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A strategic policy framework for promoting the marine energy sector in Spain

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Marine renewable energy (MRE), which includes wave, tidal, and offshore wind energy, has the potential to make significant contributions towards a sustainable energy future in a number of countries worldwide. One such country is Spain, where MREs are among the largest renewable resources; yet they are not playing their full part in the national energy mix. Among other constraints, the lack of a specific policy framework promoting this emerging sector is often pointed to as the main barrier for MRE grid penetration. This paper assesses the Spanish MRE sector, in terms of resource availability, government plans, policy regulations, and projects undertaken, with a view to establish a comparison with the situation in other European countries. In particular, the United Kingdom is used as a case study to analyze ongoing research activities, pilot projects, and lessons learned. As a result, it is found that public funding needs to be increased; the economic crisis should be seen as an opportunity for job creation and industrial development rather than a barrier; administrative procedures must be simplified and cross-national cooperation should be increased. Policies focused on these aspects may contribute to boost the MRE sector in Spain. © *2015 AIP Publishing LLC*.

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I. INTRODUCTION

The worldwide demand for electricity has been growing considerably during the last decades. In response to this, most countries now recognize the need to incorporate renewable energy resources as an alternative to fossil fuels within their energy policy, so that they can achieve future energy security and mitigate the effects of climate change (Ghezloun *et al.*, 2014). The need for increasing the share of renewable energies to the total energy production has resulted in a growing interest on marine renewable energy (MRE), which include offshore wind, wave, and tidal energy (Pelc and Fujita, 2002). Yet not fully-fledged renewables, it is generally agreed that MREs could meet total worldwide electricity demand many times over (Magagna and Uihlein, 2015). So far, it is anticipated that more than 10% of electricity could be generated from marine renewable sources by 2020. Despite this promising prediction, the MRE sector has not been able to realize its full potential in a number of countries worldwide. One of such countries is Spain where MREs are among the largest renewable resources; yet they are not playing their full part in the national energy mix (IDAE, 2011).

Several barriers to MRE grid penetration could be mentioned, but the lack of appropriate policy and regulatory frameworks has been long claimed as being among the most significant issues (Jeffrey *et al.*, 2014). Indeed, past experiences have proven that government policy makers influence significantly the accomplishment or approach vis-à-vis renewable energy

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(Goldemberg *et al.*, 2014). The wind energy policy in Spain constitutes a great example (Sáenz de Miera *et al.*, 2008). Thanks to the support at a public level, by means of a detailed renewable energy plan (updated in 2010, see IDAE, 2011), a long-term subsidization framework for renewable energies (throughout feed-in tariffs (FIT)), and growth rates of wind-installed power during the last decade in this country have been significant. In the 1998–2005 period, wind capacity has grown annually at an average rate of 42% (Sáenz de Miera *et al.*, 2008). In contrast, the lack of administrative procedures and specific policies (among others) is weighing on potential inversions in the MRE sector, which in turn is considerably less developed (Leete *et al.*, 2013 and Verbruggen *et al.*, 2010).

This paper explores the MRE sector in Spain, in terms of potentials of use (resource availability), government plans, policy regulations, and undertaken projects. This situation is then compared with the emerging MRE policy in Europe, with a special focus on the United Kingdom (UK)—one of the leading European countries in MRE development (Jeffrey *et al.*, 2014). In particular, ongoing research activities, pilot projects, and lessons learned from the UK policy are analyzed, with a view to suggest policy measures that could contribute to boost the marine energies in Spain.

A. Marine renewable energies: Overview

Marine renewable energy in the context of this paper includes wave, tidal stream, and offshore wind energy technologies, which are briefly explained below.

Offshore wind energy harnesses the power of winds that are found over the oceans, which are strong and consistent (Veigas and Iglesias, 2013; Veigas *et al.*, 2014; and Veigas and Iglesias, 2014). It is based on the same conceptual design and working principle as onshore wind energy, i.e., it aims to capture the kinetic energy of natural wind movements through turbines with a view to transform it into electricity (Pérez-Collazo *et al.*, 2015). The theoretical amount of kinetic energy in the wind that is available for conversion is related to the cube of the velocity of the winds. Notwithstanding, it has to be taken into account that wind turbines do not convert all the available energy into electric power, but a fraction of the available energy (between 40% and 50%) (Ellabban *et al.*, 2014). From 1970 to 1980, a variety of onshore wind turbine configurations were investigated with a view to maximize energy capture and minimize the cost. As a result, two types of designs were proposed, namely, horizontal and vertical axis designs. Gradually, the horizontal axis design came to dominate and it has been also adopted for offshore wind energy (Fig. 1(a)) (Siemens Ltd.). The main motivations for developing offshore wind energy instead of onshore wind energy are the following: the better quality of wind resources in the sea, where the winds are stronger and thus more energetic; and the availability of more free areas, where bigger turbines and larger wind farms can be installed (Bilgili *et al.*, 2011; Ellabban *et al.*, 2014; and Esteban *et al.*, 2011).

Wave energy is related to wind energy, since ocean waves are generated by the force of the winds over the ocean surface (Iglesias and Carballo, 2009; Iglesias *et al.*, 2009; and Iglesias and Carballo, 2010b). Once created, waves can travel large distances with little energy loss (Carballo and Iglesias, 2012; Carballo *et al.*, 2014; and Carballo *et al.*, 2015). As opposed to wind energy, it is expected that different principles of wave energy conversion—oscillating water column (OWC), overtopping (Buccino *et al.*, 2012) such as the WaveDragon (WaveDragon Ltd.) (Fig. 1(b)), etc.—will be utilised at various locations (shoreline, near-shore, offshore) to take advantage of the variability of the resource (Carballo *et al.*, 2015), which has been globally estimated at 10 TW. In particular, the wave power resource in the European coastline was found to range from 1 GW (in Sweden) to 120 GW (in the UK). On the Mediterranean side, the wave energy resource contribution from Spain, France, Italy, and Greece was estimated to be 30 GW (Vicinanza *et al.*, 2011 and 2013). Depending on what is considered to be exploitable, the wave energy resource could cover up to 66% of the total world energy consumption (Astariz *et al.*, 2015c).

Tidal energy is the energy dissipated by tidal movements and it can be classified into: (1) potential energy, resulting from the rise and fall of the tide and (2) kinetic energy, generated by

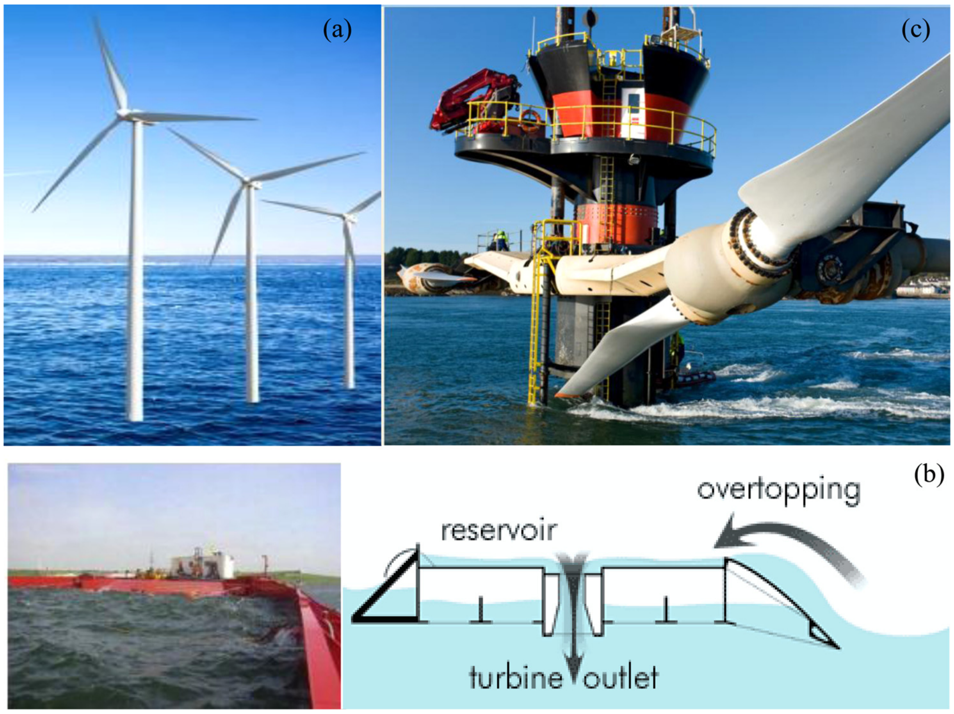


FIG. 1. Marine energy converters: (a) offshore wind turbines; (b) overtopping wave energy converter turbine. Reproduced with permission from WaveDragon Ltd. Copyright 2015 Wave Dragon Technology. (c) Tidal stream turbine. Reproduced with permission from Atlantis Resources Ltd. Copyright 2015 Atlantis Resources.

the flood and ebb currents (O Rourke *et al.*, 2010a). Both forms of energy can be used to produce electricity by means of tidal barrages and tidal stream energy converters, e.g., SeaGen turbine (Fig. 1(c)) (Atlantis Resources Ltd.), respectively. Initially, the exploitation of tidal energy was based on the construction of tidal barrages. However, due to their various environmental impacts (on both the hydrodynamics and the marine life), the interest on tidal barrages decreased (Ahmadian *et al.*, 2012; Frid *et al.*, 2012; and Hooper and Austen, 2013). Thus, the efforts have been recently focused on tidal stream energy (Evans *et al.*, 2015 and Neill *et al.*, 2014). On this basis, a number of tidal stream energy converters have been developed, which can be classified, according to their principle of operation into reciprocating or rotating devices (Denny, 2009; O Rourke *et al.*, 2010b; and Sanchez *et al.*, 2014b). The latter are the most extended and can be bottom-mounted devices or floating converters (Sanchez *et al.*, 2014a). However, so far none of the existing designs has gained universal acceptance (as in the case of, e.g., the three-bladed horizontal-axis wind turbine) (O Rourke *et al.*, 2010b). Rather, a number of analyses on different designs are being conducted with a view to determining which characteristics can maximise the power output of converters (Lee *et al.*, 2012 and Li and Çalişal, 2010). The potential impacts of tidal stream energy are also being investigated, and indeed characterising and minimising them is a crucial prerequisite to maintain the sustainable character of tidal stream energy (Ramos *et al.*, 2013; Sanchez *et al.*, 2014b; and Sanchez *et al.*, 2014c). These studies are helping designers to establish a basis on which prototypes can be successfully deployed in real environments (Willis *et al.*, 2010).

MREs present significant advantages in comparison to other forms of energy. Offshore wind energy has a higher power potential than onshore wind energy, since the winds are stronger in the ocean. Tidal stream energy is predictable and has a higher load factor than wind energy due to the properties of the fluid (water density is approximately one thousand times that of air). It also benefits from public acceptance and positive externalities (Vazquez and Iglesias, 2015b). Wave energy can be forecasted several days ahead and it is an abundant resource that has low visual and acoustic impact. As renewable sources, the MREs have low environmental impact since they do emit neither carbon dioxide nor other chemical pollutants. Moreover, a recent line of investigation is assessing the potential of combined exploitation of some MREs, namely, wave and offshore wind energy, with promising results (Astariz *et al.*, 2015c; Astariz *et al.*, 2015b; Astariz *et al.*, 2015d; Astariz and Iglesias, 2015; and Azzellino *et al.*, 2013a). So far, the following advantages of such combined systems can be anticipated: increased power production (Azzellino *et al.*, 2013b); the possible shadow effect (i.e., reduced wave heights at the inner part of the farm, which increases the accessibility); and the potential to share electrical and structural infrastructure (e.g., cabling), which can also have a positive impact on the operational costs (Astariz *et al.*, 2015a).

Of course, MREs are not without downsides, among which is the fact that the technology is not totally mature yet and therefore the related expenditures are high (Vazquez *et al.*, 2014). However, a well-planned policy framework may strengthen and accelerate the development of marine energies—which is the central topic of this paper (Vazquez *et al.*, 2014).

II. MARINE RENEWABLE ENERGY IN SPAIN

Spain has a long coast that faces the Atlantic Ocean and both the Cantabrian and the Mediterranean Sea. With almost 8000 km of coastline (Law of Coasts 22/1988), marine energies in Spain constitute promising resources. However, their degree of development is not as high as it could be expected. Indeed, other countries with less marine energy potential have a more mature sector. In Spain, a number of development projects were carried out, but specific policy measures and supporting schemes are still insufficient in some cases and undefined in others.

A. Marine energy potential

Within Europe, Spain ranks among the leading countries in terms of wind energy potential (installed capacity). By the end of 2014, Spain ranked second (after Germany), since the installed wind capacity in Spain was above 20 000 MW (Upham and García Pérez, 2015 and Vazquez *et al.*, 2014). Despite having the same working principle, and thus employing similar technology, the development of the offshore wind energy sector is not so outstanding. According to Makridis (2013), Spain has a higher offshore potential than Denmark (317 GW versus 256 GW). Whilst Denmark is a current leader in offshore wind energy (Azzellino *et al.*, 2013c), together with the United Kingdom (IDAE, 2011 and Makridis, 2013), Spain is nevertheless planning to include this renewable in the energy mix by 2020 (IDAE, 2011).

Regarding wave energy, Spain has one of the highest potential among the European countries, highlighting the case of Galicia with 66 kW/m (IDAE, 2011) (Fig. 2). Indeed, the wave energy potential for commercial exploitation in Spain is estimated at 16 GW (MEyC, 2012). The wave energy potential of the Iberian Peninsula and Portugal, and in particular, of the Atlantic coast of Spain has been the subject of a number of previous studies (e.g., Iglesias and Carballo, 2010a; Carballo *et al.*, 2015; and Rusu and Guedes Soares, 2012), with promising results. These studies pointed towards wave energy farms being able to satisfy regional electric demands (Veigas *et al.*, 2015). As it happened with offshore wind energy, Spain is far from leading the production of wave energy in Europe.

Tidal energy in Spain is also a promising resource (IDAE, 2011). Several places along the Atlantic coast were pointed as interesting future tidal stream sites, e.g., Ria de Muros (Carballo *et al.*, 2009), Ria de Ribadeo (Ramos *et al.*, 2014a), Ria de Ortigueira (Iglesias *et al.*, 2012), and Ria de Arousa (Ramos and Iglesias, 2013) in NW Spain. A recent study highlighted the possibility of satisfying the electrical demand of a port by means of tidal stream energy in NW Spain (Ramos *et al.*, 2014b). Despite this significant potential, there is a lack of tidal stream energy farms at a commercial scale in Spain.

B. Regulatory framework

Currently, there are neither concrete government plans nor a relevant legislation for the exploitation of the marine energies in Spain. This causes uncertainty over requirements,

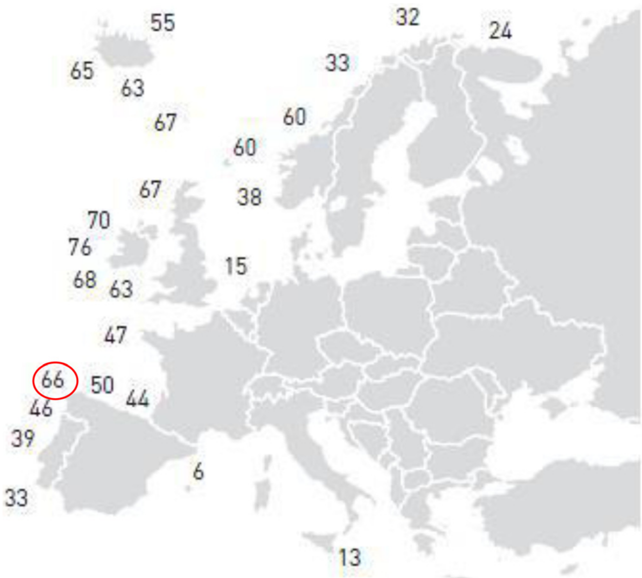


FIG. 2. Mean distribution of wave energy in Europe (kW/m).

ambiguity, and delays in consenting application processes, since procedures designed for other sectors (e.g., oil) are used instead (Simas *et al.*, 2015).

Marine energies are specifically considered only in 2 Royal Decrees (RD). The Royal Decree 1028/2007 (RD 1028/2007) establishes the administrative procedure to apply for an authorization of installations at sea for electricity generation. Even though it is mainly focused on offshore wind, a procedure for the other marine technologies (wave and tidal stream energy) is also included. The Royal Decree 661/2007 (RD 661/2007) set a FIT range between 8.43 c€/kWh and 16.40 c€/kWh for the offshore wind energy. The Spanish Ministry of Economy and Competitiveness (MEyC, 2012) suggested a hypothetical FIT scheme for both tidal and wave energy (Table I). As seen in Table I, the FIT values are quite high, if compared to those associated with the offshore wind energy; however, they have not been officially established yet.

The current economic crisis has threatened the revenue mechanisms. Indeed, the Royal Decree 1/2012, January 27th temporarily suspended all FITs for new installations of renewable energies.

C. Government plans

In Spain, the Renewable Energy Plan (Plan de Energías Renovables (PER)) 2010–2020 (IDAE, 2011) describes the current situation of the marine energy sector and sets future strategic actions for this sector. The quantitative targets for each marine technology are commented below.

For offshore wind energy, the PER states that a capacity of 50 MW is expected to be installed by the end of 2020. The electricity production, forecasted between 2011 and 2020, is shown in Table II (IDAE, 2011).

The Spanish PER sets a global objective for both wave and tidal energy, including a target for an annual installation rate of 20–25 MW between 2016 and 2020. The plan also states that 100 MW is expected to be installed by 2020, producing 220 GWh/year by then.

TABLE I. The proposed feed-in tariff (FIT) scheme for wave and tidal energy in Spain.

Period	FIT (c€/kWh)	Fixed bonus over market price (c€/kWh)
First 20 years	74.410	41.519
After 20 years	70.306	33.047

TABLE II. Forecasted electricity production between 2011 and 2020 (cumulative data).

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Offshore wind energy production (kWh)	0	0	3	34	66	111	231	498	1065	1865

In materializing the aforementioned predictions, the plan points at several kinds of barriers (technical, financial, etc.) that need to be overcome. Some of the most remarkable administrative barriers are: (1) insufficient FIT mechanisms and (2) complex and time-consuming procedures for licensing and authorization. In order to be effective, FITs should be established on the basis of real costs and positive benefits that marine energies can produce (jobs, less environmental impact, etc.) Therefore, proper ex-ante economic assessment tools must be developed (Vazquez and Iglesias, 2015b and Vazquez and Iglesias, 2015a). Concerning the total time needed to obtain approval of one MRE project, it is approximately 2 years (with some variations among different projects). The lack of previous experience in the MRE projects explains that such a long process is carried out case-by-case (Simas *et al.*, 2015).

D. Technology strategic actions

In several Spanish regions (e.g., the Basque Country and the Canary Islands), governments are promoting and developing demonstration projects, test facilities, and new MRE converters. The technology strategic actions, which are to strengthen the MRE sector in Spain, can be classified in the following groups (Villate, 2012):

- Operational ocean energy projects:
    - (–) Mutriku OWC Plant: it is the Spanish first commercial wave power plant. Its installed power is of 216 kW. It is focussed on oscillating water column (OWC) turbines and allows developers to test prototypes from a quarter scale to full size scale.
    - (–) WELCOME (Wave Energy Lift Converter Multiple España). This is a 1:5 scale wave energy converter (WEC) prototype based on APC-PYSIS technology (Supplemented Point Absorber). It was installed in April 2011 around 4 nautical miles from Las Palmas harbor (Canary Islands—Spain)—PLOCAN. Developer: PIPO systems.
- Test facilities: BIMEP (Biscay Marine Energy Platform). It is an ocean infrastructure for research, demonstration, and operation of offshore WECs at the open sea (water depth between 50 m and 90 m). In Fig. 3, a representation of the infrastructure and its main components is presented. As it can be observed, a rectangle area (4 × 2 km) has been demarcated to hold the WECs, which are connected to onshore cables by means of 4 test power connection units (BIMEP).
- New Developments (Fig. 4).

III. LESSONS LEARNED FROM OTHER COUNTRIES: THE CASE OF THE UNITED KINGDOM

The UK is amongst the European leaders in marine energy development (Foxon *et al.*, 2005). Fig. 5 shows the intense MRE activity across the UK, with a number of current and planned wave, tidal and offshore wind energy projects (European Marine Energy Centre (EMEC); Renewable UK, 2012). In 2010, the UK led the production of offshore wind energy in Europe with 15 farms in operation and a total installed capacity of 1341 MW (IDAE, 2011). As regards the tidal energy production, the level of UK tidal practical resource was estimated to be 18–200 TWh per annum. To exploit it, the Crown Estate has demarcated 26 zones for tidal energy deployment in the UK, which account for over 1000 MW (Magagna and Uihlein, 2015). Despite receiving less interest and investments (if compared to the tidal energy sector), wave energy production in the UK during the last 5 years was estimated at 0.8 GWh, as stated in Magagna and Uihlein (2015). According to Renewable UK (2013), the progress of the

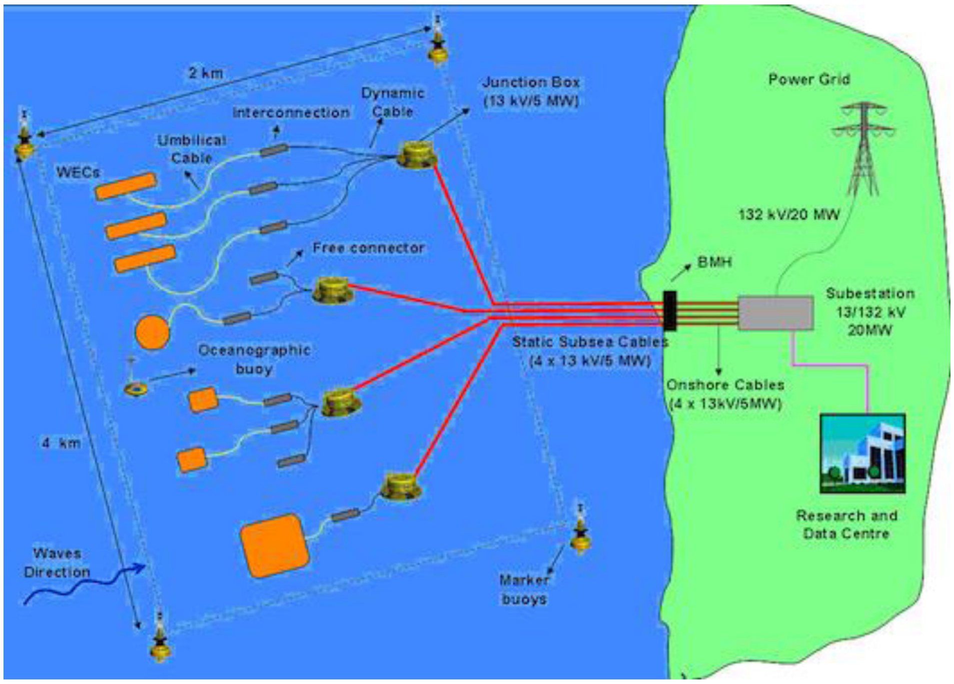


FIG. 3. BIMEP Offshore infrastructure and equipment. Reproduced with permission from BIMEP, see http://www.fp7-marinet.eu/EVE-biscay-marine-energy-platform-bimep.html for EVE Biscay Marine Energy Platform. Copyright 2013 BIMEP.

marine energy sector in the UK has been driven by a number of supporting initiatives encouraged by the Government and other stakeholders, as explained below.

A. The UK policy framework

The UK marine energy strategy is characterized by introducing "technology push" and "market pull" supporting mechanisms (Jeffrey *et al.*, 2014). These mechanisms are mainly financial supporting initiatives that can be classified in three groups (Renewable UK, 2013): (1) Government funding to support specific projects; (2) revenue support policies; and (3) funding bodies (e.g., The Carbon Trust, The Department of Energy and Climate Change, etc.). Some of the most remarkable initiatives (Jeffrey *et al.*, 2014) are shown in Fig. 6.

The success of the UK strategy may be due to several key aspects, which are summarized below.

- The variety of schemes. The aforementioned initiatives (revenues, funding bodies, etc.) allow supporting a range of activities that can cover different needs of the sector.
- The supporting mechanisms cover a different stage of development from underpinning research through to full scale test infrastructure and deployment activities (Fig. 6). This allows having a

FIG. 4. New Spanish technology developments: (a) 300 kW wave buoy, Galicia 2011; (b) 1 PowerBuoy prototype to demonstrate improved electronic "tuning" for changes in wave conditions, Santoña, 2012; (c) 150 kW Wave Energy Power Buoy Project based on a linear converter, Canary Islands, 2014.

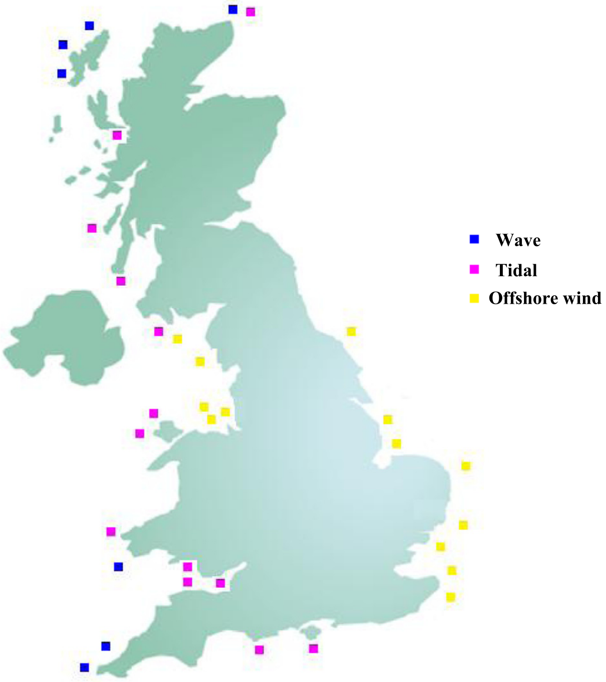


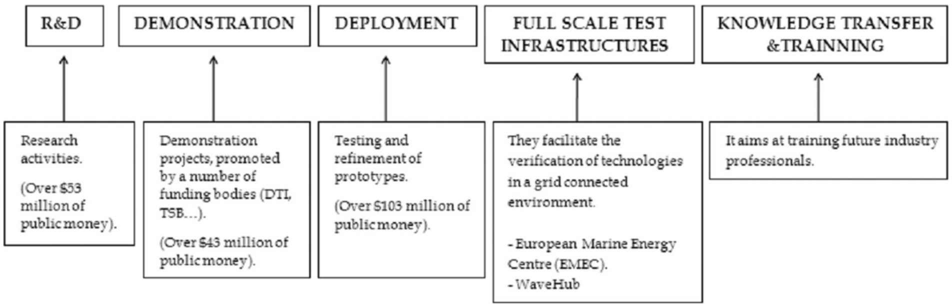
FIG. 5. MRE activity in the UK: current and planned wave, tidal and offshore wind energy projects across the UK (location of sites are approximate).

wide perspective of the technology development process. Therefore, lessons learned from the most developed projects can be incorporated to the less mature technology, producing savings in both money and effort.

- The timing of support mechanisms has a significant impact (Magagna and Uihlein, 2015 and Jeffrey *et al.*, 2014). Some of the decisions were taken in advance. For example, the early establishment of the EMEC was a strategic decision that has helped to accelerate the development of the sector in the UK. On the other hand, the establishment of the Renewable Obligation (RO) premium improved the confidence within the private sector, by reducing the risk of investment.
- The UK strategy has a long-term approach, i.e., it is based in current investment in order to obtain future benefits.

B. UK technology developers

The UK policy framework is favourable for technology developers since it reduces the investment risk. Thus, for instance, over the 100 tidal energy companies involved in the development of tidal energy technology, the UK accounts for more than 30% of tidal developers



Research activities.
(Over $53 million of public money).

Demonstration projects, promoted by a number of funding bodies (DTI, TSB…).
(Over $43 million of public money).

Testing and refinement of prototypes.
(Over $103 million of public money).

They facilitate the verification of technologies in a grid connected environment.
- European Marine Energy Centre (EMEC).
- WaveHub

It aims at training future industry professionals.

FIG. 6. UK policy initiatives within the marine energy sector.

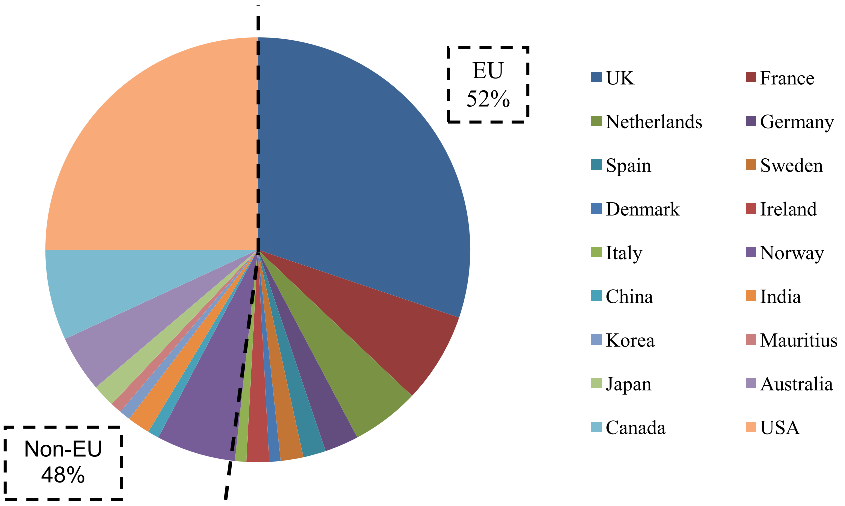


FIG. 7. Distribution of tidal developers in the world.

(EMEC) (Fig. 7). A similar percentage can be associated to the amount of wave energy developers, but at a European scale (EMEC) (Fig. 8). While among tidal stream energy devices, the horizontal axis turbine is the most extended design (Fairley *et al.*, 2013); there is a lack of consensus amongst the various wave energy converters. Indeed, three different wave energy converters account for 82% of research efforts, which adds uncertainty and weighs on the number of wave technology developers (Magagna and Uihlein, 2015).

The existence of technology developers in a country is not trivial at all. It implies that the national energy resources may be exploited by national companies, which may contribute to benefit the country at different levels: economically, socially (by creating jobs and promoting a healthier electricity technology), and environmentally (by reducing the CO_2 emissions, for example). In this sense, public investment is justified by the benefits generated.

IV. POLICY RECOMMENDATIONS FOR THE SPANISH MRE SECTOR

The degree of development that is experienced in the Spanish marine energy sector is still small in comparison to its energy potential. By analysing the case of the UK, it can be seen

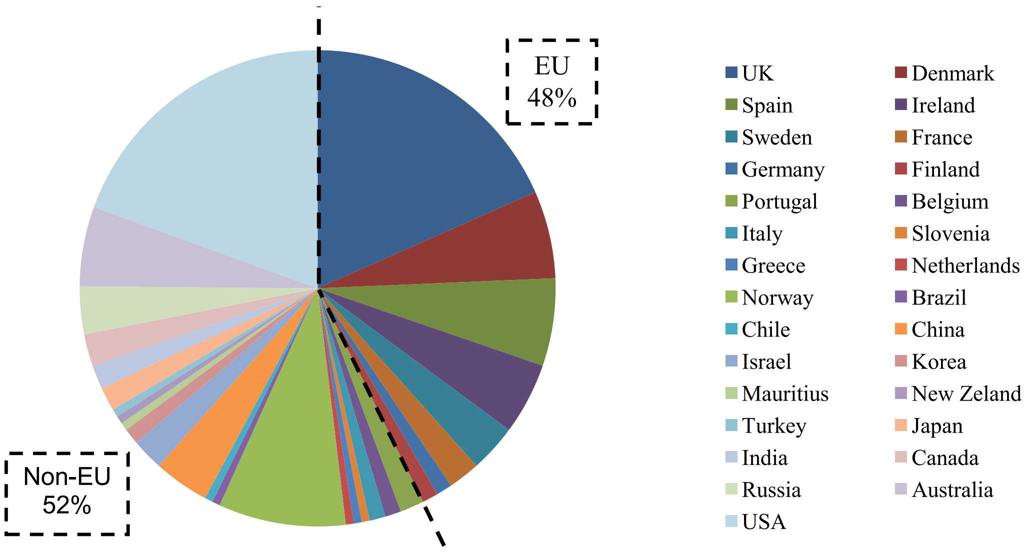


FIG. 8. Distribution of wave developers in the world.

that Spain would become a major player in the marine energy sector if more attention was paid to the regulatory framework and the financial incentives.

First, public funding has to be increased. Marine energy technologies are not currently cost competitive with conventional sources. Therefore, a long-term strategic approach should be adopted until this emerging sector could be privately funded entirely. The economic crisis may be a barrier for the public funding, but it should be seen as an opportunity, since this funding will bring in turn long-term social benefits such as energy security, carbon emissions reductions, job creation, and economic development.

Second, the permissions, licenses, and other requirements needed to develop a marine energy project should be clearly defined with simple processes, which would be preferably designed *ad hoc*. Coordination between consenting authorities should be improved as well. This would contribute to lower the risk associated to the MRE as an emerging sector.

Last but not least, there is a potential of cross-national cooperation (between Spain and other European countries, such as the UK). This cooperation could be focused on the testing of devices and infrastructure to promote knowledge exchange and to avoid replication. This may have also cost saving implications for both policy makers and technology developers (Bailey *et al.*, 2012). On the other hand, the potential also exists for technology developers to move towards clusters in order to gain infrastructural, economic, informational, technical, and other benefits. The advantages of joint projects are potentially considerable, but need to be offset against other factors. The main barrier for cooperating is the desire to establish local competitive advantages in the emerging MRE technologies as a way of achieving national economic growth (Bailey *et al.*, 2012).

V. CONCLUSIONS

Within the European countries, Spain has a promising potential in marine energies (wave, tidal stream, and offshore wind energy). While it has considerable scope for marine energy development, this sector in Spain is having a late development in comparison with other countries that have similar marine energy resources. The lack of both concrete government plans and a relevant legislation for the exploitation of the marine resources is one of the main challenges to be addressed.

In this context, this work had two main aims: (1) to identify strengths and weaknesses in current national regulatory frameworks affecting the development of the marine renewable energy sector and (2) to provide recommendations on how the weaknesses might be corrected to accelerate the growth of the marine renewable sector in Spain.

The government's Renewable Energy Plan (PER) 2010–2020 includes the promotion of marine energies. Indeed, it is expected that marine energies will take part in the energy mix by 2020. Nowadays, a number of technological strategic actions are taken, including test facilities and new developments. These actions encourage the private sector implication in the development of marine energy technology. However, there is a lack of both concrete action plans and detailed supporting initiatives in order to achieve the proposed goals.

As for the comparison between the UK and Spain, the strategic actions recommended in this work are: greater public funding specifically assigned for the development of the marine energy sector and cross-border learning opportunities that may contribute further to the growth of the marine renewable energy industry in Europe. It is important to highlight that, apart from the UK, other European countries could be used as examples of successful strategies. For instance, Denmark has recently simplified the requirements for licensing marine energies projects.

To conclude, the design of accurate energy policies is inextricably linked to the development and promotion of the marine energy sector. Hence, implementation of energy policy or strategy to develop this new technology is important and vital to ensure its success as the leading "green" energy source worldwide.

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