon\_Index_i = -\sum_{i-1}^{n} p_i \ln p_i$, where p_i represents the share of investments across wave and tidal technologies.

Table 2
Approximation of direct and indirect jobs in marine energy in 2011.

Country	Jobs – National statistics	Academic researchers	Approximation of jobs generated by spin-offs, start-ups	Approximation of direct and indirect jobs 2011[a]	Range of jobs
United Kingdom	800	320	305	***800***[b]	672–928
Ireland	101 only direct FTE	54	35	***179***[c]	150–206
France	Na	63	95	***281***	236–326
Portugal	Na	47	20	***119***	99–138
Spain	Na	64	55	***212***	178–245
Norway	Na	25	120	***258***	216–299
Sweden	Na	41	50	***162***	136–187
Germany	NA	26	55[d]	***144***	120–167
Denmark	100[e] FTE	26	80	***178***	149–206
Italy	NA	39	19	***100***	84–116

[a] Future calculations might change the presented information.

[b] Renewable UK (2011).

[c] SEAI.

[d] Much of the uncertainty 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.

[e] 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.

Table 3
Leverage ratios for sampled multi-annual wave and tidal projects enjoying public funding.

Country	**Number of projects retrieved**	**Funds mobilized (millions of euro)**	**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

Large-scale wave energy conversion test sites were identified across Europe as public support for the development of the sector (Appendix C).

A limited number of initiatives was funded through NER 300, a financing instrument managed jointly by the European Commission, the European Investment Bank and Member States. The selected marine energy projects featured a NER 300 funding rate five times greater than that for projects relating to wind technology and two times greater than offshore wind projects. In total, the financed marine energy projects were aimed at installing around 24 MW, a tenfold increase with respect to the 2011 level. The ambitious initiatives were sustained by public intervention in the cases of the UK (tidal energy) and Ireland (wave energy).

The pre-commercial stage of the marine energy sector involved high costs and little employment (Function 6, mobilisation of resources). Employment in the marine energy sector represented barely 6% of all employment in the offshore wind sector (Corsatea and Magagna, 2013). In order to estimate direct jobs in 2011, the present analysis used the number of publishing researchers and the size of marine companies.

The quantity of human resources allocated in the sector was estimated to be in the range of 2000–2800 persons. One third of this pool was directly involved in basic research (Table 2), working in universities, or in consultancy groups that engage in collaborations with academia. Nordic countries, such as Norway and Denmark, were more active in the commercialisation of the technology, with potential for entrepreneurial resources three times greater than academic resources. An increase in demand for jobs relating to operation and maintenance services was expected to occur with the deployment of arrays of marine energy devices.

In the context of future deployment, the effectiveness of public funding – measured by the level of private investment that it can induce – was an important factor. Leverage ratios determined the private investment induced by national subsidies to research (Table 3). These ratios took account of the possibility that certain research projects could have been developed independently of the availability of available public money (counterfactual analysis).[24] The policy significance of these ratios illustrates the extent to which public money can be multiplied within ongoing marine energy projects.[25] As shown in Table 3, the UK and Denmark seemed to exhibit comparable ratios, with one euro of public money raising 0.8 private euros.[26]

Targeted public efforts give *guidance for research* (*Function 4*) and also focus on marine energy deployment. Instruments such as *feed-in tariffs* and *quota systems* can create opportunities for the marine renewable energy market. One can observe high

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[24] *Without counterfactual analysis*: total money (i.e., the original public 'lever' money, plus the private money induced) divided by the original lever money.*With counterfactual analysis*: 'total additional investment' (private money) divided by 'total public grant' (or grant equivalent). The second method accounts for causal impact: some of the private investment would have happened independent of the level of public intervention.

[25] Considering that the main objective of public subsidies has to do with their capacity to raise the interest of the industries and to account for additional investment, the analysis includes only projects involving non-null private contributions. Such an analysis also allows to make a comparison across countries, leaving aside projects in which the state had provided all the financial support because its priority was the technology itself rather than private co-financing.

[26] Norway and France showed a greater capacity to raise private money, albeit on the basis of a limited number of marine projects.

Table 4
Support schemes across European member states.

	Fit/FIP (c euro/kwh) – wave and tidal	Fit/FIP (€ct/kwh) – wind energy	Quota system
Denmark	5–8	1.3	
France	15	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)–1
Norway			0.049 (2013)–1
UK			0.104 (Great Britain)–0.050 (Northern Ireland) 2

1 Quota obligation per MWh of electricity sold or consumed; 2 Nb of roc/MWh.

Table 5
Evolution of wave and tidal energy 2020 targets (SOWFIA,; European Commission, 2009; SI Ocean).

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

n.a.: Not applicable.

subsidisation (FiT) of electricity produced from marine energy (Table 4). Countries such as Denmark and Portugal show a level of FiT for wave and tidal energy more than double that for other renewable energy technologies (e.g., offshore wind).

However, public support should be accompanied by the presence of strong institutions, able to enhance the legitimation of the new technology (function 6). One can see how many changes have taken place since governments initially formulated goals for wave and tidal energy (Table 5).

In light of these facts, one might imagine that the scarcity of resources might not be as challenging as finding the appropriate support for the technology to pass through the commercialisation ‘valley of death’.

6. Results and policy implications

The marine energy innovation system can be described through the TIS approach. In the process, interactions among private and public actors are explored and understood in view of their capacity to endorse the development of the system and its transition along the technological life-cycle. More precisely, TIS explores the conditions which are met along the path from the pre-development stage to take-off and acceleration phase, which finally lead to market saturation.

One can see that the first two functions of the marine energy TIS were well developed; however, those functions typically make a less critical contribution to surpass the pre-development phase for the marine energy innovation system. Most of the European countries invested in marine energy *knowledge creation* (function1). Early-stage research in marine energy technology allowed product rather than process innovation, reflected in the development of diverse wave and tidal energy devices. Dominant prototypes and a certain degree of technological convergence was observed for the tidal devices, less for wave devices (Huckerby, 2012; Si Ocean, 2014). Once knowledge was created, network interactions contributed further to the development of the sector. The publishing and patenting data demonstrated intense collaboration both in academia and in companies' initiatives. The *academic network* presented scientific collaborations, and significant contributions to knowledge diffusion (citations) were provided by British and Irish researchers; Irish works were cited more and obtained with smaller scientific interactions[27] than works involving French and Spanish co-authors. The UK was dominant in knowledge creation and diffusion and was perceived by countries entering the sector as having an important leadership role (Jeffrey et al., 2013). Italy was least productive in knowledge creation, with few publications and marine patents; however, Italian marine energy initiatives were intensified through collaboration networks (e.g., with Denmark). Countries such as Spain, Portugal and Denmark, though involved in publishing, were less involved in the patenting of marine energy technology. Ireland also patented less than France or Germany. As regards all these divided specialisations in basic research (e.g., British, Irish, and Spanish) or in applied research (e.g., France, Germany, and Sweden), the *European network*, through framework programmes, encouraged partnerships facilitating knowledge diffusion (function 2) between first and late movers in the industry (shown by Cordis data). The *European network* was able in turn to overcome the scarcity of interactions at national level between different stakeholders (Vantoch-Wood and Connor, 2013). More recently, decision-makers have also become involved in the creation of a framework enabling sharing of knowledge. At European level, the European Commission developed an action plan for enhancement of cooperation between different stakeholders, aimed at building capacity for the ocean energy sector. An Ocean Energy Forum being set up in 2014 will aim to accelerate the way to commercialisation.

Business opportunities (function 3) across countries show a landscape divided between entrepreneurs and venture capital; the UK, Denmark, Norway and Ireland had the highest number of entrepreneurial initiatives, whereas France, Germany and

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[27] Fewer co-authors per publication.

Sweden were present through several initiatives of private equity investors in companies dealing with marine energy technologies. The overall evaluation of commercialisation initiatives revealed that the UK and Norway were putting to work a large and diversified spectrum of business opportunities of marine energy technology. The greater the diversification of technologies, the greater the chance of cost reductions and successful development. Moreover, technological diversity would, by stimulating learning effects and private R&D investments, encourage new developers to enter the market (Del Río and Bleda, 2012) and favourable coalitions to be formed. The latter in turn would attract further public or private funding for marine energy technological development. For example, in France and Sweden public support was considerable and led to private initiatives, whereas in Germany the road to commercialisation seemed to be the result of diversification decisions by multi-technology companies already involved in the development of other renewable energy technologies.

Despite all these achievements, the technology has not reached commercialisation. A successful market formation (function 5) could be enacted in three phases (Bergek et al., 2008; Del Río and Bleda, 2012): creation of protected markets for emerging technologies, installment of aligned network interaction facilitated (endorsed) through public instruments, and creation of a bridging market allowing volumes of market interactions to evolve (Foxon et al., 2005). While the second and third phases still need time to realise, the first, materialised in the policy-making of the 'niche', has helped infant projects to be developed and demonstrated, through the creation of pre-permitted development facilities (Winskel, 2007). The UK and Portugal have longer experience of building public infrastructures facilitating the deployment of ocean energy devices, while France and Sweden are rapidly catching up. This public support has significantly helped private initiatives to overcome the high cost of marine energy projects. This stage is further supported by European funding seeking to get the technology closer to the market. Ambitious British and Irish initiatives are sustained by NER300 funding and aim to install ten times the 2011 marine energy capacity. Furthermore, the European Commission issued guidance in 2014 and acknowledged the need for a targeted support framework for ocean energy technologies, stressing that 'support scheme design should foster technological innovation […] for projects of first commercial scale deployment' (European Commission, 2014).

Public support for technology development and deployment needs to be investigated in additional dimensions, such as the effectiveness of public spending (function 6), guidance for research (function 4) and legitimacy for the development of the sector (function 7).

First, public funding seemed to complement private initiatives that featured suboptimal levels in the presence of uncertainty. Results indicated that, for every euro allocated through ERDF/FP7 funding, an additional 60 cents, approximately, were invested by national public and private organisations in marine energy projects. The national public money also seemed effective in mobilising funding for innovation activities in marine energy technology, as one euro of national public money raised an additional 80 private cents.

Secondly, the potentialities of publicly induced innovation as a function of deployment support, such as feed-in tariffs (Pound et al., 2011), indicated that Ireland was the country offering the highest levels of guidance for research (function 4). However, such support still needs to be developed in some countries with respect to others: countries with lower potential (Portugal and Italy) offer higher tariffs than other countries, while countries with higher natural potential (France) had not enacted specific tariffs for wave and tidal energy, but used the tariff applied for small hydroelectric plants. A change in French legislation has been promised when the technology is more mature, thus putting investors' decisions on hold. As in the case of offshore wind, such deployment support could be vital for the development of the sector (Jay, 2011; Wieczorek et al., 2012).

Thirdly, institutional ability to create legitimacy for marine energy (function 7) is less evident. One could note that countries such as Denmark and Ireland (to a lesser extent) are also committed to the development of offshore wind, and could seek interconnections capable of reducing the present cost of the offshore structures. The UK, though committed to the development of offshore wind technology, has not formulated stringent and stable targets able to reinforce innovation activities for wave and tidal (Table 5). This in turn could introduce further uncertainty in the investment decisions of marine energy developers. In the presence of uncertain signals, investors could postpone the kind of risky investments that would lead to innovation (Johnstone et al., 2010a). In a risky environment, a subsequent consequence was the need for government programmes supporting technology development (Bergek et al., 2008). Besides not being stable, most targets for wave and tidal energy were not binding. The real constraint for each of the Member States is met by the level of electricity produced from renewable sources: the increase in the share of renewables in a decade for certain countries such as the UK, Ireland, France or Italy must be of the order of several times in order to meet the RES target (Corsatea and Magagna, 2013). Most likely a portfolio of strategic energy technologies (including wave and tidal energy) was needed to achieve the targets. However, these targets exerted little *stringency* in creating opportunities for marine energy developers. Finally, the formulation of national targets and sensitivity to them could have led to rather hesitant sector advancement.

To sum up, marine energy has not passed beyond the 'valley of death'. In order for the system to take off, entrepreneurial experimentation and production is crucial; in this phase entrepreneurial capacities are mobilised to build the new technological system (Wieczorek et al., 2012). System builders are also the authorities in charge of energy policies which could offer guidance for research (function 4), ensure legitimacy (function 6) and effectively mobilise resources for system development. In the absence of coordinated plans and given poor connectivity between industry and decision-makers, a blocking mechanism for the marine renewable energy innovation system might emerge (Del Río and Bleda, 2012). Anticipating the risk of a lack of coordinated action, the European strategy focuses on stimulating interaction in order to accumulate a critical mass of actors able to formulate solutions in a bottom-up manner (European Commission, 2014). Two-way communication between stakeholders and decision-makers was encouraged, with exchanges that could ensure that social legitimacy and marine project credibility develop on the basis of stakeholder perceptions and perspectives (Thomson and Boutilier, 2011; Kerr et al., 2014).

In addition to the two main parties involved in the process, the technology developers and decision-makers, a third party was recently invoked as a part of the development of the sector, namely the local community. Working together, the industry community and decision-makers could contribute to the formation of a policy community, mobilising resources around marine energies at national and local levels (Breukers and Wolsink, 2007). Public attitudes and community commitment could play an important role for the 'industry-in-the-making' (Kerr et al., 2014). Although 77% of the UK population was in favour of marine energies (DECC, 2013), the actual deployment of the devices triggered both local community pride (Bailey et al., 2011) and concerns about environmental impacts, consultation processes and community benefits (Devine-Wright, 2011; Voke et al., 2013). In order to facilitate large-scale implementation of these technologies, other studies have advocated cooperation between ecologists, industry specialists and government bodies (Miller et al., 2013). To sum up, virtuous synergies among various members of the policy-making community cannot develop without effective public policies, which in turn are determined by public acceptance of the technology (Corsatea and Dalmazzone 2012).

7. Conclusions

The present work presents European countries' participation in knowledge creation, diffusion and demonstration in marine energy technology in 2011. Alongside these system activities, barriers to innovation activities are identified and proposals for removal of factors that hamper the system are offered.

First, an intense process of knowledge creation was identified in the UK, Ireland and in the Nordic countries. Other countries' limited investments in knowledge creation could be overcome by intensification of the knowledge diffusion function. In this respect, the European research network, through FP7 funding, encouraged public–private partnerships able to facilitate knowledge diffusion between early and late movers in the industry.

Numerous and diverse product innovations were identified in the UK and Norway, but also an intensification of preoccupation with getting the technology closer to the market. Awareness of these facts enabled policymakers to refine the design of policies and support in such a way as to more effectively pursue the desired level of technological innovation. Accordingly, in helping to reduce the high cost of marine energy technology, 'nursery markets' were created to provide opportunities for the infant industry to develop. For example, publicly supported centres provided the infrastructure needed for the successful demonstration of marine devices. The UK has a longer tradition in this respect; however, recently ambitious projects have been developed and receive public support (France and Sweden), or greater involvement of multi-technology companies (Germany). European funding has also been directed at accelerating the commercialisation process and financing further wave and tidal arrays initiated by the UK and Ireland.

Finally, public support is crucial for early-stage research on marine energy technology: public support was efficient in stimulating private investment in the research sector, when measured by leverage ratios. However, national targets seemed less efficient at creating a long time horizon for private investors, due to consecutive, unexpected variations. An analysis of the stringency and stability of national policies showed them to be weak when it came to creating a positive environment for innovation activities in the marine energy sector. In the presence of uncertain signals, marine energy technology development needs more public support, as more uncertainty in markets could divert private investment. Marine energy technology still faces significant cost constraints, and, in order to overcome this problem, stable mobilisation/allocation of resources is needed for the further development of marine energy.

While the top-down formulation of targets has thus far facilitated hesitant progress in the sector, an alternative approach involving intermediate levels of decision-making could enhance synergies among participants. Thus, the creation of a policy community involving technology developers and marine industry could foster a positive environment for the development of innovation activities.

Moreover, an evaluation of the marine energy sector taking countries' non-binding national targets as its point of departure limits the assessment of potentialities that exist in the countries that did not reveal them explicitly as an option for their energy mix (e.g. Norway). Alternatively, tighter synergies between authorities in charge of energy policies, researchers and technology developers could foster market acceptance of the technology and thus be an effective element of the innovation inducing mechanism.

Disclaimer

The views expressed in this paper are purely those of the writer and may not in any circumstances be regarded as stating an official position of the European Commission.

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Appendix A

See Table A1.

Table A1
Number of knowledge institutes and scientific publications on marine wave and tidal (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	Electricity Division, Uppsala University (7, 50%) Chalmers University of Technology (2, 14%)

* The publications are accounted as fractions.

Appendix B

See Fig. B1.

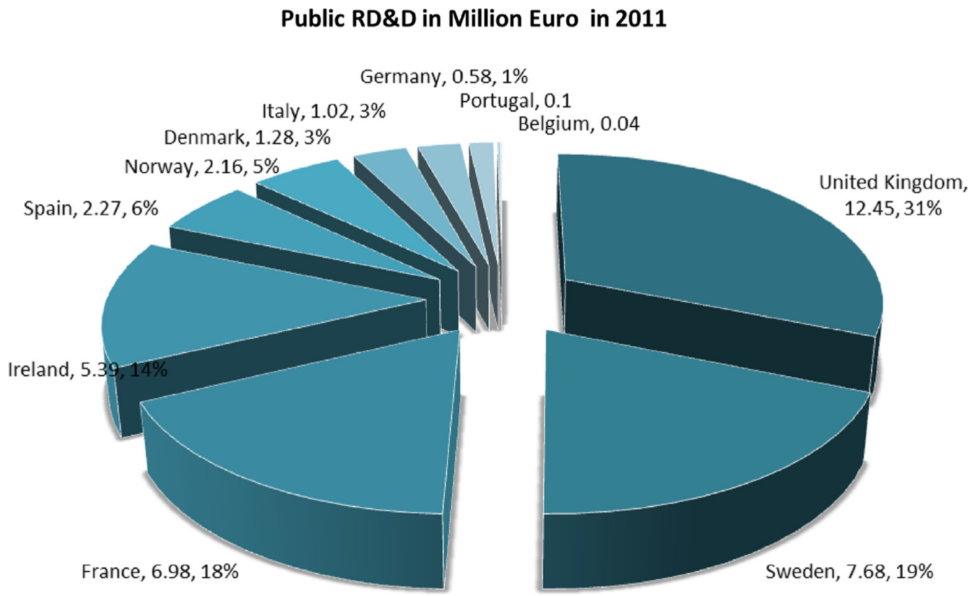

Fig. B1. Public RD&D investment in millions of Euro and in percentage for wave and marine energy technology across European countries in 2011.

Appendix C

See Table C1.

Table C1
List of sites and organisations from which information on impact assessment activities have been collected. main source of the data: Greaves et al., 2011; http://www.scotland.gov.uk/Publications/2013/09/5811/9.

Site name	Location	Founded	Test site characteristics/events	Organisation facilitating measurements – SOWFIA
Helligsø[a],	Denmark	2003[b]	✓ Single wave device testing berth ✓ 30 wave energy devices have been tested in scale 1:10–1:4.	
SEM-REV[c]	France	2010	✓ 2.5 mva power cable connected to the national grid through an onshore substation. ✓ 2 wave buoys and a matrix of current profilers provides continuous wave climate information. ✓ 15 km off the town of Le Croisic at 35 metres depth of water.	Ecole Centrale de Nantes
Reunion	France	2011	✓ Stage 1: manufacture, deployment and operation of a single, autonomous CETO 4 unit. ✓ French public funding $5 million[d]. ✓ Stage 2: grid connected 2 MW array; Stage 3: 15 MW grid connected	SAS SEAWATT
Atlantic Marine Energy Test Site	Ireland		✓ Testing of pre-commercial devices. ✓ Grid connected for wave energy converters.	Sustainable Energy Authority Ireland & Irish Marine Institute
Galway Bay	Ireland	2005	✓ Two device berths within test area. ✓ 37 hectares, mean water depth of 23 m and tidal range – 4 m.	Sustainable Energy Authority Ireland & Irish Marine Institute
Belmullet, Co. Mayo Ireland	Ireland	2013–2014	✓ 10 MW export capability. ✓ Two 10kv cables, two separate off-shore test areas, 1x 50m water depth, 1x 100m water depth.	
Runde	Norway	2004		Runde Environmental centre (REC)
European OWC Wave Power Plant (Pico)	Azores, Portugal	1990–2008	✓ Two complete air ducts and equipment sets (used by FP7 Marinet project), and two bell mouth sets are pre-installed	WavEC
Pilot Zone	Portugal	2008–2010[e]	✓ Total capacity 80 MW (medium voltage). ✓ 250 MW (high voltage). ✓ Demonstration, up to 4 MW; pre-commercial, up to 20 MW.	WavEC

Table C1 (*continued*)

Site name	Location	Founded	Test site characteristics/events	Organisation facilitating measurements – SOWFIA
			✓ Water depths: 30–90 m; distance to coastline: 5–8 km	
WaveRoller Peniche[f]	Portugal	2007	✓ 2007, 2008//Waveroller No 1 and No 2 proto device in Peniche, Portugal. ✓ 2009 // Bench testing for active controlled PTO. ✓ 2010 // Site development services. ✓ 2012//Deployment of the first grid connected WaveRoller Power Plant in Peniche, Portugal.	WavEC
EMEC Test Site, Orkney	Scotland	2003	✓ 14 full-scale grid-connected test berths and two scale test sites.	European Wave Energy Centre & Scottish Power Renewables
Islay	Scotland	2011	✓ Demonstration Tidal Array in the Sound of Islay [g].	Scottish Association of Marine Science (SAMS)
Khyle Rhea	Scotland			Scottish Association of Marine Science (SAMS)
BIMEP[h]	Spain		✓ High energy potential (21 kW/m). ✓ Water depth between 50–90 m. ✓ Closest point to land: 1 km. ✓ Power connexion units of 13 kV and 5 MW. Overall power: 20 MW.	Ente Vasco de la Energía
Lysekil	Sweden	2002	✓ 10 WECs, thirty biological buoys, one substation, an observation tower placed on a skerry (Klammerskär) and one subsea power cable[i].	University of Uppsala
Sotenas[j]	Sweden	2011	✓ Stage 1: 1 MW total installed power, aiming to expand to 10 MW.	Seabased Industry AB
WaveHub	UK	2010	✓ Four separate berths are available to lease, each with a capacity of 4–5 MW; connexion to UK's grid network via a 25 km subsea cable operating at 11 kV.	University of Plymouth, University of Exeter & WaveHub

[a] http://www.scotland.gov.uk/Publications/2013/09/5811/9.

[b] http://vbn.aau.dk/files/57371143/Wave_Dragon_Development_History_and_Results_Achieved, wave dragon tested in 2003.

[c] Mouslim et al. (2011).

[d] http://www.carnegiewave.com/files/reports/2011/07_Project_Pipeline.pdf.

[e] http://www.wavec.org/content/files/Portuguese_pilotzone_2009.pdf.

[f] http://www.wavec.org/content/files/Sessao_I_2_Erkki_Kasanen.pdf.

[g] http://www.scottishpowerrenewables.com/pages/sound_of_islay.asp.

[h] Ricci et al. (2011).

[i] Lejerskog et al. (2011).

[j] Melo, A.B., Sweeney, E., Villate JL., Global Review of Recent Ocean Energy Activities, www.dialytics.com/sitebuildercontent/sitebuilderfiles/melo_mts_2013.pdf.

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