Inter-sectoral relations to accelerate the formation of technological innovation systems: determinants of actors' entry into marine renewable energy technologies

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Abstract

Decarbonizing the energy system requires new technologies, whose formation and diffusion needs the attraction of actors from different sectors to compose the value chain. Sectoral interactions are crucial and dependent on contextual and technological factors, as well as firm-specific characteristics. This paper examines the determinants of firm diversification towards a new technology and their role in sectoral interactions. We combine concepts from technological innovation systems (TIS), sectoral innovation systems and organization studies to examine the drivers of actors' entry as well as their impact on systems' formation, through the effect on inter-sectoral relations associated with technological variety and relatedness. The development and demonstration of marine renewable energy technologies (MRET) in Portugal over the past two decades provides the empirical case. A database of 237 companies includes responses from a survey of a large part of the actors involved in MRET and potential entrants. A standard binary logit model estimates the effect of a set of drivers of firms' entry in MRET. Firms are more driven by variety-led factors and technology maturity, than by their technological capacity and sectoral proximity. We derive implications for policy and theory, namely for the conceptualization of inter-sectoral relations in TIS.

Keywords: technological innovation systems, inter-sectoral relations, relatedness, firms, energy technologies.

Brief running title: Drivers of actors' entry and of inter-sectoral relations to accelerate innovation

1. Introduction

Limiting global warming to safe values around 1.5 ºC requires far-reaching technological change and a large-scale transformation of the economy (IPCC, 2018; IEA, 2021). Pervasive transformational processes, such as electrification and digitalization, are having a growing impact across multiple sectors, including energy and transport, and this increases the complexity of transitions (Grubler et al., 2018; Dolata, 2018). Firms and other organizations will play a key role in accelerating these transitions (Köhler et al., 2019; Bakker, 2014). More specifically, they can mobilize resources that become redundant in other sectors due to sustainable transitions or economic crises and thus contribute to the emergence of new industries (Bergek et al., 2015; Mäkitie et al., 2018).

Industry formation is central in the emergence of new technologies. Large-scale transformation requires a structural change in established industries, namely in the capital goods industry, as recognized by classical economists such as Smith (1776) and Marshall (1890). Indeed, the industrial context can serve as a source of competences and resources for the formation of industries around the new technology, via novel recombinations of existing knowledge and artifacts (Weitzman, 1998, Arthur, 2009; Hidalgo, 2018). These recombinations are not entirely random, but are largely path-dependent (Dosi, 1988).

Interactions with existing industries provide opportunities for the development of complementarities that are critical for the access to key resources and markets (Markard and Hoffmann, 2016; van der Loos et al., 2020). In fact, the technology's value chain often integrates multiple sectors in addition to those in which it is mainly embedded (Bergek et al., 2015; Malerba, 2002; Stephan et al., 2019; Hannon et al., 2019). For example, the lithium-ion battery technology value chain links sectors such as electronics, chemical and transportation (Malhotra et al., 2019). The capacity to attract suppliers and influence their direction of search and investment is a crucial innovation process (function) in emerging technological innovation systems (TISs) (Bergek et al., 2008).

The decision of firms to diversify into new activities depends on both contextual factors (Bergek et al., 2015) and firm-specific variables such as technological and innovation capacity (Laurens et al., 2018). The studies on the interactions between sectors tend to focus on inter-sectoral knowledge spillovers (Stephan et al., 2019) and learning (Malhotra et al., 2019), overlooking other types of resources that existing firms have to bring to build the value chain of the new technology. For example, the producers of offshore platforms for oil & gas brought their skills and assets to accelerate the development of offshore wind energy in Norway (Mäkitie et al., 2018), as the same being observed for firms from other sectors such as shipbuilding, maritime (transport) and cable industries (van der loos et al, 2020; Hannon et al., 2019).

To address this gap in the literature, we raise the following question: *Which factors lead firms from different sectors to engage with new technology innovations?* The response to this requires the answer to two sub-questions: *how is the firm's decision influenced by its sector?;* and *which factors increase the likelihood of other sectors being involved in the technology?*

We use theories and concepts from technological innovation systems, sectoral innovation systems and organization studies to uncover the determinants of the decision of firms to embark on the development of new technological innovations. Considering that resources from different sectors that reinforce the value-chain of a focal technology are mobilized through firms, the main hypothesis of this study is that the creation of inter-sectoral relations is a function of the determinants of firms' decisions. For the empirical analysis, we study the involvement of companies in the research, development and demonstration (RTD) of marine renewable energy technologies (MRET) with different degrees of maturity[1], particularly wave energy and offshore wind energy, over a 20-year period in Portugal. This is the perfect setting for the study given that much of the manufacturing and assembly of key components in MRET— in Portugal and abroad—relies on local suppliers (Fontes et al., 2016; Magagna et al., 2017; Varela-Vázquez et al., 2017; Bento and Fontes, 2019). Portugal, an intermediate developed economy, has remarkably rapidly created a local system around new marine renewable energy technologies (Bento and Fontes, 2016): this country has been a pioneer in wave energy technology (Fontes et al, 2016), and has shown great dynamism in the

[1] With over 20GW installed and 200 GW expected for the coming years, offshore wind energy has already taken off (IRENA, 2020). However, a sub-market of offshore wind that uses floating platforms (or floating offshore wind) for water depths typically deeper than 50 or 60m is still in pre-commercialization. The IEA's Energy Technology Perspectives situates floating offshore wind turbine (a key component in the power plant) with a Technology Readiness Level of 8 designated as "First of a kind commercial" of 11 ("Proof of stability reached") that would correspond to full commercialization. For comparison, wave energy is in stage 4 ("Early prototype") and the different concepts of tidal range from 5 ("Large prototype" for stream or current) to 8-9 ("Commercialization in controlled environments" for tidal range). See https://www.iea.org/articles/etp-clean-energy-technology-guide (last access 24/5/2021).

development of advanced offshore wind energy technologies for deep waters (Bento and Fontes, 2019). The study focuses particularly on the motivations of firms from different sectors (including declining activities) to provide the competences and resources required for the development of MRET through the qualitative and quantitative analysis of data obtained from a survey and from secondary sources.

This research contributes to broaden the understanding of the role of inter-sectoral relations in the mobilization of resources other than knowledge (Stephan et al., 2019; Malhotra et al., 2019), or to also include assets sourced from other sectors beyond the core industry (Mäkitie et al., 2018). The paper also contributes to the recent calls to further the knowledge about the microfoundations of TIS growth (Andersen et al., 2020). It examines the factors that drive firms' decisions to enter and strengthen the supply-chain of emerging TISs. In particular, this investigation sheds light on the mechanisms behind the innovation process related to the influence in the direction of search, a crucial function in emerging TISs (Bergek et al., 2008).

The article is structured as follows. Section 2 develops the conceptual framework based on the determinants of firms' entry that affect the sectoral interactions, thus contributing to the development of the system. Section 3 explains the empirical context and the research strategy. Section 4 presents the results, before discussing their meaning, implications and limitations in Section 5.

2. Actors' entry and inter-sectoral relations in transitions

2.1 Technological innovation systems and sectoral interactions

The studies on technological innovation systems have devoted growing attention to the mechanisms through which the interactions with the context influence the dynamics of industry formation (Bergek et al., 2015; Markard and Hoffmann, 2016; van der Loos et al, 2021). Technological innovations often integrate several components and subsystems that are part of a complex system (Arthur, 2009; Murmann and Frenken, 2006). The development, production and use of these technologies and components require the setting-up of a value chain that comprises different capabilities, such as competences and assets, provided by several sectors (Carlsson and Stankiewicz, 1991; Stephan et al., 2019). In line with the sectoral systems of innovation (cf. Malerba, 2006), sectors refer to a collection of actors that share similar knowledge bases, production processes and outputs. Sectors have the same structural elements as TIS, such as networks of actors and institutions (Bergek et al., 2015; Malerba, 2006), but their system boundaries are different (Malhotra et al., 2019). Indeed, while a sector is typically present in different TISs, a TIS may have actors from different sectors, due to the various components that integrate its value chain (Bergek et al., 2015). Therefore, inter-sectoral relations become more dense in advanced stages of the TIS lifecycle (Markard, 2018) and are a function of the number and types of sector involved in the technology's value chain (Stephan et al., 2019).

Sectoral interactions influence the systemic interplay of actors and institutions acting in a specific technology (Carlsson and Stankiewicz, 1991; Bergek et al., 2015). In particular, inter-sectoral interactions support the innovation processes (functions) involved in the development, production and use of a focal technology. TIS studies have identified a set of functions that contribute to the performance of the system (see a review in Bergek et al., 2019).[2] Hence, the TIS configuration evolves with the maturity of the system (Markard, 2020). To analyze the influence of inter-sectoral relations in TIS growth, we draw on the effects in the structured-inspired four dimensions proposed by Markard (2020): 1) actor base; 2) institutions structure and networks; 3) technology performance; 4) context relationships.

The access to resources available in the context depends on the ability to create interactions with other sectors (i.e. sectoral overlaps or couplings) (Bergek et al., 2015; Mäkitie et al., 2018). This is not limited to the sector in which the technology is mainly embedded. Instead, the ability to create interactions also includes other sectors. For example, floating offshore wind energy benefited from the interactions with other sectors such as metallurgy, shipbuilding and construction to access resources and form its value-chains (Bento and Fontes, 2019; van der Loos et al., 2020).

Two factors are crucial for the attraction of different sectors to an emerging TIS, i.e. to the development of inter-sectoral relations (Stephan et al., 2019; Trajtenberg et al., 1997): technological variety and technological relatedness.

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[2] Knowledge development and diffusion, entrepreneurial experimentation, influence on the direction of search, market formation, legitimation, resource mobilization, development of positive externalities (Bergek et al., 2008).

Note that both factors refer to the sector that is the source of relevant capabilities, and they have an important role in the decision to diversify made by companies from that sector (Nemet & Johnson, 2012).

Relatedness signifies that firms (Dosi, 1982, Rumelt, 1974), namely through inter-organizational relationships (Boschma, 2005), tend to start searching for new opportunities in the proximity of their core activities with a view to achieving economies of scope (Penrose, 1959). Industries are related whenever their activities require similar capabilities (Boschma, 2017). Thus, relatedness between industries may facilitate firm diversification from industries (Steen and Waver, 2017; Makitie et al, 2018) and markets (Helfat & Heisenhard, 2002; Lüthge, 2020) experiencing slow growth to more promising ones, since it enables existing assets to be redeployed or recombined (Karim & Capron, 2016). The relatedness literature has put particular emphasis on technological and product relatedness (Boschma and Frenken, 2011; Breschi et al, 2003; Hidalgo et al, 2007), but relatedness between industries has several dimensions encompassing also business and market capabilities (Tanner, 2014; Makitie et al, 2019). Therefore, the types and combinations of assets (tangible and intangible) that can be redeployed by diversifying firms vary (Lüthge, 2020). This is likely to have important implications for firms' decisions regarding entry in emerging fields in which they have no technological capabilities, but to which they can contribute with other relevant complementary assets (Teece, 1986; Rothaermel, 2001). However, the opportunities thus created are still underexplored by the research addressing the motives that lead firms from established industries to diversify into (related) low carbon industries (Makitie et al, 2019).

Variety denotes the incentives for firms, namely large companies, to operate in different sectors to fully grasp the potential of multipurpose resources (Cantwell, 2006; Piccone and Dagnino, 2015). This strategy may be based on different motivations. Firms may attempt to withstand the disruptive impact of changes in the configuration of their industries that reduce the value of their core capabilities (Henderson and Clarke, 1990; Tushman and Anderson, 1986). They may also attempt to exploit new opportunities, namely those related to the emergence of new technologies (Eggers and Kaul, 2018). Firms may also be reacting to regulatory pressures, namely environmental regulation, which will force them to re-think their business positioning, eventually revealing new opportunities that would have been overlooked otherwise (Li, D. et al, 2019; Dyerson & Pilkington, 2005; Porter and Van der Linde, 1995). The capacity to exploit new opportunities can be enhanced when firms are able to link and integrate knowledge from different technology domains, which tends to be associated with more original innovations (Fleming, 2001; Arts & Veugelers, 2015; Castaldi et al, 2015). This strategy can be more complex and risky for the firm, but is facilitated when firms have stronger technological competences and a more diversified knowledge base, which will support the identification, integration and absorption of more distant knowledge (Granstrand et al., 1997; Cohen and Levinthal, 1990, Savino et al, 2017). Such knowledge may be present in different industries, with diverse knowledge bases, and therefore benefits can accrue from the establishment of relations between firms from previously unrelated industries (Janssen and Frenken, 2019), which are less likely to collaborate spontaneously but can be encouraged through policies.

This literature is nevertheless limited in providing an account of the microeconomic factors that determine these two types of inter-sectoral relation, that are discussed more in detail next (Ceipek et al., 2019).

2.2 Sectoral interactions and determinants of actors' entry

Sectors impact TIS development through the participation of firms. Firms decide to enter into an emerging technology based on several factors that will be the basis of the inter-sectoral relations. The technology's capacity to affect these determinants and attract firms from different sectors in order to form its supply-chain will define its influence on the direction of search (Bergek et al., 2008). According to Bergek et al. (2008: 415), the influence on the direction of search is important because: "*If a TIS is to develop, a whole range of firms and other organizations have to choose to enter it. There must then be sufficient incentives and/or pressures for the organizations to be induced to do so*." Put more clearly, influence on the direction of search denotes the capacity to provide “guidance of search processes within a TIS” as well as “guidance toward entry into a TIS” (Bergek, 2019).

This raises the question of the drivers of the actors' entry. Management and organization studies identify several types of factors that intervene in the technological diversification of firms (activities and competences), which can be specific to the firm or to the industry/sector

(Laurens et al., 2018). In respect to the firm specific factors, such as the size of companies, there is evidence that larger firms tend to present higher levels of technological diversification (Chandler, 1990; Granstrand et al., 1997) and to diversify to related technologies over time, in order to seize economies of scope (Cantwell, 2006). The technological content of firms' activities also increases their capacity to identify and benefit from new opportunities associated with emerging technologies (Laurens et al., 2018; Grandstand, 1998). In the same way, firms operating in more profitable conditions are better able to diversify into promising technologies (Schommer et al., 2019; Wu and Levinthal, 2013). The capital ownership can also motivate companies to diversify, particularly foreign direct investment (FDI) that can enable the transfer of technical and non-technical competences from abroad (Elekes et al., 2019). Finally, firms' innovative capacity improves the ability for technological diversification. Knowledge intensive service (KIS) firms have generalizable competencies that can be deployed in innovation activities in different sectors (Shearmur and Doloreux, 2018). On the other hand, technological capability proxied by innovation outcomes, such as patents and publicly funded research projects, signals advanced science and technology (S&T) knowledge and the capacity to benefit from technological opportunities (Todorova and Durisin, 2007; Cohen and Levinthal, 1990).

Regarding the factors specific to the sector, proximity (technological, competences, resources or finality) increases the probability of entry into complementary activities (Wu and Levinthal, 2013; Helfat and Eisenhardt, 2004; Rumelt, 1974). Specifically, sectors that are closer to those where firms operate (similar in knowledge and skills) offer more opportunities to deploy underutilized resources that are specific to these sectors (Penrose, 1959; Adner and Zemsky 2016; Wiersema and Beck, 2017). Namely, this has been shown to have a positive effect on intensifying relations between firms and sectors in the case of clean energy technologies (Laurens et al., 2018).

2.3 Conceptual framework

The previous sub-sections improve the understanding about the factors that drive the decision of firms to diversify into a specific technology (Section 2.2), as well as the determinants that increase the probability of other sectors to be involved in the construction of the focal system (Section 2.1). Now we need to understand how these factors shade light on the mechanisms that influence the attraction of other sectors to the system.

Table 1 presents the drivers of actors' entry and how they contribute to developing the four dimensions of the emerging system. Firms bring the resources of at least their core sectors into the system. The sectoral relations that enable TIS growth depend strongly on two main mechanisms: variety and relatedness (cf. Section 3.1). Therefore, the determinants of firm entry shed light on the sources of these two mechanisms that will contribute to progress in each dimension of the system.

TIS dimension	**Sectoral factors**	**Drivers of firm entry**	**Rationale**
Actor base	Relatedness	Size	Larger companies increasingly diversify to interrelated technologies to better play economies of scope *(Cantwell, 2006)*
	Variety	Technological content	Higher technological content increases opportunities to enter in emerging technologies *(Laurens et al., 2018; Grandstand, 1998)*
Institutions' structure and networks	Relatedness	Energy activities	Closer activities to those where firms operate (with similar knowledge & skills) offer more opportunities for them to deploy excess/ underutilized resources (*Penrose, 1959; Adner and Zemsky 2016; Wiersema and Beck, 2017; Laurens et al., 2018)*
	Variety	Profitability	Higher/lower than sectoral average profitability motivates companies to diversify, searching for new opportunities/higher performances (*Schommer et al., 2019; Wu and Levinthal, 2013; Helfat and Eisenhard, 2004; Bass, Catlin and Wittink, 1977*)
Technology performance	Relatedness	Patents, R&D projects	Innovation capacity, reflected in activities relevant to the development of the firms' S&T knowledge, improves the absorptive capacity to take advantage of spillovers (*Todorova and Durisin, 2007; Cohen and Levinthal, D.A., 1990*)
	Variety	Knowledge intensive services (KIS)	Knowledge intensive service firms tend to possess more generic capabilities for problem-solving, and can play an important role in the innovation of their partners (*Shearmur and Doloreux, 2018; Miles et al, 1995)*
Context relationships	Relatedness	Complementarity	Proximity (technological, competences, resource or finality) increases the probability of entry *(Wu and Levinthal, 2013; Helfat and Eisenhardt, 2004; Rumelt, 1974)*
	Variety	Foreign capital (FDI)	FDI brings technical and managerial competences and opens access to foreign knowledge (*Elekes et al., 2019*)

Table 1. Dimensions of TIS growth, type of sectoral relations and drivers of firms' entry

Each driver of the firms' entry influences TIS growth in different ways. While some drivers can have a higher impact through variety-led sectoral interactions, such as technological content, profitability, knowledge intensive services (KIS), foreign capital, others may contribute through relatedness-led type of sectoral interactions such as firm size, energy activities, patents, R&D projects, proximity/complementarity (close activities). On the other hand, the various TIS dimensions may benefit from the two types of inter-sectoral relations. For example, the actor base enlarges through the entry of large (size) companies seeking to diversify in areas related to their main activities (e.g. metalwork firms seeking more applications (with higher value) to their production in the construction of structures for floating offshore wind); or thanks to firms that feature high technological content stepping in to explore more opportunities of application of their transversal competencies (e.g. information technology (IT) or robotics companies finding new applications for their technology in the development of offshore wind).

Figure 1 shows the proposed conceptual framework about the drivers of firms' entry that activate sectoral relations with the focal TIS. Diversifying firms bring with them the resource of their core sectors to build up the value chain components of the emerging system (Stephan et al., 2019). The drivers act differently upon the diversification strategies of firms that are situated in sectors more or less related to the focal TIS. Depending on the type of sectoral interactions that the drivers influence most—see drivers in orange or blue if they affect respectively variety or relatedness more —they can give rise to different timings. Relatedness-led interactions bring in closer sectors whose integration is more obvious, while variety-led interactions connect sectors whose contribution is less evident or which are more difficult to attract given their distance—and thus may take longer to integrate into the system—but that bring critical and differentiated resources to the system. As a result, the system expands and becomes more complex in this process (Markard, 2018), by incorporating an increasing number of suppliers from different sectors. Therefore, the TIS moves from an embryonic state (depicted in the diagram with undefined bounds) to a more structured shape.

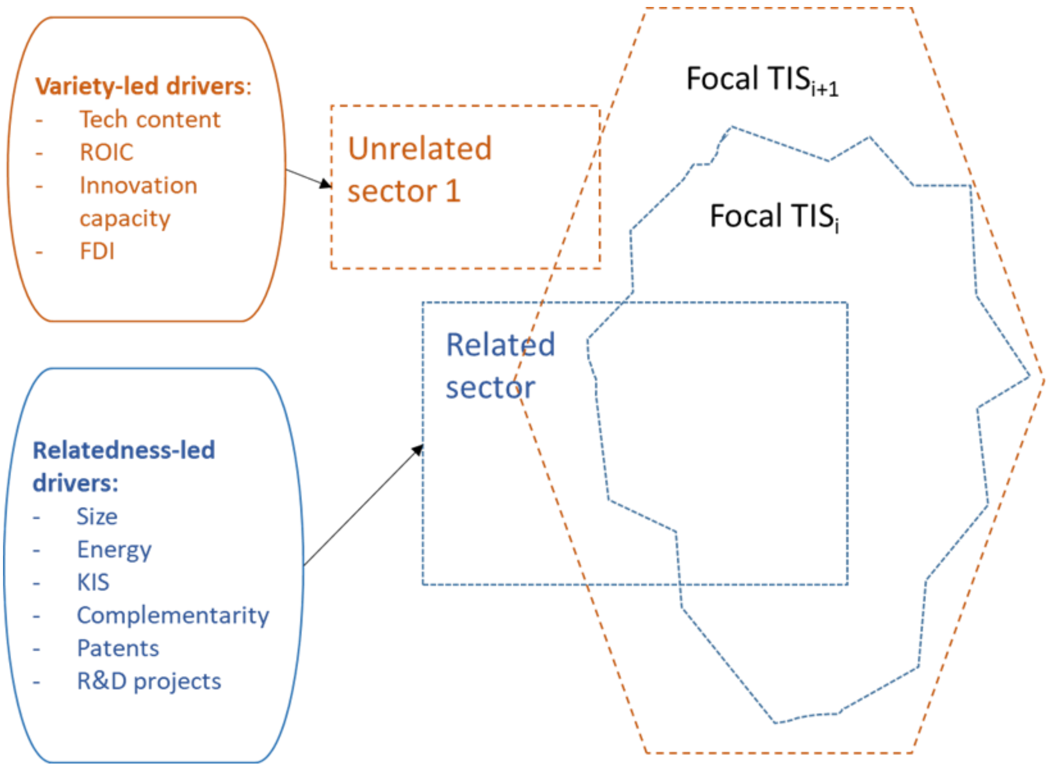

Figure 1. Conceptual framework

Therefore, we formulate the following research hypotheses for the determinants of the interactions between a focal sector and the other sectors of the economy.

The first hypothesis refers to the possibility that inter-sectoral relations are a function of the determinants of the firms' decisions that were found in the literature review, in the following terms:

Hypothesis 1: the decision of companies to diversify into the focal technology depends on firms and sectoral drivers.

The second hypothesis explains the intensity of inter-sectoral relations more specifically with variety-led factors such as technological content, profitability, knowledge intensive services (KIS), foreign capital, as follows:

Hypothesis 2: the decision of companies to diversify into the focal technology depends more on factors associated to variety-led relations.

Conversely, the third hypothesis refers that the intensity of the relations of the focal system with the other sectors are explained more particularly by relatedness-led factors such as firm size, energy activities, patents, R&D projects, proximity/complementarity (close activities), as following:

Hypothesis 3: the decision of companies to diversify into the focal technology depends more on factors associated with relatedness-led interactions.

To shade light on the nature and drivers of the inter-sectoral relations that accelerate the formation of new technological innovation systems, we test the explaining value of these three hypotheses against the emergence of new renewable energy technologies under a specific institutional setting in the next sections.

3. Methods

3.1 Research strategy and data

The study aims to understand the factors that attract firms to enter into new technological innovation systems. We investigate the microfoundations of inter-sectoral interactions that contribute to the development of the value-chain that supports new technologies. Figure 2 presents the organization of this investigation.

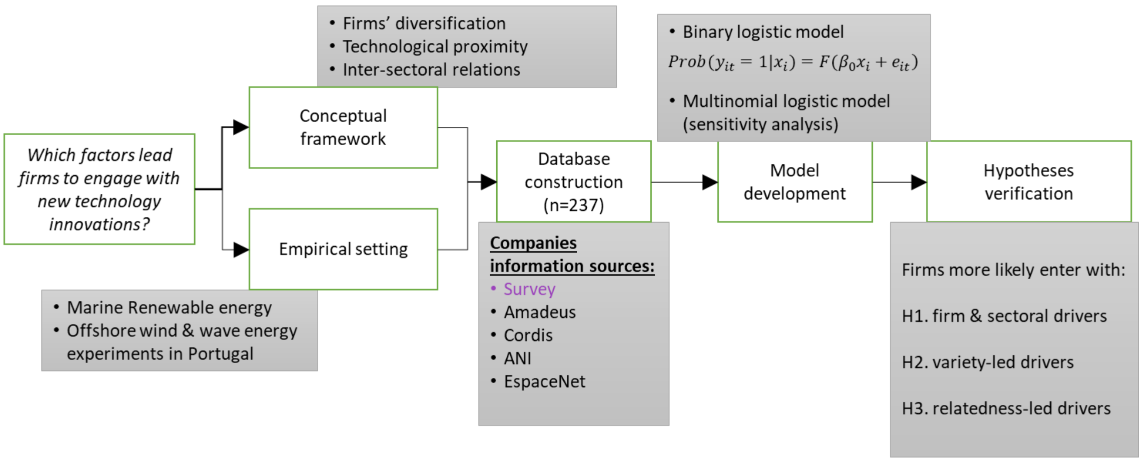

Figure 2. Structure of the research

The empirical analysis examines the case of marine energy technologies (i.e. wave energy and floating offshore wind) in Portugal. Unlike classic fixed-bottom offshore wind for which the design has stabilized in the past two decades (van der Loos et al., 2020; Dedecca et al., 2016), more emergent MRET concepts such as floating offshore wind and (more so) wave energy are still in the fluid phase of experimentation before the emergence of a clear dominant design (Anderson & Tushman, 1990).

Experimental activities in MRET involve the setting-up of several generations of increasingly larger prototypes, which require the manufacturing and assembling of a variety of components and systems. They also entail prototype testing at sea, for long periods, to assess the reliability and survivability of the technology, which involves sea installation, operation and monitoring activities (Bjørgum and Netland, 2017; Magagna et al., 2017). A substantial part of these activities can benefit from competences and resources present in existing sectors. Given the relevance of these activities for the development of the technology, the need to attract firms from existing sectors as suppliers or partners will arise much prior to the commercialization of the technologies, at a time of high technical and market uncertainty.

Thus, the case of MRET in Portugal illustrates well the challenges faced by the actors before the establishment of a dominant design, which include a limited number of players, high asset specificity, pervasive market and technology uncertainty, low external legitimacy and high financial costs due to limited track records (Kirkwood and Srai, 2011).

The study focuses on the firms from the sectors that can contribute with competences and resources to the development of the new technology innovation, entering MRET through their involvement in experimental activities[3]. These firms were identified through:

i) Secondary sources. We constructed a database of firms involved in MRET as partners or suppliers in experimental projects, in two steps. The first step identified all European and Portuguese Research, Technological Development and Demonstration projects in MRET, funded between 1992 and 2018 and with Portuguese firms as participants (52 projects). The second step uncovered the suppliers of the firms involved in the principal experimental projects of wave and offshore wind energy technologies that were conducted in Portugal. These projects had been identified in previous research (Fontes et al., 2016; Bento and Fontes, 2019).

[3] The research did not include MRET firms, i.e. firms that were responsible for the development of the technologies, focusing only on the firms from other sectors that contributed with complementary competences and resources to that development.

ii) A questionnaire. We conducted a survey of firms from sectors identified as potential contributors to the development, production, installation and operation of MRET (OTEO, 2014; Fontes et al., 2019)[4]. Firms were inquired about their eventual participation in MRET activities, which permitted to identify three groups of firms: active, i.e., firms that were currently involved in MRET or that had been involved at some point in time; not active but intending to enter MRET in the future; not active and with no interest in MRET (see Appendix 2).

Based on these sources, we built a database with 237 companies, including 197 respondents to the questionnaire and 40 firms that were partners or suppliers in MRET experimental projects but did not answer the questionnaire. The database includes 109 firms that are active in MRET and 128 firms that are not active, 67 of which declared they intended to enter into MRET in the future.

We collected additional data on firms' characteristics, main sector of activity and innovation capacity from a variety of databases (e.g. Amadeus, CORDIS, ANI-National Innovation Agency, EspaceNet). The main sector of activity of a firm is the primary NACE Rev.2 code of the firm with four digits, as this already provides enough detail about its activity, keeping the level of analysis manageable. In the case of active firms that answered to the questionnaire, we also obtained information about the novelty of the products or services they provided to MRET: developed specifically for MRET; adaptation of existing ones to new applications; or currently sold (see Appendix 2).

3.2 Variables

Table 2 presents a description of the variables and their sources. The first two variables are the dependent variables and reflect the company's decision to enter into MRET. Relative to *"Active"*, *"Active_level"* distinguishes, in the "not active" group, firms that in their answer to the questionnaire have expressed the intention to become active in MRET in the future, and those that have shown no interest in MRET.

[4] The survey included the firms previously identified as involved in MRET as partners or suppliers in experimental projects.

The second group of variables refers to the company’s sectoral relatedness, i.e. the degree of complementarity of its main sector of activity to the core sectors of the technologies. Following the categorization proposed in the ICTSD report (Wind, 2009), MRET core sectors (cf. NACE Rev.2 code) are: Manufacture of metal structures and parts of structures (25.11); Manufacture of instruments and appliances for measuring, testing and navigation (26.51); Manufacture of electric motors, generators and transformers (27.11); Manufacture of electricity distribution and control apparatus (27.12); Manufacture of other electronic and electric wires and cables (27.32); Manufacture of wiring devices (27.33); Manufacture of engines and turbines, except aircraft, vehicle and cycle engines (28.11); Manufacture of bearings, gears, gearing and driving elements (28.15); Building of ships and floating structures (30.11). The company *i* is considered related if its primary activity sector (NACE code with 4 digits) shares the same two ("*Complementarity 2-digit*") or three ("*Complementarity 3-digit*") first digits of the MRET core sectors.

The third group of variables deals with the company’s innovation capacity. We assess innovation capacity against two proxies: the participation in RTD projects; and the number of patents granted. The former includes European (Horizon 2020) and national (Portugal 2020) funded projects. Companies are also assessed on whether (or not) they have been granted any European patent (cf. EspaceNet).

The fourth group of variables reflects the firm characteristics, namely: the size measured by the number of employees ("Employees"); the internationalization level measured by the share of foreign capital in the ownership ("% Foreign Capital); and the financial health reflected by the profitability as measured by the return on invested capital ("ROIC").

The fifth group of variables comprises the sector characteristics. It includes variables focusing on the technological content of the company's activity sector, based on the EUROSTAT indicators on High-tech industry and Knowledge-intensive services (EUROSTAT, 2018). Accordingly, the variables "LowMedTech" and "HighMedTech" are dummies assuming the values 1 and 0 if the firm has the primary sector classified respectively in the "low and medium-low technology" and "high and medium-high technology". The services are classified as knowledge-intensive services ("KIS") and less knowledge-intensive services "LessKIS".

Finally, we also include a variable called "*Energy*" to designate companies active in the energy field. We identified these companies in the following manner: three researchers, separately, went through the list of companies in the sample and identified those for which the main activity deals with energy, with reference to either the main sector of activity (NACE) or the nature of their activities; then we retained only those companies that were either unanimously identified as “energy firms” by each of the researchers, or consensually agreed in the meeting for the reconciliation of the lists.

Variable	*Description*	*Source*	*Type*
*Active***	If the company declared* itself as active in MRET (1= active, 0=not active)	Survey	Dummy
Active_level	How the company declared itself in relation to MRET (1 = not enter, 2 = expect to enter; 3 = entered)	Survey	Scale
*Complementarity 2-digit***	If the company's activity sector is part of the core sectors for MRETs according to the ICTSD report (Wind, 2009), NACE sector with 2 digits	Wind 2009, Amadeus	Dummy
*Complementarity 3-digit***	If the company's activity sector is part of the core sectors for MRET according to the ICTSD report, NACE sector with 3 digits	Wind 2009, Amadeus	Dummy
*National project***	If the company participated in a Portuguese project P2020	ANI	Dummy
*European project***	If the company participated in a European project H2020	Cordis	Dummy
*Patents***	If the company has a European patent	EspaceNet	Dummy
Employees	Number of employees; Last available year	Amadeus	Numerical
% Foreign capital	% Foreign shareholders (% Nº of shareholders)	Amadeus	Numerical
ROIC	$Return\ on\ investment = \frac{EBITDA^{***} - depreciation - amortization - taxes}{Net\ current\ assets + Tangible\ fixed\ assets + Intangible\ fixed\ as}$	Amadeus	Numerical
*LowMedTech***	If the company activity sector is classified as the low or medium low technology sector	(Bureau van Dijk, 2019; EUROSTAT, 2018)	Dummy
*MedHighTech***	If the company activity sector is classified as the high or medium high technology sector		Dummy
*Knowledge-intensive***	If the company activity sector is classified as knowledge-intensive service sector		Dummy
Energy	If the company activity sector is in the Energy sector	Expert elicitation	Dummy

* A subset of 40 companies of the 237 did not answer the questionnaire but were considered active due to their direct (as partner) or indirect (as supplier) involvement in the projects.
** Dummy variable: Yes=1; No=0.
*** EBITDA =Earnings before interest, taxes, depreciation and amortization.

Table 2. Description of variables, sources and types

Table 3 presents the correlation matrix between the independent variables with the respective significance. It shows that the significant correlations are not high (above 50%, except for "*Complementarity 2-digit*" and "*Complementarity 3-digit*" which are not considered in the same model), thus allowing us to consider all variables. Table 4 presents descriptive statistics of the variables for the 237 observations (or companies), with few missing values (1.6%). We also present descriptive statistics for continuous variables without outliers.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13
1. Complementarity 2-digit(D)	1.00												
2. Complementarity 3-digit(D)	0.63***	1.00											
3. National project (D)	0.00	-0.05	1.00										
4. European project (D)	0.00	-0.03	-0.04	1.00									
5. Patents (D)	0.02	0.10	-0.01	0.05	1.00								
6. Employees	0.11	0.21***	-0.07	0.15**	0.21***	1.00							
7. % Foreign capital	0.01	0.05	-0.03	0.02	0.09	-0.05	1.00						
8. ROIC	0.05	0.05	0.03	0.03	0.02	0.12	-0.01	1.00					
9. LowMedTech (D)	0.35***	0.29***	0.04	-0.08	0.02	0.09	-0.03	0.02	1.00				
10. MedHighTech (D)	0.58***	0.29***	-0.09	0.16**	0.13**	0.13**	0.00	0.04	-0.20***	1.00			
11. Knowledge intensive (D)	-0.46***	-0.29***	0.08	0.07	-0.03	-0.17**	0.05	-0.07	-0.46***	-0.35***	1.00		
12. Less Knowledge intensive	-0.27***	-0.17***	-0.06	-0.14**	-0.10	0.01	-0.03	0.03	-0.27***	-0.21***	-0.47***	1.00	
13. Energy (D)	-0.08	0.03	-0.13**	0.05	0.05	0.23***	0.00	-0.08	-0.07	-0.07	0.17***	-0.08	1.00

Note: the table displays the Pearson correlations between the variables. *, ** and *** are significance at 10%, 5%, and 1%, respectively.
(D) dummy variable

Table 3. Correlation matrix

	Observations	Mean	Median	Minimum	Maximum	Std. Dev.
1. Complementary 2-digit (D)	237	.211	.000	.000	1.000	.408
2. Complementary 3-digit (D)	237	.097	.000	.000	1.000	.296
3. National project (D)	237	.139	.000	.000	1.000	.346
4. European project (D)	237	.160	.000	.000	1.000	.367
5. Patents (D)	237	.034	.000	.000	1.000	.181
6. Employees	221	79.036	17.000	1.000	1745.000	196.259
6a. Employees without outliers (L)	198	70.763	20.000	2.000	1003.000	147.518
7. Foreign capital	228	.515	.500	.000	1.000	.455
8. ROIC	210	.078	.092	-7.247	2.272	.659
8a. ROIC without outliers (L)	191	.102	.090	-1.570	.974	.318
9. LowMedTech (D)	237	.207	.000	.000	1.000	.405
10. MedHighTech (D)	237	.135	.000	.000	1.000	.342
11. Knowledge intensive (D)	237	.443	.000	.000	1.000	.497
12. Less Knowledge intensive	237	.215	.000	.000	1.000	.411
13. Energy (D)	237	.266	.000	.000	1.000	.442
14. Active – Wave	109	.303	.000	.000	1.000	.459
15. Active – Wind	109	.450	.000	.000	1.000	.497
16. Active – Both (wave and wind)	109	.257	.000	.000	1.000	.437

(D) Dummy variable: Yes=1; No=0. (L) lower/higher 1%.

Table 4. Descriptive statistics

3.3 Model

The binary logit model is the appropriate model (Hosmer and Lemeshow, 2000) to study the probability of an event whose outcome is characterized by a categorical variable with two possible results. We use a binary logit model against the aforementioned database to estimate the effect of the explanatory variables in the decision of firms to develop activities in MRET:

$$Prob(y_i = 1|x_i) = F(\beta_0 x_i + e_i) \quad (1)$$

where the dependent variable *y* is firm's *i* decision to be active in MRET (y_i assumes the value 1 if the firm is active and 0 otherwise) and x_i represents the set of independent variables, as presented in Table 2.

As a robustness check, we test the stability of the results of the binary logistic model by running the same explanatory variables in a multinomial logistic regression model. The dependent variable includes an additional possible outcome—beyond active and non-active—for non-active firms that are interested in MRET and are considering becoming active in the future (*"Active_level"*). We run both models in R with the packages *DescTools* and *nnet.*

4. Results

4.1 Characteristics of active firms

Figure 3 presents the relation between the decision to enter into MRET and several technological and sectoral characteristics of the firms. MRET has low requirements in terms of sectoral proximity, innovation capacity, technological content of products/services and industry. For example, as for sectoral relatedness, sectoral proximity (sharing the first 2 digits of the activities classification) and complementary sectors (sharing the first 3 digits of the classification and included in the core sectors for MRET according to the ICTSD report) are not highly associated with participation (i.e. active firms), comparing with the other variables.

However, the share of energy firms that are active in MRET is higher than that of non-energy firms.

The data show that the technological content (of products) is not an obstacle to the firm’s decision to diversify to MRET. The share of firms active in MRET decreases with the technological content of their products. Similarly, the proportion of companies supplying less knowledge intensive services that are active is slightly higher than the percentage of knowledge-intensive ones (59% vs. roughly 51%). Regarding innovation capacity, the participation in national projects is not associated with the firm's decision to enter in MRET. However, the majority of the firms holding at least one patent are active in MRET.

Overall, the characteristics of the active firms suggest that technological content or knowledge intensity of activities, innovation capacity, and sectoral proximity, are not likely to become barriers to entering into MRET.

The involvement of this type of firms can be illustrated with two cases. One concerns firms from sectors such as manufacture of metal structures and shipbuilding. Several firms from these sectors, particularly the former, have been involved in the manufacture of the parts of the conversion systems as well as provided products or services to support their installation. But among these, two firms have moved beyond being occasional suppliers to become more closely involved in product development in several wave energy and offshore wind projects. One of them, the metalwork company, has turned into a key supplier in offshore wind, developing a new line of business with export potential as platform structure provider, and becoming an important contractor to other firms from the sector. The other concerns firms that provide services associated with sea installation and operation, including maritime works, sea-diving, renting and installation of specialized equipment. In the absence of specialized marine engineering companies, these firms, that had no previous connections with the energy area, have entered several projects becoming increasingly proficient in the handling of marine energy projects.

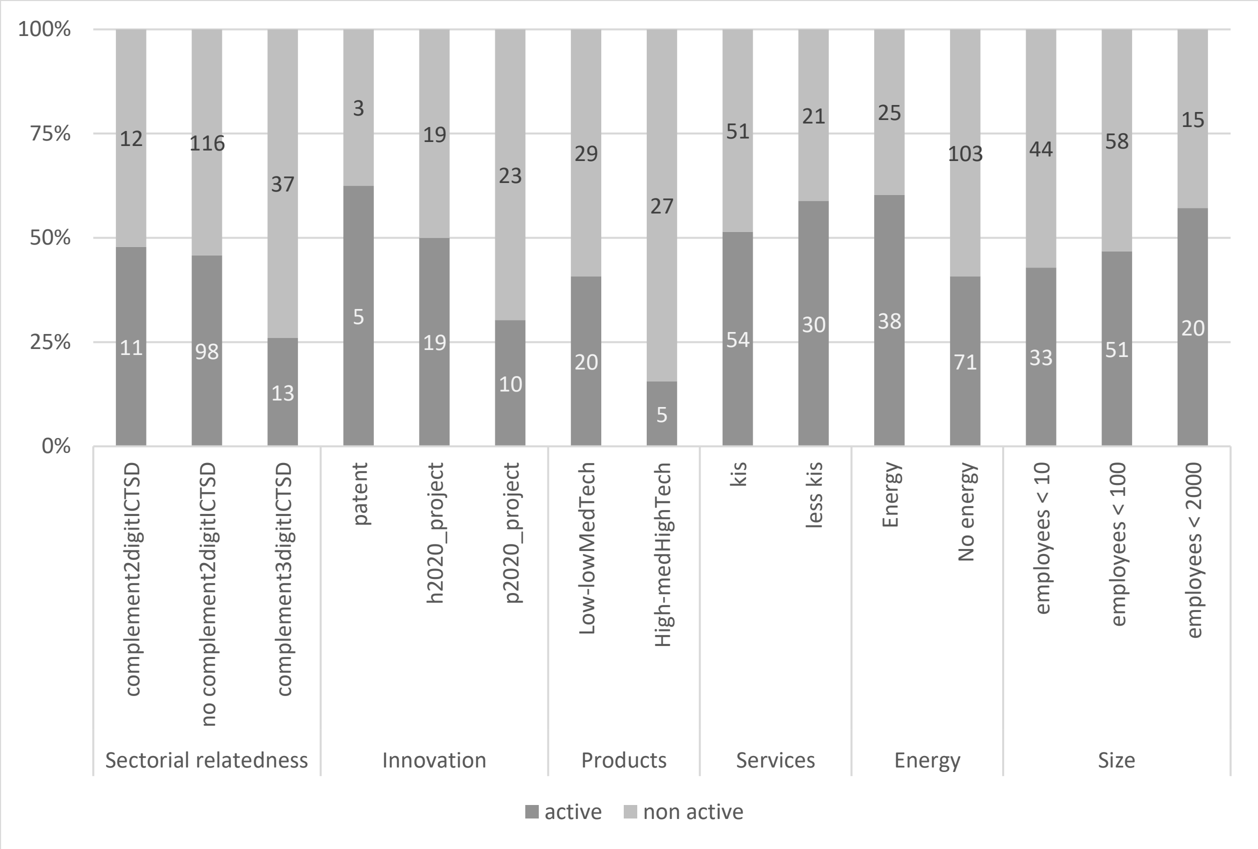

Figure 3. Distribution of firms in active and non-active in MRET by explanatory variable. For example, as for patents, there are eight firms with patents (100%) of which five are active (63%) and three are non-active (37%). See section 3.1 for sources.

Figure 4 presents the novelty of the products or services that active firms supply to MRET, based on the information provided by firms that answered to questionnaire. Firms can either provide new products or services, adapt them, or simply supply existing ones. As expected, firms bring more new products or services if they are more profitable (higher ROIC), are knowledge-intensive, have high technological content and patents. The majority of energy firms and large companies also developed new products and services to enter in MRET. But companies in which foreign capital is dominant (including local branches of multinational companies) commercialize only current or adapted products/services. All in all, the low profile of active firms in terms of innovation and technological capacity did not seem to be a barrier to innovate in MRET.

The innovative behavior of energy companies is more clearly expressed by the case of the large energy incumbent. After providing some support to early wave energy projects, it has actively engaged in the development of a new technology in the then emerging area of floating offshore wind, first partnering with and then acquiring a high technology (foreign) start-up that developed a new type of platform. The incumbent deployed its extensive experience on onshore wind technology, mainly its capabilities in project management and supply chain coordination. This combination enabled the development of a leading technology in the field of floating offshore wind. Other energy companies, especially those with previous involvement with renewable energies, have also had some early involvement in innovative projects in wave energy.

Besides energy companies, innovators can be found among smaller technology-based firms, often from knowledge intensive service sectors that bring advanced competences in areas that contribute to the development of MRET. A particularly interesting case is that of firms in the advanced materials area that have been critical to the production of lighter and sea-resistant structures, especially for wave energy. In one such case, the development and implementation of a new structure also led to innovative activities being conducted by an established plastics company. But there are other cases in which innovation activities also emerge in less technology intensive sectors, an example being the already mentioned metalwork company whose work for offshore wind involved extensive product and process innovations.

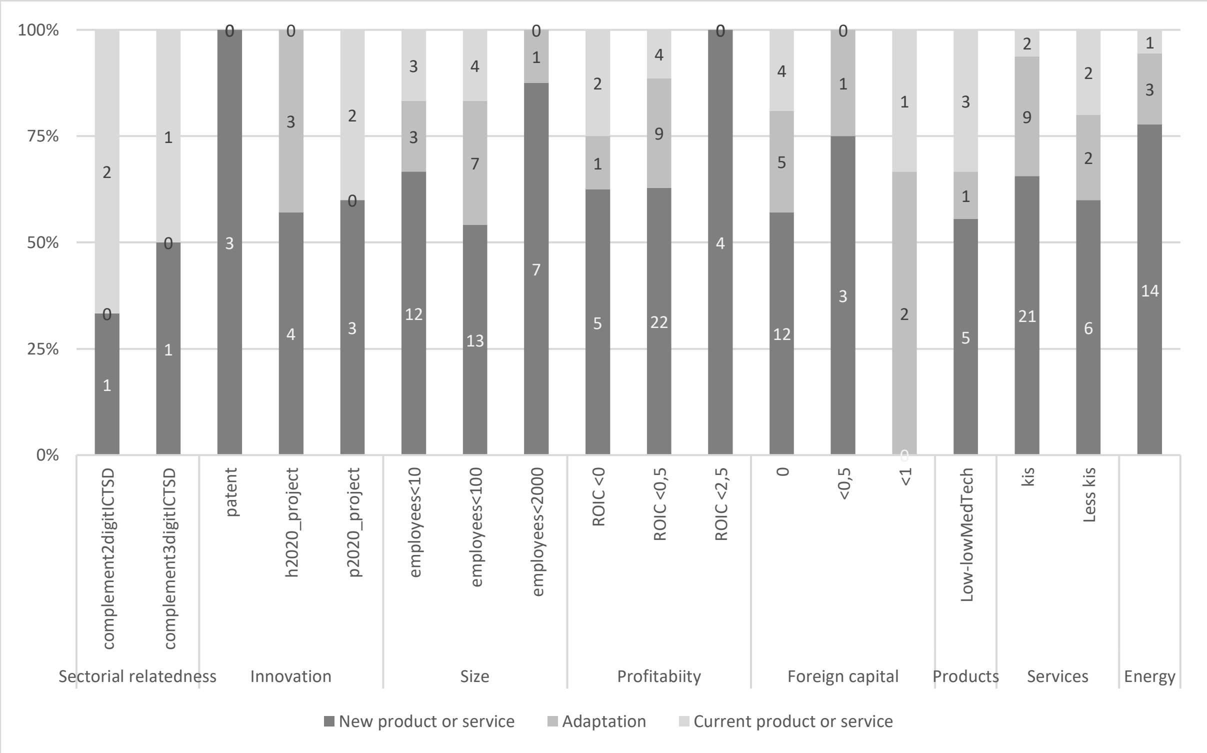

Figure 4. Distribution of active firms that answered to the questionnaire by explanatory variable in terms of the type of innovation they brought to the system: new product or service; adaptation (of currently sold products or services); current product or service (without any adaptation). See section 3.1 for sources.

4.2 Drivers of entry

We apply a binary logit regression (OLS) to assess the effect of the factors which may impact the decision of the surveyed firms to enter into MRET. Table 5 presents the results of the full model including all drivers, as well as of two partial models that analyze in more detail the effect of the variables underpinning inter-sectoral relations: technological relatedness and technological variety. The full model provides a good fit with a Pseudo R^2 higher than 50%.

The results show that "Complementarity (2digits)" (i.e. proximity) and variables associated with innovation capacity—particularly “National projects”—have either a negative or no statistically significant effect. Particularly for the latter, the results confirm an inverse relationship between the national projects and activity in MRET. This might be in part explained by the lack of continuity of support policies for MRET, namely during the financial crisis of 2009-2010, as discussed by Fontes et al. (2019). These results confirm the previous analysis of raw data, about the role of low barriers to entry in MRET. On the other hand, “Energy” firms have a positive and significant effect in the partial model, but lose significance in the full model, which indicates that other determinants are more important to explain the firms’ decisions.

The technological content of the companies in low/medium-low technology sectors has a positive and highly significant coefficient. That is, the firms in sectors with a medium- high or high technological content (i.e. the default category) have a negative propensity to be active in MRET. Service firms show a higher tendency to become active in MRET. In particular, less knowledge-intensive service (Less KIS) firms have a positive and significant coefficient. The odds of becoming active for these firms are 39.33 (exp(3.672)) times the odds of entering for a firm with a medium-high or high technological content, all other things being equal. In other words, a less knowledge-intensive service firm is almost 40 times more likely to become active than firms from sectors with higher technological content. These results again confirm the outcomes from the early correlation analysis.

Overall, the technological variety model explains the firms’ decisions slightly better (i.e. higher Pseudo R^2) and includes a higher number of variables that remain significant over the different models, when compared to the technological relatedness model.

We address outliers by winsorizing independent variables at the 1st and 99th percentiles before estimating coefficients in the model "All drivers without outliers". The results remain stable after excluding the outliers. The results remain roughly the same if we winsorize at 5th and 95th percentiles (not shown).

As a further sensibility check, we run the same model in a multinomial version (Appendix 1). In this model, the dependent variable can assume multiple values from 1 to 3, whether the company declares to be non-active (defined as default), to show interest in becoming active (value 2 or “Interest”), or to be active in MRET (value 3 or “Active”), respectively. In the case of firms declaring the intention to enter into MRET (“Interest”), there is no explanatory variable with statistical significance. The results generally confirm the conclusions of the binomial analysis for the “Active” firms, especially for the coefficients with significant variables: complementarity; national projects; medium low or low technological content; and service companies, notably less knowledge-intensive service.

Dependent variable: Active				
	Tech. Relatedness	Tech Variety	All drivers	All drivers *without outliers*
Complementarity (2-digit)	-1.152***		.138	.122
	(.380)		(.641)	(.681)
National project	-.842**		-1.141**	-1.194**
	(.436)		(.482)	(.492)
European project	-.143		-.033	-.077
	(.390)		(.466)	(.487)
Patents	.454		1.691	1.663
	(.805)		(1.039)	(1.059)
Size (Nº of employees)	.001		.001	-.0003
	(.001)		(.001)	(.001)
Energy	.709**		.613	.351
	(.334)		(.404)	(.429)
% Foreign Capital		-.458	-.481	-.489
		(.329)	(.361)	(.379)
Profitability (ROIC)		-.001	-.023	.478
		(.216)	(.229)	(.543)
Low/Medium-Low tech		1.700**	2.215**	2.832**
		(.692)	(.870)	(1.137)
Less-Knowledge-intensive		2.699***	3.672***	4.251***
		(.699)	(1.024)	(1.259)
Knowledge-intensive		2.119***	2.771***	3.171***
		(.648)	(.981)	(1.218)
Constant	-.031	-1.852***	-2.608***	-2.979**
	(.199)	(.633)	(.974)	(1.209)
Observations	221	203	191	172
Pseudo R²	.236	.369	.517	.516
Log pseudo likelihood	-141.230	-128.004	-110.886	-100.151

"Active" is the dependent variable which equals 1 if the firm was found or declared in the survey to be active in the development of MRET, or 0 otherwise. See the list of variables in Table 2 for a detailed explanation of the independent variables and sources. Standard errors are in parentheses. Pseudo R^2 corresponds to the Nagelkerke R^2. Notation of the significance levels: *p<0.1; **p<0.05; ***p<0.01.

Table 5. Results of Logit analysis (with ordinary least squares) of the decision of firms to enter into MRET

4.3 Determinants of inter-sectoral relations

Additionally, we run the multinomial model separately by type of sector and technology. Figure 5 shows the coefficients of the full model, for firms that declared “Interest” or “Active”, by type of sector, i.e. in terms of the sector's technology content and the knowledge intensity of the services. The high tech category shows more heterogeneous results, which is likely to be due to the lower number of observations. In terms of major and significant effects, when comparing firms in Low tech and High tech sectors the number of patents always has a positive effect (except for “interest” of Low techs). In addition, national research projects increase both the “interest” and “activity” of High techs; profitability increases the probability of High techs becoming “active” whereas complementarity and European projects reduces this probability. Regarding the firms in service sectors, European research projects increase both the “interest” and “activity” for less knowledge-intensive service firms, while national projects decrease their “interest”; patents have a negative effect on the “interest” of knowledge-intensive service firms. These latter firms tend to be more specialized and have a lower capacity to redeploy their competencies into MRET. Finally, in terms of the determinants of the inter-sectoral relations, technological variety variables such as share of foreign capital and profitability only discourage the “interest” and “activity” of Low techs, while foreign capital and profitability, respectively, decrease and increase the “activity” of High techs. In contrast, technological relatedness variables have more significant effects across the sectors but their effects are confounding. The exception is energy, which has a positive and statistically significant impact on activity, excluding less knowledge-intensive services.

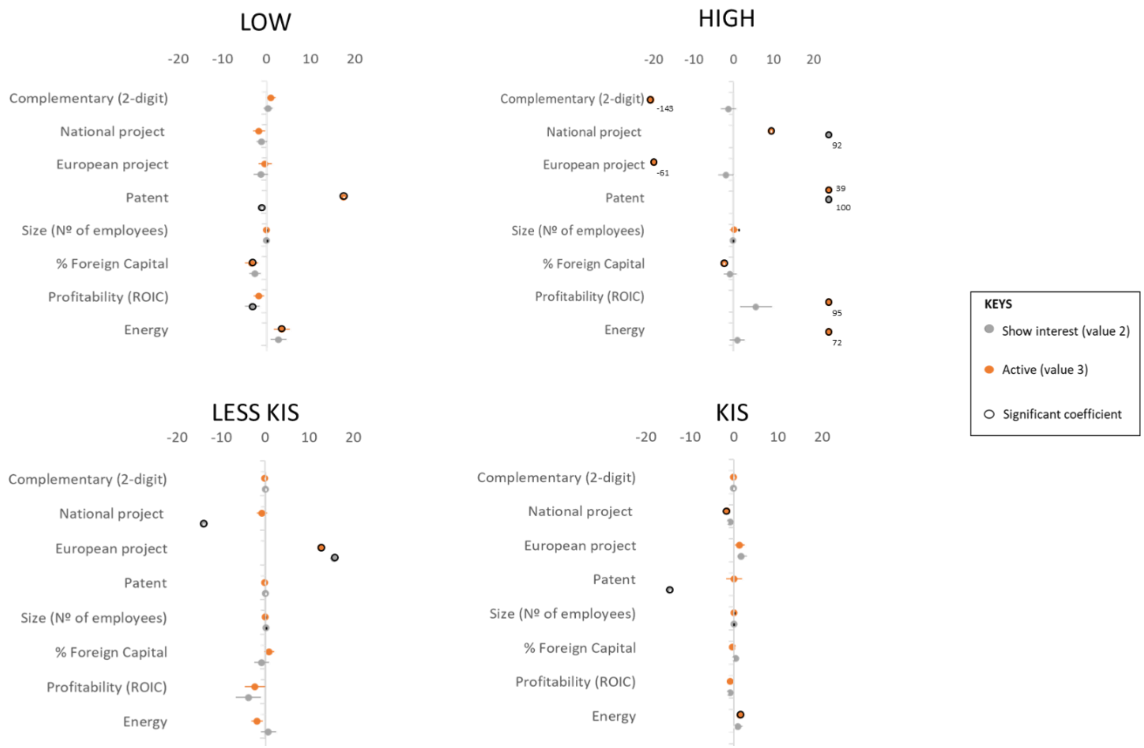

Figure 5. Coefficients of the multinomial logit regression of the decision of firms to enter in MRET by technological content of the home sector: Low Tech (n=40), High tech (n=25), Less KIS (n=90) and KIS (n=36). (non-active as default)

Figure 6 shows the coefficients for a similar multinomial model for different technologies. We analyze the impact of the maturity of technologies on the decision to enter, since wave energy is in an earlier stage and floating offshore wind is approaching commercialization.

There are differences in the drivers of entry into more or less emergent technologies. Firms from sectors with lower technological content have a high likelihood (and significant) to enter into both technologies, but particularly into the emergent wave energy. Similarly, service firms, notably less knowledge-intensive services, have a greater probability of entering in wave energy. However, foreign capital and national projects have a negative effect on the decision to enter into the less mature technology (wave energy). Patents increase the likelihood of becoming active in wave energy and also in both technologies. In the case of the more mature offshore wind, it is interesting to note that the probability of entering is only increased by being less knowledge-intensive service.

Therefore, the results highlight the fact that entry in the less mature wave energy—either alone or combined with offshore wind—is attractive to a wider variety of firms than entry in the more mature offshore wind alone.

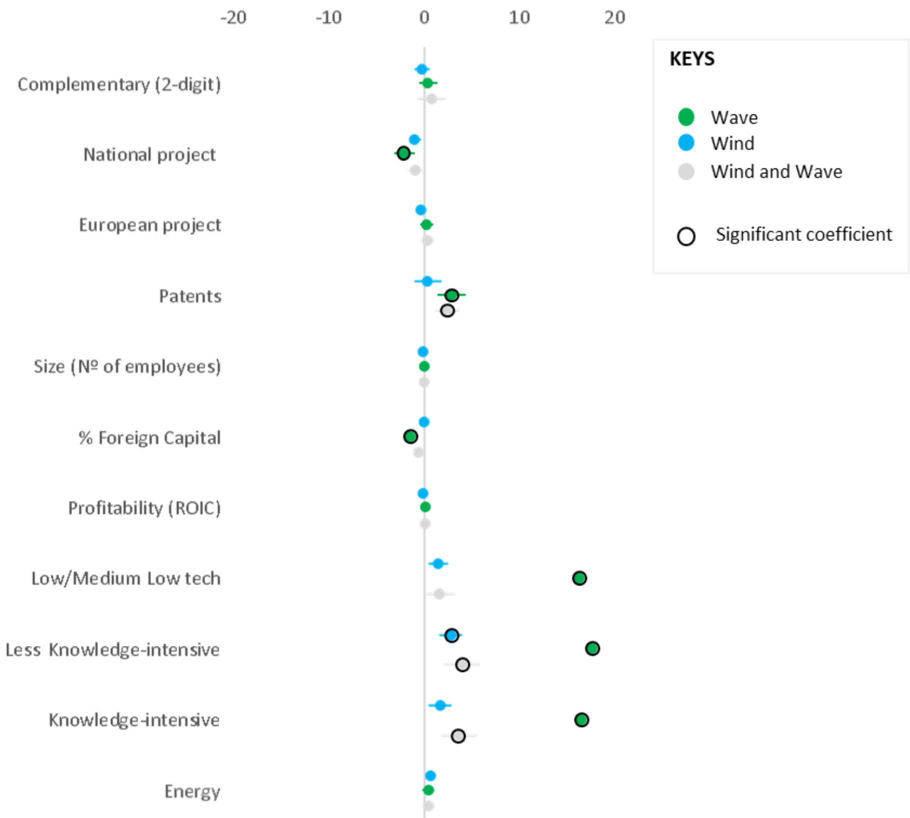

Figure 6. Coefficients of the multinomial logit regression of the decision of firms to enter by type of technology (wave in "green", offshore wind in "light blue" and wave and offshore wind in "gray"). Inactive as default.

5. Discussion

This research aimed at understanding the determinants of firms' entry into emerging technological innovation systems. In particular, it analyzed the effect of the determinants of firms' entry into the establishment of different types of inter-sectoral relations—associated with technological diversity or with technological variety—that are required to build up the components of the value chain of new technology innovation, using the development of marine renewable energy technologies in Portugal as the empirical setting.

The results show that, contrary to initial expectations, technological proximity between sectors and high technological capacity are not necessary for entry. This suggests that there are opportunities for firms from less proximate and less technology intensive sectors.

However, the probability of entry increases slightly for service firms, particularly less knowledge intensive service firms (Less KIS). These companies are a source of variety that creates links between different knowledge bases and act as facilitators.

The types of sectoral interactions have different relative importance. The analysis shows more consistently significant factors associated with variety-led interactions than with relatedness-led interactions. Several factors, such as low/medium-low technology content and (especially Less) knowledge-intensive service, proved to have a consistent positive effect.

Finally, the analysis indicates dimensions which are particularly important in the formation of the system. The variables that are more consistently significant—technological content and knowledge-intensive service—are associated with the development of the TIS dimensions actor base and technology performance (see Table 1). This highlights the role of the technological and political dimensions (Bergek et al., 2015) in the development of new technology innovations like MRET. Technology performance is crucial for advancing towards commercialization. The actor base underlines the importance of stable prospects and policies to attract supply-side actors (Bakker, 2014).

5.1 Implications for theory

The results from this study offer three main contributions to the theory. Firstly, they enlarge the knowledge about the role of context in TIS growth. The study extends the understanding of TIS-context interactions (Bergek et al., 2015) by analyzing the behavior of firms from other sectors. It examines the role of different relationships between sectors (Markard and Hoffmann, 2016), particularly of two types of inter-sectoral relations—associated with technological variety and with technological relatedness—in the construction of the value chain that supports emerging TISs. The analysis also extends previous studies on the effect of inter-sectoral interactions in technological innovation systems beyond the effect on knowledge creation and dissemination (Stephan et al., 2019; Malhotra et al., 2019), to include the access to other technical and non-technical resources.

Secondly, the results shed light on the microeconomic foundations of the influence in the direction of search, which is a crucial function in a system's growth (Bergek et al., 2008). By bridging different streams of the literature, e.g. management/organization studies and sustainability transitions, the analysis was able to estimate the effect of the micro-level factors behind inter-sectoral relations. It uncovers the heterogeneity of actors and their diverse motivations, which gives entry points for the policy to influence the direction of search. This also shows that no single strategy can effectively attract different firms/industries to compose the value-chain (see Section 4.2).

Therefore, the paper contributes to a better understanding of the mechanisms that attract new actors. These mechanisms interplay, at different levels, with firm level factors underpinning different types of inter-sectoral relations that enable the development of the system. But this raises questions about the content and the delimitation of the "influence in the direction of search" function. The widely used definition refers to it as "the extent to which supply-side actors are induced to enter ...or… direct their search and investments towards the TIS" (Bergek et al., 2008: 578). This definition entails a conflation of distinct meanings. The first part focuses on the sectoral relations to build the value chain, while the second part points to the importance of the technology for the companies. The definition also has a problem of conceptual delimitation. It clearly overlaps with those of other functions, such as resource mobilization, materialization and even experimentation, for the study of the same phenomena of "inter-sectoral relations", i.e. firms from other sectors that bring necessary resources to the system. Given the growing importance of inter-sectoral relations and combinatorial processes in innovation (e.g. Youn et al., 2015), future works must clarify both the definition of the function influence in the direction of search and its relationship with the other functions.

5.2 Implications for policy

These results show that high technological capacity and sectoral proximity are not requirements for entry; this indicates that there are opportunities for a greater variety of existing sectors to be mobilized than the literature usually considers (e.g. Boschma, 2017). Technology development may recombine knowledge already present in the context, as to progress faster, opening opportunities for firms from other sectors to diversify (Janssen and Frenken, 2019). This is important news for policymakers willing to guarantee that the development of emerging technologies has positive impacts on the more established or traditional industries. However, the absence of technological capacity and sectoral proximity may challenge the establishment of inter-sectoral relations, as it limits the scope of overlaps with competencies and resources from established sectors (Bergek et al., 2015; Mäkitie et al., 2018).

So far, MRET in Portugal have shown a limited capacity to attract high technology firms that bring in and recombine specialized competences from other sectors. This is especially evident in what concerns the manufacturing industry, the very few exceptions being some firms in more proximate sectors such as electric equipment or electricity production, including the large energy incumbent that assumed a leading role in offshore wind, after being less directly involved in several pioneer wave energy projects. In what concerns knowledge intensive services, and despite the prevalence of Less-KIS sectors, it was possible to identify several firms that provide services with a high technological content in areas such as materials, robotics, instrumentation or logistics. Interestingly this type of KIS has a stronger weight among the firms that expressed the intention of entering MRET in the future. This is important since their contribution can particularly important to the innovation process. But, so far, the participation of high technology firms may still be beyond the needs of technologies that are far from maturity and may require more than incremental technological advances. This is also a problem that needs to be overcome if a competitive industrial value chain is to be built around MRET. Under these circumstances, policies should promote and/or remove the obstacles to interactions, namely by favoring the creation of linkages between sectors (Janssen and Frenken, 2019), including the incentive to technological diversification from High tech sectors. In this respect, typical policy instruments are targeted R&D funding, demonstration projects, mandatory disclosure of results, promotion events (Jacobsson et al., 2017).

5.3 Conclusions, limitations and research agenda

We have conducted a survey of companies in sectors relevant to MRET development, complemented by search in secondary sources, obtaining information from 237 companies that include the majority of the companies that have participated in R&D and demonstration activities in marine renewable energy technologies in Portugal in the past two decades, as well as a number of companies that expressed the intention to do so in the future. The analysis focused on the factors that explain firm entry into MRET and have produced three main findings. Firstly, typical drivers of firm diversification found in the literature only partially explain the decisions of companies to enter in MRET. Secondly, drivers associated with variety-led sectoral interactions had more weight in the decision of firms than those related to relatedness-led sectoral interactions. Thirdly, firms from a wide spectrum of sectors found opportunities in MRET, motivated by factors that align with the needs of the system in terms of the construction of an actor base and improvement of the technology performance.

The analysis represents two significant improvements over the literature on the mechanisms of TIS growth. First, this paper contributes to identifying the firm level factors that determine the decision to enter emerging technological innovation systems. Previous research shows how the TIS development process is influenced by the interactions that are established with the context (Bergek et al., 2015; Markard et al., 2018). However, little was known about the factors that affect the technology's capacity to attract actors from existing sectors that provide resources and competences for the development of the new value chain. Our findings reveal some of the factors that participate in the firms' decision to diversify, such as technological content and knowledge capacity (these two latter factors with low requirements). Second, it highlights the microfoundations of the sectoral interactions associated with technological variety and technological relatedness. Hence, this research not only contributes to a better operationalization but also reveals shortcomings in the innovation process influence on the direction search, which is a crucial function in the emergence and growth of new systems. Our work also identifies levers at the level of sectors and sectoral relations that can be targeted by policies to stimulate investment in the system.

The analysis has some limitations. Despite being well-accepted in the literature (e.g. Laurens et al., 2018), the use of the main activity of a firm to measure technological content and proximity of firms overlooks the possibility of heterogeneity between firms in the same sector—even in NACE codes defined at 3 digits. Firms can be characterized by their main sector but also have activities in other sectors. For instance, the analysis revealed a scarcity of high technology companies among those active in MRET, contrary to expectations. However, some of the firms identified, particularly from the knowledge intensive service sectors, provide services with high technological content (e.g. robotics). Nevertheless, the still reduced involvement of high technology firms from other sectors may limit more consequent technological improvements and *in fine* the technology trajectory.

Generalization of these findings is limited to the socio-economic nature of the context and to the technologies with MRET characteristics. Subsequent research could expand the knowledge about the determinants of firms' entry to different types of technologies. Future work could also deepen the knowledge on the firms' behavior after entry, namely by examining the strategies pursued by firms with different profiles and the transformative impacts on both the technology and the context. For example, we have not analyzed the firms' survival in the system, or the benefits of early move strategies by pioneers. In the future, more data will be available to enable these analyses.

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Appendix 1. Results of multinomial logit analysis (with ordinary least squares) of the decision to enter into the development of MRET

	Dependent Variable: Active_level							
Model	**Tech Relatedness**		**Tech Variety**		**Full model**		**Full model without outliers**	
Active level (ref.Non Active)	Interest	Active	Interest	Active	Interest	Active	Interest	Active
Complementarity (2-digit)	-.026	-1.175***			.043	.166	-.261	-.008
	(.416)	(.437)			(.695)	(.753)	(.722)	(.808)
National project	-.452	-1.046**			-.578	-1.385***	-.763	-1.504***
	(.489)	(.488)			(.524)	(.531)	(.557)	(.541)
European project	.600	.203			.527	.332	.734	.355
	(.526)	(.510)			(.575)	(.587)	(0.606)	(0.629)
Patents	-.611	.197			.481	1.910	.477	1.956
	(1.267)	(.930)			(1.511)	(1.291)	(1.533)	(1.334)
Size (Nº of employees)	-.002	.0002			-.002	.0004	-.002	-.001
	(.001)	(.001)			(.002)	(.001)	(.002)	(.001)
Energy	.831	1.190**			.800	1.074*	.675	.735
	(.524)	(.477)			(.593)	(.557)	(.617)	(.576)
% Foreign Capital			-.005	-.459	-.298	-.639	-.335	-.655
			(.424)	(.391)	(.458)	(.432)	(.487)	(.454)
Profitability (ROIC)			-.114	-.067	-.102	-.091	-.772	.058
			(.293)	(.284)	(363)	(.350)	(0.674)	(0.674)
Low/Medium-Low tech			.161	1.784**	-.567	2.495***	.696	3.170***
			(.580)	(.755)	(.667)	(.939)	(.760)	(1.196)
Less Knowledge-intensive			-.290	2.564***	-.131	3.635***	.132	4.316***
			(.677)	(.764)	(.979)	(1.130)	(1.088)	(1.366)
Knowledge-intensive			.029	2.133***	-.272	2.908***	.293	3.295**
			(.503)	(.696)	(.800)	(1.075)	(.917)	(1.306)
Constant	.110	.671***	.020	-1.148*	-.093	-1.955*	-.016	-2.261*
	(.281)	(.242)	(.472)	(.676)	(.756)	(1.056)	(.893)	(1.292)
Log pseudolikelihood	-219.207		-203.241		-177.268		-158.865	
Pseudo R²	.287		.417		.585		.597	

Active" is the dependent variables that can assume multiple values from 1 to 3, whether the company declares to be non-active (1), have the intention to become active (2) or to be active (3) in MRET, respectively. See the list of variables for a detailed explanation of the independent variables and sources. Standard errors in parentheses. Pseudo R2 corresponds to the Nagelkerke R2. Notation of the significance levels: *p<0.1; **p<0.05; ***p<0.01.

Appendix 2. Information obtained from questionnaire survey

The survey targeted firms from sectors identified as potential contributors to the development, production, installation and operation of MRET, including firms previously found to be active in MRET. It was conducted with two main objectives: (i) to ascertain the position towards MRET of firms from these sectors; (ii) to obtain information about the nature and conditions of firms' involvement.

This paper used only two questions from the questionnaire:

Participation in MRET

Question: The firm is / has been involved in activities related to marine renewable energy area (e.g. offshore wind, wave energy, tidal energy)? *[choice directs to set of questions related to specific situation; dummy]*

1. Yes, is currently involved
2. Yes, has been involved but abandoned these activities
3. No, but envisages to become involved in the future
4. No, and has no intention of operating in the area

Answers to this question were coded as:

Variable Active - Active: 1 & 2; Not active: 3 & 4
Variable Activity level - Entered: 1 &2; Expect to enter: 3; Not enter: 4

Note: In the paper, the categories "Active" and "Entered" include also firms that were found to be active through participation in experimental projects as partners or suppliers, but did not answer to the questionnaire.

Novelty of products or services supplied to MRET

Question: Please indicate the nature of the products/services supplied by the firm to the marine renewable energy area *[multiple responses from list, dummy]*

1. Products, systems or methods developed specifically for this area
2. Adaptation of products or systems already part of the firm portfolio, to new applications for this area
3. Supply of standardized products or systems, which are part of the firm current offer
4. Services involving new strategies or methods for testing, installation, operation or maintenance of systems
5. Services, which are part of the firm current offer, for testing, installation, operation or maintenance of systems

Answers to this question were coded as:

New products or services: 1 & 4
Adaptation of existing products: 2
Currently sold products or services: 3 & 5