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Intersectoral Knowledge Spaces of Emerging Technologies and Innovation Opportunities for Established Industrial Sectors

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Abstract
The paper investigates how the emergence of new sustainable technologies can induce innovation and change in the industrial sectors that contribute competences and resources to their development. For this, it develops and tests a framework to address knowledge recombination processes at the intersection of diverse sectoral knowledge bases. The paper maps the intersectoral knowledge space formed as part of the emergence of a new sustainable technology, marine renewable energy, and proposes that the position of a sector in that space – in terms of variety of connections and (un)relatedness between the connected sectors – is associated with differentiated opportunities for innovation and engagement in diversification into a new business. This research contributes to the literature on the industrial transformative effects of new technologies by uncovering some of the processes through which intersectoral knowledge relationships generate opportunities for knowledge (re)combination and innovation in firms from existing sectors. The results can inform policies that aim to combine sustainability and industrial development goals.

Keywords Intersectoral relationships · Knowledge (re)combination · Innovative firm behaviour · Technology emergence · Sustainable energy technologies

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Introduction

This paper aims to contribute to a better understanding of the transformative effects of new sustainable technologies, that is, how the development of these technologies can induce innovation and change in other sectors of the economy. This is an important question as the presence of co-benefits from the development and deployment of sustainable technologies can accelerate energy transition and contribute to industrial transformation (Andersen et al., 2026; Geels et al., 2023).

The sustainable transitions literature provided some contributions to address this question, investigating the interactions between the system being formed around a new technology and the context – namely the industrial context - within which it emerges (Bergek et al., 2015). However, this literature focused on the impact of the interactions on the development of the new technology (Mäkitie et al., 2018; Markard & Hoffmann, 2016), with limited research addressing their effects in the industrial context. That research found evidence of innovation and change in existing sectors that engage with the new technology as resource providers (Fontes et al., 2021). But the processes that lead to these effects need to be better understood.

The paper addresses this gap, by mobilising contributions from innovation and technological change and evolutionary economic geography literatures. These literatures enable us to take in consideration the knowledge combination processes that occur as part of these interactions and thus to better explain their innovation outcomes.

The research starts from the question of how intersectoral relationships, established along the process of emergence of a new technology, create conditions for the combination of new and existing knowledge, generating opportunities for innovation in existing sectors that contribute with competences and resources to its development.

To answer this question, we propose an analytical framework based on two main literature-derived premises. First, that the development of a new technology entails combination of new and existing knowledge (Arthur, 2009; Krafft et al., 2011; Plechero & Grillitsch, 2023) and that relationships between different sectors, with diverse knowledge bases, are an important element of this process (Stephan et al., 2019). These relationships form an 'intersectoral knowledge space' (Lamperti et al., 2020) that provides fertile ground for knowledge sharing and generation of new knowledge combinations, creating opportunities for innovation.

Second, that the opportunities for innovation and the type of innovation that result from these interactions are influenced by the configuration of the intersectoral knowledge space, as its characteristics – in terms of knowledge variety and relatedness - affect the recombination process (Antonelli et al., 2010). Thus, the position of a sector in the knowledge space shapes the innovation opportunities that arise for its firms (Lamperti et al., 2020), influencing the variety of sectors to which it is connected and the relatedness between their knowledge bases.

Based on these premises, we develop and apply a two-dimensional framework to account for the extent and type of innovation opportunities that arise for firms in existing sectors, as a result of their interaction with the system emerging around the new sustainable technology. The case of marine renewable energy technologies (MRET) in Portugal is used as empirical setting. This choice is based on the fact that

MRET are complex technologies whose development rely, from very early stages, on resources present in a variety of existing sectors, both established - including sea-related traditional industries experiencing some decline - and new (Bjørgum & Netland, 2017; van der Loos et al., 2021).

The empirical research maps the intersectoral knowledge space for this technology and examines how differences in its configuration are associated with variations in firms' innovative behaviour. The results suggest that the characteristics of the knowledge space have a differentiating effect on the sectors' firms ability to identify and explore the innovation opportunities arising at the interaction between different sector knowledge bases.

The paper adds to the sustainable transitions literature, by contributing to a better understanding of how a new sustainable technology can drive change in the established sectors that provide resources to its development. It does it by uncovering some of the processes through which intersectoral knowledge relationships generate opportunities for technology-oriented innovative behaviour among firms from these sectors. The research also contributes to the literature on intersectoral knowledge interactions, by exploring the processes at work in the knowledge space formed by these interactions, along the development of a new technology. It proposes and empirically illustrates the use of a framework that contributes to a better understanding of the innovation outcomes associated with knowledge recombination between sectors differentially positioned in the intersectoral knowledge space.

The paper is organised as follows. Section 2 reviews the literature on intersectoral relationships, knowledge combination and innovation and develops the analytical framework. Section 3 describes the empirical context and research strategy. Section 4 presents the results and Section 5 concludes the paper.

Literature Review

The Development of New Technologies Creates Opportunities for Established Sectors

The emergence and development of a new technology is a complex process that requires the creation of a new system around the technology (Carlsson & Stankiewicz, 1991). This systemic view was further conceptualised by the sustainable transitions literature through the concept of technological innovation system: the network of actors and institutions that jointly interact in a specific technological field and contribute to the generation, diffusion, and utilisation of a technology (Bergek et al., 2008; Carlsson & Stankiewicz, 1991). More recently, this literature has also stressed the role of context structures (sectoral, political, technological, geographical) within which the new system is embedded and with which it interacts as part of its development (Bergek et al., 2015). Research has focused on the contribution of these interactions and the complementarities they generate to accelerate the development of the new technology (Mäkitie et al., 2018; Van der Loos et al., 2021).

However, less attention has been given to the reverse effect of these interactions, that is, to the capacity of the new technology to induce change on its context (Andersen et al., 2020; Fontes et al., 2021). In particular, there is limited research on the transformative effects of the interactions with existing sectors that provide resources to the development of the new technology (Braunerhjelm et al., 2000; Stephan et al., 2019). Moreover, the scarce research revealed the presence of some transformative effects (Fontes et al., 2021) but did not delve into the processes that take place as part of these interactions and enable change to occur in the existing sectors. An understanding of these processes would be important to potentiate the transformative potential of new sustainable technologies.

Research on the process of new technology development has shown that intersectoral interactions provide opportunities for the recombination of new and existing knowledge and artifacts (Arthur, 2009; Stephan et al., 2019), which can also drive new activities in established sectors (Dolata, 2009; Janssen & Frenken, 2019). It is therefore relevant to understand how these recombination processes occur and how firms from existing sectors can benefit from them to innovate, creating opportunities for diversification and change (Helfat & Eisenhardt, 2004).

Interaction Between Sectors and Knowledge Combination for Innovation

The development of a new technology requires creation of new knowledge. New knowledge results from the reconfiguration of old knowledge, or from novel combinations of new ideas with existing knowledge (Arthur, 2009; Fleming, 2001; Schilling & Green, 2011). To achieve these novel combinations, it may be necessary to bring together and integrate a variety of existing technologies, some of which previously unrelated (Grillitsch et al., 2018; Krafft et al., 2011).

Technologies are often complex systems consisting of a diversity of components and subsystems, integrated into larger systems, whose production requires different knowledge bases and production processes (Murmann & Frenken, 2006). So, their value chains encompass different sectors that have the needed knowledge bases and production competencies (Malerba, 2002; Stephan et al., 2019). Innovation processes along the development of new technologies will thus require interactions and knowledge flows between different sectors. These interactions can support mutual learning and integration between these sectors' diverse and sometimes distant knowledge bases (Malhotra et al., 2019; Stephan et al., 2019).

The literature on innovation and technological change has long argued that innovation is a combinatorial activity (Arthur, 2009; Henderson & Clark, 1991; Schumpeter, 1934) and that technological spillovers across different industries are critical for innovation (Klevorick et al., 1995). Intersectoral relationships enable access to and integration of diverse knowledge that can be recombined into more novel innovations (Arts & Veugelers, 2015; Janssen & Frenken, 2019). Thus, interactions between a variety of sectors increase knowledge diversity offering better conditions for the creation of new knowledge (Stephan et al., 2019).

However, for firms within sectors intersectoral relationships can be difficult to establish and manage, because of the differences between sectors in knowledge bases, i.e., in knowledge about technologies and markets (Malerba, 2002). In particular, integration of knowledge more distant from the one prevailing in the sector is complex, increasing the risks inherent to the innovation process (Fleming, 2001).

The problems associated with distant knowledge are explained by the fact that prior (related) knowledge is necessary to identify, assimilate and combine the new knowledge (Cohen & Levinthal, 1990). That is, some cognitive proximity is required (Boschma, 2005; Nooteboom, 2000). Thus, even when firms search outside their sector, there will be a tendency to bring-in and combine knowledge that is more related to the existing knowledge base (Caviggioli, 2016; Criscuolo et al., 2018; Li et al., 2020). However, it was also shown that search for more distant knowledge, despite its greater complexity, increases the variety of technological opportunities (Cantner & Pyka, 1998) and can result in greater novelty and originality, and therefore in more radical innovations (Fleming, 2001; Schoenmakers & Duysters, 2010).

One basic notion that can be derived from this literature is that knowledge that is more related to own knowledge bases is more easily identified, assimilated, and recombined with the existing one, as compared with less related knowledge, even if the latter can eventually offer greater rewards (at the cost of higher risks). This notion holds when we move from the firm level to the sectoral level, to discuss the process of knowledge combination across sectors. Frenken et al. (2007) introduced the concepts of related and unrelated variety to address this question. While variety – a diversified composition in terms of industries in a region – is necessary for innovation, the level of relatedness between industries produces different effects. Diversity in terms of related industries – related variety – is more likely to result in knowledge spillovers; while diversity in terms of unrelated industries – unrelated variety – may generate less spillovers, given the greater cognitive distance between actors. Later, Castaldi et al. (2015) argued that the two types of variety give rise to distinct types of innovation. Related variety is behind most innovations, while unrelated variety produces results less frequently but is behind more radical innovations.

The assessment of relatedness between industries presents some difficulties. According to the concept of relatedness, 'two activities, such as products, industries, or research areas are related when they require similar knowledge or inputs' (Hidalgo et al., 2018, p. 452). Since it is difficult to measure these inputs, several approaches were developed to indirectly infer relatedness (Whittle & Kogler, 2020). One of the most influential was proposed by Hidalgo and Haussman (2009) as part of the economic complexity framework (Shahmoradi & Ellili, 2024), based on the notion of capabilities and their association with products. The production of a product requires specific capabilities, understood as a set of tangible and intangible features that are non-tradable. The capabilities required by different products are diverse. They are also unevenly distributed geographically; thus, each place offers a specific group of capabilities. Those capabilities are hard to measure directly. But the co-occurrence of production of a product in two places indicates that those places have the capabilities to produce it, because when two goods require similar institutions, infrastructure, physical factors, knowledge, and technology, they will tend to be produced together (Hidalgo et al., 2007). Thus, Hidalgo and Hausmann (2009) proposed this indirect method of measuring capabilities. Boschma et al. (2012) proposed the application of an indicator of relatedness based on Hidalgo et al. (2007) calculation of proximity between products, to measure the degree of relatedness between new and existing industries in an analysis of the emergence of new industries.

The above discussion shows that knowledge interactions between different sectors raise some challenges but can also create conditions for the combination of more diverse knowledge and thus generate opportunities for innovation. But it also shows that the nature of the knowledge being combined has implications for the innovation outcome. Knowledge combination across related sectors may be more frequent, but produces more incremental innovation, while knowledge combination across unrelated sectors may be less frequent but creates more radical innovations.

The recombination of unrelated knowledge can be particularly important in the early phases of technology development (Kalthaus, 2020), namely in the case of new sustainable energy technologies, which have been described as complex systems that rely on contributions from a variety of technologies (Barbieri et al., 2020) requiring a broader search for knowledge (Fabrizi et al., 2025).

Thus, to understand the knowledge combination processes that occur as part of the emergence of a new technology, it is pertinent to account for both the variety of sectors involved and the relatedness between them.

Intersectoral Knowledge Spaces

Given the role played by intersectoral knowledge interactions in the creation of new knowledge that support the development of new technologies, it is relevant to understand which conditions can make these interactions more conducive to knowledge combination and innovation.

Knowledge networks have been described as mechanisms that support processes of knowledge circulation and sharing (Huggins et al., 2012; Phelps et al., 2012). In particular, the literature on recombinant innovation has described networks as playing a significant role in knowledge combination processes (Fleming, 2001; Krafft et al., 2011). This literature has namely pointed out that the characteristics of the knowledge space in which recombination takes place are relevant for the outcome of such processes (Antonelli et al., 2010). The ‘knowledge space’ is represented as a network in which nodes are constituted by units of knowledge at a given level of aggregation. Antonelli et al. (2010) focused on knowledge networks formed by the co-occurrence of technological classes in patents and found that the characteristics of the knowledge space in terms of variety and heterogeneity affected the effectiveness of knowledge recombination. Tsouri et al. (2022) used data from collaborative projects funded by European framework programs to capture the (re)combinatory processes. They found that structural properties of the network (namely the actors’ embeddedness in the network) and several types of proximity (geographical, institutional, and organisational) have an impact on the evolution of the network related to the emerging technological field.

In this paper we move to a higher level of aggregation, as we are interested in understanding whether the characteristics of the knowledge space formed by the intersectoral knowledge relations influence the recombination process and its innovation outcome. We argue that the configuration of this space affects the capacity to access and combine knowledge originating from different sectors, in the context of innovation processes requiring multiple knowledge bases (Sorenson et al., 2010).

Lamperti et al. (2020) introduced the notion of intersectoral knowledge space to define the network of knowledge flows between industries. According to these authors the position of an industry in this network affects the competitiveness of that industry by influencing its capacity to benefit from the intersectoral knowledge flows. In terms of network configuration, the centrality of actors, which reflects their positioning in the network (Wasserman & Faust, 1994), has been considered an important element, as it is related to different opportunities for accessing the relevant resources that circulate in the network (Powell et al., 1996). Lamperti et al. (2020) point to three main effects of a sector centrality in the intersectoral knowledge space. First, by enabling access to diverse knowledge, it enlarges the variety of opportunities to innovate. Second, by providing exposure to different knowledge flows from different application contexts, it facilitates the recombination of knowledge across diverse technological domains, resulting in more significant novelty. Finally, it may also help improve absorptive capacity and the ability to deal with different technologies and understand application contexts, permitting to match knowledge to industry and market conditions. Therefore, a higher centrality, representing a 'better' positioning of a sector in the intersectoral knowledge space, captures the existence of a set of opportunities and capabilities to the firms belonging to it.

While this approach was applied to assess the competitiveness of existing sectors, we argue that it can similarly be applied to the intersectoral flows taking place as part of the process of development of a new system around a technology. First, it permits to map the flows across sectors and identify more intense (i.e. a higher number) and diverse (i.e. with a higher number of other sectors) connections, which can be regarded as areas of that space in which conditions for processes of knowledge combination are more likely to occur. Second, it permits to identify sectors that are more central in that space and thus are better positioned to access a set of opportunities and capabilities that arise from their position in the space of knowledge flows.

The sector position in terms of the number of different sectors with which it is connected accounts for the intensity and diversity of the interactions. But it does not consider the potential differentiation introduced by the cognitive distance between the sectors, that is, the degree of (un)relatedness between them. However, as seen above, whether sectors and their knowledge bases are more or less related influences the easiness of knowledge combination, and the degree of novelty of innovation that may result from this combination. Thus, it also needs to be included in an analysis of the processes taking place in the intersectoral knowledge space.

Analytical Framework

In this section we develop an analytical framework to address our research question: how intersectoral relationships, established along the process of emergence of a new technology, create conditions for the combination of new and existing knowledge, generating opportunities for innovation in existing sectors that contribute resources to the development of that technology.

We start from the notion that development of a new technology entails processes of combination of new and existing knowledge elements (Arthur, 2009;

Krafft et al., 2011). The access to and integration of this diverse knowledge involve the establishment of technological relationships between different sectors, with diverse knowledge bases (Stephan et al., 2019). The knowledge interactions thus established form a space for knowledge circulation, sharing and combination between sectors: an 'intersectoral knowledge space' (Lamperti et al., 2020). Knowledge combination processes within this space generate innovation opportunities related to the new technology, which can be exploited by firms from the sectors involved. Accordingly, and going back to our question, we propose that the knowledge interactions between the emerging technological system and its industrial context create conditions for novel knowledge combinations, which can provide opportunities for innovation in the latter.

However, the characteristics of the intersectoral knowledge space affect the recombination process, and the position of a sector in that space influences the innovation opportunities that arise for its firms (Antonelli et al., 2010; Lamperti et al., 2020). Two important characteristics can be derived from the literature on knowledge recombination: variety of sectors and level of relatedness between sectors.

Variety is related to the possibility of combining more diverse knowledge, which increases the innovation opportunities. Connections with a greater variety of sectors favour exposure to more diverse knowledge. The position of a sector in the knowledge space – in terms of the variety of sectors to which it is connected - influences the innovation opportunities that arise to its firms. Firms from sectors that are more central – that is, connected with a wider set of other sectors - are exposed to more diverse knowledge and to knowledge from different application domains (Lamperti et al., 2020; Powell et al., 1996) which increases their opportunities to innovate and (potentially) produce more novel innovations.

Relatedness is concerned with easiness of combining knowledge and with the type of innovation outcome. Relationships between related sectors, that is, whose activities require similar capabilities (Boschma, 2017), are easier to establish and knowledge combination is also easier due to cognitive proximity (Nooteboom, 2000). Conversely, relationships between less related sectors are more difficult to establish, and both the identification of opportunities and the process of knowledge combination are more complex. However, the latter may lead to more innovative outputs than the former (Castaldi et al., 2015). The position of a sector in the knowledge space – in terms of the relatedness to the sectors to which it is connected – introduces some differentiation in the innovation opportunities that arise. When a sector is connected to more related sectors there are likely to be more opportunities to innovate. But innovations are likely to be more novel when a sector is connected to more unrelated sectors.

Hence, we define a two-dimensional framework that allows to account for the extent and nature of the opportunities arising for firms from existing sectors to innovate, as a result of their interaction with the emerging technology system (Table 1).

Table 1 Combined effect of variety of intersectoral connections and degree of relatedness upon innovation opportunities

Connections with	Related sectors	Unrelated sectors
High variety of sectors	Easier to combine knowledge More opportunities to innovate Less novel innovations	More difficult to combine knowledge Less opportunities to innovate More novel innovations
Low variety of sectors	Easier to combine knowledge. Limited opportunities to innovate Less novel innovations	More difficult to combine knowledge Limited opportunities to innovate More novel innovations

Data and Methods

Empirical Setting

The empirical setting for the analysis is the activities conducted as part of the development of Marine Renewable Energy Technologies (MRET) in Portugal. MRET encompass both ocean energy, i.e., energy derived from the sea - mechanical energy from waves or tides - and energy produced on the sea - offshore wind, fixed or floating. The technologies being developed in Portugal – wave energy and floating offshore wind – have not yet reached the commercial stage, and therefore activities concern mainly research and experimental development (Fontes et al., 2024; Bento & Fontes, 2019; Vieira et al., 2019).

MRET are complex technologies that require contributions from different technological fields, to develop the energy conversion concepts, turn them into performing systems and devise strategies to best operate them at sea. These activities, conducted in pre-commercial stages, demand the development and test of different generations of prototypes, often followed by feedback to R&D for an eventual rethinking of concepts or reconfiguring some elements and their implementation. Very early prototypes of some core system elements can be developed and tested in laboratory using modelling techniques, but combinations of system elements (increasingly closer to real size) need to be built, assembled and tested in sea conditions (from tanks to open sea) to assess technology performance, reliability, and survivability in the sea environment (Bjørgum & Netland, 2017; Bento & Fontes, 2019).

Building and assembling components and systems, installing them at sea, monitoring their operation requires resources and competences present in firms from a variety of existing sectors (Mäkitie et al., 2018; Fontes et al., 2021), from established (e.g.: metalwork, shipbuilding, sea transport; marine engineering) to emerging (e.g.: new materials; robotics). This entails the establishment of relationships between very different sectors, several of them previously unrelated, from early stages. Some of these activities rely on off-the-shelf products or services, but others require adaptations to the new type of activity or even new developments, that is, create innovation opportunities. These features make MRET an interesting setting for this research.

Research Approach

The empirical research is conducted at two levels: the network level (the knowledge space) and the firm level and involves four steps, summarised in Fig. 1.

At network level, the objective is to uncover the configuration of the intersectoral knowledge space. The first step consists of mapping the network of relationships between sectors formed by collaborative R&D and innovation projects, that is, the 'intersectoral knowledge space'. Network analysis has been widely used to represent knowledge flows and recombination processes in innovation systems, particularly where innovation depends on the integration of heterogeneous knowledge bases across organisational and sectoral boundaries (Powell et al., 1996; Fleming, 2001). In the context of emerging technologies, where formal market relations are still limited and knowledge is largely generated through collaborative experimentation, inter-organisational collaborations provide a particularly relevant empirical window on these processes (Tsouri et al., 2022).

For network analysis, rather than relying on stated preferences, the analysis draws on revealed interactions, as observed through participation in collaborative R&D and innovation projects. Such collaborations imply concrete engagement in joint problem-solving activities and therefore constitute meaningful channels for knowledge exchange and recombination (Huggins et al., 2012). Therefore, the paper draws on secondary data, from national and European publicly funded projects with the participation of Portuguese firms, which involve research and experimental activities in wave energy and offshore wind energy. These projects generate networks that facilitate contacts and constitute channels and conduits for knowledge sharing between sectors, which may or may not be related at the outset, opening opportunities for cross-fertilisation and recombination of knowledge (Arts & Veugelers, 2015; Fabrizi et al., 2025; Janssen & Frenken, 2019).

A total of 64 projects were identified, involving 206 firms (60 Portuguese and the remaining foreign)[1]. To map the network that represents the intersectoral knowledge space, firms involved in these projects are identified and associated with their principal sector of activity, according to the NACE Rev2 classification at 4 digits. The remaining project partners (e.g., research organisations, other non-private organisations) were not considered, since we are mapping knowledge relations between industrial sectors. The nodes in the network are the 62 different sectors to which belong the firms in the projects. To capture the interaction between the sectors, an adjacency matrix was built, where two sectors are linked if firms belonging to them are partners in the same project. The adjacency matrix was valued, and the strength of each tie reflects the number of partnerships established between firms from the two sectors.

The second step consists of the analysis of the network in terms of the centrality of the different sectors, to assess variety[2]. We use degree centrality, defined as the number of direct connections an actor has to other actors in the network (Wasserman

[1] European projects obtained from CORDIS database: https://cordis.europa.eu/projects/en. National projects obtained from the National Innovation Agency database: https://projetos.ani.pt/.

[2] For network analysis as well as network representation we used Node XL Pro (version + 1.0.1.444+).

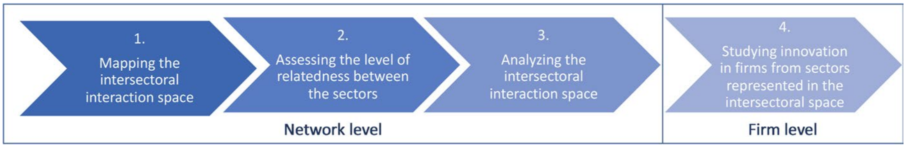

Fig. 1 Research approach: steps of the analysis

& Faust, 1994). Since each node is a sector, degree centrality indicates the number of other sectors to which each sector is linked in the knowledge space, and therefore the variety of sectors to which it is connected. As discussed above, nodes (sectors) connected with a wider variety of sectors have better conditions to combine diverse knowledge originating from different sectors. In fact, more central nodes have access to a larger information set and greater capacity to retain and process knowledge flows (Lamperti et al., 2020). Firms in these most central sectors may have better conditions to innovate, not only because of the wider range of technological opportunities, but also because of better knowledge about the application contexts where these can be exploited.

The third step consists of assessing the level of relatedness between sectors that are connected. To analyse sector relatedness, we follow the approach of the economic complexity framework (Hausmann et al., 2014; Hidalgo et al., 2007; Hidalgo & Hausmann, 2009) and use a measure of proximity between sectors that is based on the probability of co-occurrence of exports with revealed comparative advantages.

We expand the approach traditionally used in the economic complexity framework, since it only considers data on goods, and we noticed a strong presence of service sectors in the intersectoral knowledge space. The inclusion of services entailed assembling a universal matrix of products combining export data from goods and services following the works of Mishra et al. (2020), Stojkoski et al. (2016) and Zaccaria et al. (2018).

For goods exports data, we draw on the Dataverse database (The Growth Lab at Harvard University, 2019), using the Harmonized System (HS92) classification with two digits, which implies 97 categories of goods. Although goods data are available at six digits, they were used at a lower granularity to make them comparable with service data. For service exports data, we used the COMTRADE database for services in 19 categories combining 1, 2, and 3 digits, following the Extended Balance of Payments services classification (EBOPS92).

For the universal matrix, we selected 112 countries corresponding to around 90% of world trade in 2018, considering the data availability of the 19 categories of services between 2000 and 2018. The universal matrix of products (goods and services) was used to assess the links between products and countries by their annual exports.

Revealed Comparative Advantage (RCA) is used to measure one country's advantage in the production of one product (Stojkoski et al., 2016). To calculate the RCA the Balassa index was used. Applying it to our universal matrix with 112 rows (countries) and 116 columns (products), we get a new matrix with the numerical values of RCA. Then we transform it in a binary matrix, for each year, using M_{ij} to each pair of country and product:

$$\mathrm{M_{ij}} = \begin{cases} 1, \text{ if } & \mathrm{RCA_{ij}} > 1 \\ 0, & \text{otherwise} \end{cases}$$

The binary matrices represent the diversity of each country (or the number of products that it exports with RCA) and the ubiquity of each product (or the number of countries with RCA that export that product). The binary matrix allows us to calculate the proximity between products, using the equation:

$$P_{jj\prime} = \frac{\sum_i M_{ij} M_{ij\prime}}{\max(k_j, k_{j\prime})}$$

where $P_{jj'}$ is the proximity between products j and j' and k_j is the ubiquity of product j. Proximity indicates the conditional probability that a country that exports product j will also export product j' (Hausmann et al., 2014). The average proximity for each pair of products was calculated based on the annual values from 2000 to 2018, and a proximity matrix was built, which supports the analysis of the relatedness between sectors. The proximity value ranges from 0 to 1. The definition of a threshold between related and unrelated is not easy, as pointed out by Boschma et al. (2012). Following these authors, we established the threshold at 0.25.

In the fourth step, we focus on firms belonging to sectors that compose the intersectoral knowledge space (the network) previously mapped and characterised. The objective is to understand whether the position of a sector in the intersectoral knowledge space - considering the variety and relatedness of the sectors to which it is connected - had some influence on the opportunities for innovation of its firms. That is, to assess whether the position of a sector led its firms to engage in innovation activities, and to gain some insights into the nature of these activities.

We use data from a questionnaire survey to Portuguese firms in sectors identified as potential contributors to MRET[3], which inquired whether and how they were involved with the technology. We excluded firms whose main business is the development of MRET, since we are interested in firms from other sectors that may diversify into the new area.

Firms that declared to be involved were asked questions about the nature and conditions of that involvement. Two of these questions are relevant for the purposes of this research. One concerns the degree of novelty of the products or services currently being supplied to MRET, and those expected to be supplied in the future. Other concerns the organisational changes that were introduced in the firm's activity or structure, to answer to the requirements of acting in the new area. Firms could select from a set of changes that encompass acquisition of new skills, material investments, process changes, new alliances, firm positioning (business model, capital structure). The questionnaire data was complemented with information from secondary sources concerning firms' characteristics, including their main sector of activity.

[3] The survey targeted: firms identified as involved in MRET as project partners or as suppliers of experimental activities conducted in Portugal; firms from sectors identified in various studies as potential contributors to the value chain to be formed around these technologies.

Research Results

Network Level of Analysis

The intersectoral knowledge space, resulting from the reconstruction of the network of interactions within R&D and innovation projects, is represented in Fig. 2. 62 different sectors appear connected in the network, both with related sectors (ties in blue) and with unrelated sectors (ties in red). The diagram also represents intra-sector ties, that is, those established between companies from the same sector (ties in green). The thickness of the line represents the strength of the tie, that is, the number of dyads between two sectors.

It is possible to observe that ties with unrelated sectors predominate, being present in all sectors. They are particularly relevant in manufacturing industries. In fact, several industries only establish relationships with unrelated sectors (both other industries and services). Intra-sector ties are less frequent and only occur in eight sectors.

Figure 2 also depicts the degree centrality of each sector - the number of direct ties with other sectors it establishes in the network - which is reflected by the size of the node.

Among the most central sectors in the knowledge space - those connected to a wider variety of other sectors - service sectors predominate, namely knowledge-intensive business services, which are often critical in knowledge combination processes (Doloreux & Shearmur, 2013). In addition, we observe the relevance of sectors associated with the production of electricity (the application sector) and with construction (critical for the installation of the technology, even in experimental stages). The most central manufacturing sector is the production of instruments and appliances for measuring, testing and navigation (NACE 2651), while other manufacturing industries are in peripheral zones of the intersectoral knowledge space.

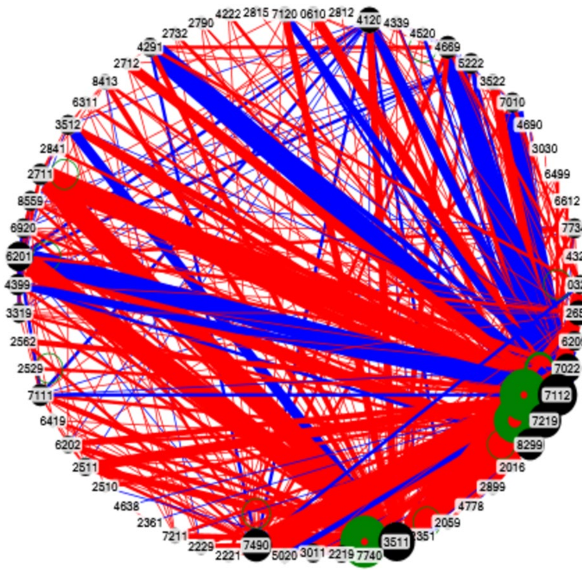

Fig. 2 The intersectoral knowledge space

Firm Level of Analysis

To assess whether the structure of the intersectoral knowledge space is associated with differences in the innovation opportunities for diversification of firms from different sectors, we use data from the questionnaire survey on the behaviour of firms that declared to be active in MRET.

The questionnaire identified 47 Portuguese firms that are involved in MRET activities as resource suppliers in development projects. Of these, 36 answered the question about the novelty of products or services supplied to MRET and 26 about the novelty of the products services they expect to supply in the future (Table 2). 35 firms answered the question about organisational changes, 20 mentioning introducing some type of change driven by their activity in the new area.

For these firms, becoming involved in MRET as a supplier of resources or competences represents a move to a new market, while simultaneously maintaining more or less extensive activities in their existing markets (Bento et al., 2021). However, the data permits to distinguish between different behaviours. Some firms supply current products or services, that is, may only be attempting market diversification, profiting from the emergence of a new market for their existing products. But other firms supply products or services developed for the new area, or introduce substantial adaptations in existing ones, to adjust them to new requirements. These firms are effectively engaged in innovation, which can support product/ service diversification and be the basis for changes in their business (Helfat & Eisenhardt, 2004; Karim & Capron, 2016). Since the adaptation of a product/service to a new application entails lower differentiation from existing products/services - i.e., lower novelty – than new developments, the two activities are addressed separately.

Data on organisational change gives some insights into the extent to which involvement with the new technology led to adaptations in firms' activities. The data permits to distinguish between firms that did not introduce any changes and those that did. The types of changes introduced provide some additional insights into the domains in which these efforts take place.

The 36 firms for which we have information on innovation behaviour belong to 17 sectors, confirming that MRET development requires access to resources from a variety of existing sectors. In this group, service sectors are also prevalent, which can be partly explained by a high incidence of knowledge-intensive firms that provide technological knowledge in complementary areas or offer specialised management and/or operation competences that can have an important role in innovation processes (Doloreux & Shearmur, 2013).

Table 2 Novelty of products services supplied to MRET by firms surveyed

Novelty of products/services supplied to MRET	Current		In future	
	Nº firms	%	Nº firms	%
Develop products or services specifically for MRET	20	56%	17	65%
Adapt products or services to new applications in MRET	10	28%	2	8%
Only supply currently offered products or services	6	17%	7	27%
Total	**36**	**100%**	**26**	**100%**

This set of sectors is mapped against the range of sectors encompassed by the intersectoral knowledge space, with a view to assessing their centrality in that space, in terms of the variety of sectors to which they are connected. Similarly, the relatedness between this group of sectors is assessed, using the data previously obtained.

This enables us to obtain data on the variety and the relatedness for the sectors to which the firms active in MRET belong, and to position these sectors in one of the 4 categories resulting from the intersection of the two dimensions defined in the conceptual framework: variety of sectors/degree of (un)relatedness of sectors (Fig. 3). Following this exercise, the firms that belong to each sector are classified according to the category of their sector (Table 3). We then analyse the innovative behaviour of firms in each sector category.

Despite the relatively small number of cases, the results provide tentative evidence consistent with the expectations derived from the analytical framework.

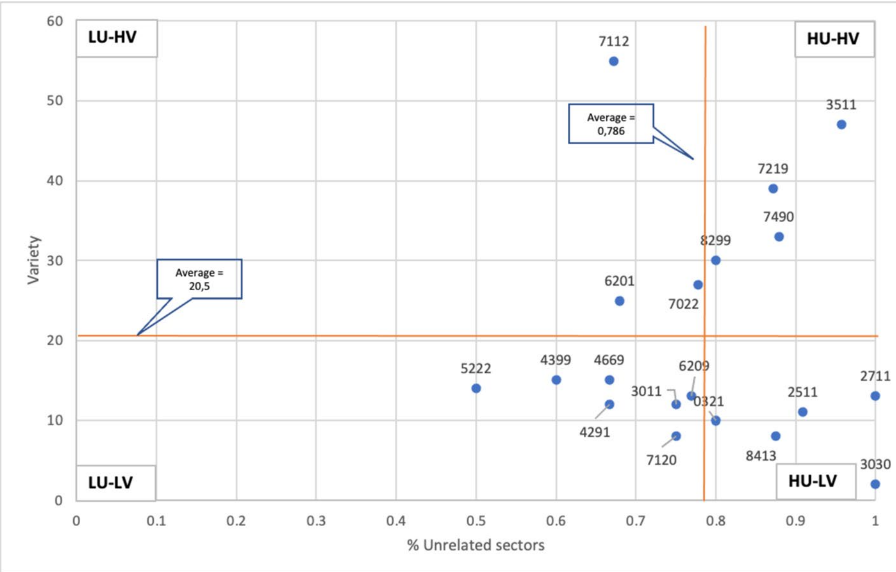

Fig. 3 Position of MRET-related sectors in the two-dimensional framework

Table 3 Distribution of firms surveyed by sector category

Sector category	Label	Nº firms	%
High variety of sectors - High degree of unrelatedness	HV-HU	8	22%
High variety of sectors - Low degree of unrelatedness	HV-LU	11	31%
Low variety of sectors - High degree of unrelatedness	LV-HU	4	11%
Low variety of sectors - Low degree of unrelatedness	LV-LU	13	36%
Total firms		**36**	**100%**

As shown in Table 4, in this sample, firms from sectors connected with a high variety of other sectors (high centrality) and with a higher proportion of unrelated sectors (HV-HU) develop new products specifically for MRET relatively more frequently. Rather, firms from sectors connected with a high variety of sectors (high centrality) and with a lower proportion of unrelated sectors – i.e., more connected to related sectors – (HV-LU) are also innovative but are more frequently engaged in substantial adaptations of existing products to new applications in the MRET area. In addition, firms in these two categories of sectors are never exclusive suppliers of current products. Moreover, although several of them combine new/adapted with current products, a substantial proportion does not supply existing products at all.

Conversely, firms in sectors connected with a lower variety of sectors (low centrality) are more often observed to act primarily as suppliers of existing products. This is particularly evident in the case of firms in sectors that combine low centrality with connections with a higher proportion of unrelated sectors (LU-HU). The latter are also the least frequently present among the sectors active in MRET, as shown in Table 3, which suggests that less opportunities are being created for them by the new technology.

If we also consider these firms' perspectives concerning future activity in MRET (Table 5), we observe that the data follow a similar tendency, but that there is an important change in the case of sectors connected with a higher variety of sectors but

Table 4 Innovative behaviour by sector category - current activities

	High variety high unrelat.	High variety low unrelat.	Low variety high unrelat.	Low variety low unrelat.	Total
New products	30%	30%	5%	35%	100%
Adaptions to new applications	20%	50%	10%	20%	100%
Current products	0%	0%	33%	67%	100%
Grand Total	**22%**	**31%**	**11%**	**36%**	**100%**

Table 5 Innovative behaviour by sector category - expected activities

	High variety high unrelat.	High variety low unrelat.	Low variety high unrelat.	Low variety low unrelat.	Total
New products	29%	41%	0%	29%	100%
Adaptions to new applications	0%	0%	0%	100%	100%
Current products	14%	14%	29%	43%	100%
Grand Total	**23%**	**31%**	**8%**	**38%**	**100%**

with a lower proportion of unrelated sectors – i.e. more connected to related sectors – (HV-LU): future expectations involve relatively more frequently the provision of new products.

In what concerns the need to introduce organisational changes to answer to the needs of MRET, differences between sectors are consistent with the type of innovative behaviour (Table 6). In this sample, firms from sectors found to be less likely to innovate, in particular sectors with limited connections and with more unrelated sectors (LN-LU), are also the ones that refer relatively more frequently they did not introduce changes. Conversely, firms from sectors found to be more likely to innovate – i.e., those with more connections, either related or unrelated (HV-HU & HV-LU) – are also the ones that refer relatively more frequently the need of introducing organisational changes. Such changes can be regarded as a willingness to adjust the activities to answer the new opportunities. It is worth mentioning that the most frequently mentioned changes are related with access to new competences through recruitment or training of human resources, the establishment of new alliances, and the reorganisation of the product portfolio.

These results suggest that firms that are developing new products or adapting products to new applications – when compared to those only supplying existing products – are more frequently from sectors whose central position offers greater opportunities to profit from the intersectoral interactions and the resulting knowledge combination processes; even if the nature these opportunities is also influenced by the level of (un)relatedness of the interacting sectors' knowledge bases. Dedicated innovation activities represent a greater engagement with the new area than the simple supply of current products (that can be more occasional). Such engagement is further strengthened by expectations of continuity of innovation in the future and by the introduction of organisational changes to adapt to the needs of the new area. Taken together these efforts reflect a more consistent attempt, by these firms, to turn innovation opportunities into actual business changes.

A Sectoral Lens on Intersectoral Positioning and Innovation Patterns

While the previous analysis highlights systematic tendencies linking sectors' position in the intersectoral knowledge space to firms' innovative behaviour, these patterns may mask important heterogeneity across sectors. To further qualify the results, we

Table 6 Organisational changes introduced to answer to MRET needs

	High variety high unrelat.	High variety high unrelat.	High variety high unrelat.	Low variety low unrelat.	Total
Organisational changes	23%	38%	8%	31%	100%
No organisational changes	18%	24%	18%	41%	100%
Grand Total	**21%**	**33%**	**12%**	**35%**	**100%**

introduce a sectoral lens that examines the sectoral composition across the four categories of the analytical framework.

In this sample, sectors positioned in the High-variety/High-unrelatedness quadrant (HV–HU) are predominantly science- and technology-oriented activities, including research and experimental development and professional scientific services. Firm in these sectors are typically characterised by broad knowledge bases and experience in combining diverse and cognitively distant knowledge domains, which create conditions for the development of new products or services for MRET.

The High-variety/Low-unrelatedness quadrant (HV–LU) is mainly populated by engineering, technical consultancy, and computer programming activities. These sectors are embedded in multiple intersectoral interactions but operate within relatively related knowledge domains. This positioning is consistent with the prevalence of innovation through adaptation and system integration, whereby firms adjust existing competences to new application contexts rather than pursuing fully novel developments.

In contrast, sectors in the Low-variety/Low-unrelatedness quadrant (LV–LU) include construction-related activities, shipbuilding, port services, and wholesale of machinery. These sectors tend to occupy more specialised and application-oriented roles in the development of MRET, with fewer intersectoral connections and stronger ties to related activities. Correspondingly, firms in these sectors are more frequently involved as suppliers of existing products or services, with more limited engagement in dedicated innovation activities.

Finally, the Low-variety/High-unrelatedness quadrant (LV–HU) is sparsely populated and includes manufacturing and other activities that combine limited connectivity with greater cognitive distance from the core knowledge domains of MRET. The peripheral positioning of these sectors in the intersectoral knowledge space suggests fewer opportunities for sustained knowledge recombination, helping to explain their lower presence among innovating firms.

Discussion and Conclusions

The objective of this paper was to gain a better understanding of how the emergence of new sustainable technologies can induce innovative activity in the industrial sectors that contribute with competences and resources to their development, potentially driving diversification and transformative change. To address this question, the research focused on the intersectoral knowledge relationships formed as part of the emergence of the new technology and investigated whether and how they created conditions for knowledge recombination, generating innovation opportunities for firms in existing sectors.

More specifically, the paper proposed that the characteristics of the intersectoral knowledge space formed affect the recombination process (Antonelli et al., 2010; Tsouri et al., 2022) and that the position of a sector in that space influences the innovation opportunities that arise for its firms (Lamperti et al., 2020). Based on these insights it devised a framework that permitted to address the extent and nature of opportunities arising for firms to conduct innovative activities associated with the emerging technology. The framework combines two theory-driven dimensions along which the sector position in the intersectoral knowledge space potentially affects the innovative behaviour of its firms: the variety of connections with other sectors and the degree of (un)relatedness between the sector and those to which it connects. Four stylised categories of sectors were identified, which were expected to result in different opportunities for knowledge combination and therefore innovative behaviour by sectors' firms: High variety/High unrelatedness; High variety/Low unrelatedness; Low variety/High unrelatedness; Low variety/Low unrelatedness.

This framework was applied to the case of the emergence of marine renewable energy technologies in Portugal. The research mapped the intersectoral knowledge space for MRET, positioned the sectors involved along the four categories and examined the innovative behaviour of firms belonging to each sector category. The results suggest that sectors' position in the intersectoral knowledge space, along the dimensions proposed, is associated with differentiated firms' innovative behaviour. In this case, and in line with theory, innovative activities tended to be relatively more frequent in sectors with a higher variety of connections (Lamperti et al., 2020; Stephan et al., 2019); and the nature of these activities would also be influenced by the level of (un)relatedness of the connected sectors (Castaldi et al., 2015; Criscuolo et al., 2018; Schoenmakers & Duysters, 2010). Innovative firms also were more frequently engaged in organisational changes that could uphold more extensive transformations in the firms' activities and business orientation (Karim & Capron, 2016).

This research provides new insights into the processes that enable firms from existing sectors to benefit from their involvement with emerging technologies. By analysing the knowledge recombination processes at the intersection of the diverse sectoral knowledge bases, it uncovered some features that present firms with different conditions to identify and exploit innovation opportunities arising from the combinations between new and existing knowledge.

The research has some limitations. Formal R&D and innovation projects are more likely to capture knowledge-intensive and engineering-oriented activities, while incremental or tacit knowledge exchanges typical of some mature industries may be underrepresented. The framework was applied to a relatively small sample, as we were constrained by the still limited number of firms active in the MRET area. This precluded the use of more advanced statistical methods and, as a result, the analysis only permitted to identify systematic patterns and associations rather than establish causal effects. Despite this limitation, the tendency shown by the data available is consistent with theory, offering new insights into the processes through which involvement in the development of a technology can lead to innovation and change in existing sectors. However, the analysis addressed one specific technology and its development in one particular country and thus results may be influenced by the technology idiosyncrasies and the country context. Subsequent research applying the framework to other technologies and contexts, can improve its robustness and the generalisation of findings.

The contributions of the paper to literature are twofold. Firstly, it contributes to a debate in the sustainable transitions literature on the capacity of new technologies to induce innovation and change in the established sectors that contribute to their development (Andersen et al., 2020; Fontes et al., 2021). It illustrates how intersectoral interactions are associated with differentiated conditions for knowledge recombination and innovation in existing sectors, shedding light on the processes through which new technologies may contribute to sectoral transformation.

Secondly, the paper adds novel insights to the literature on intersectoral knowledge spaces (Lamperti et al., 2020; Tsouri et al., 2022; Stephan et al., 2019), proposing and empirically showing that the characteristics of the knowledge space affect knowledge combination across sectors, thus influencing the extent and nature of the opportunities arising for firms from sectors that occupy different positions in that space, in terms of variety and degree of relatedness of connections.

The results of this research have several implications for innovation and industrial policy, particularly in the context of emerging sustainable technologies that rely on contributions from a wide range of existing sectors. The findings suggest that policy, rather than focusing exclusively on the support of specific technologies or individual firms, can play an important role in shaping the intersectoral knowledge spaces within which processes of knowledge recombination and innovation take place. Given the often-exploratory nature of intersectoral knowledge recombination, policy interventions should be conceived as learning-oriented and adaptive (Kivimaa & Kern, 2016; Schot & Steinmueller, 2018).

A first policy implication concerns the role of sector centrality. The analysis suggests that sectors that are more centrally positioned in the intersectoral knowledge space tend to offer their firms broader opportunities to access diverse knowledge sources and application contexts (Lamperti et al., 2020), which is associated with a higher likelihood of innovation-oriented engagement. From a policy perspective, this suggests that fostering innovation in emerging technologies may require instruments that explicitly target the connectivity and positioning of sectors within intersectoral knowledge networks. In particular, policies that promote cross-sectoral collaboration (e.g. foster cross-sectoral projects, encourage the participation of firms from peripheral or mature sectors in emerging fields) and support innovation intermediaries or brokers can play a critical role in shaping intersectoral knowledge spaces (Klerkx & Leeuwis, 2009).

A second implication relates to the degree of relatedness between the sectors connected in the intersectoral knowledge space and its implications for the nature of innovation (Frenken et al., 2007; Castaldi et al., 2015). The results suggests that policy instruments should be differentiated according to the type of knowledge recombination targeted, combining diffusion- and adaptation-oriented support in contexts of related variety with more experimental, risk-sharing instruments when fostering innovation based on unrelated knowledge combinations (Janssen & Frenken, 2019; Grillitsch et al., 2018).

A third implication concerns the role of mature or established sectors, many of which occupy more peripheral positions in intersectoral knowledge spaces but nevertheless play critical roles in the development and deployment of emerging technologies (Bento et al., 2021). For these sectors, involvement in emerging technologies often takes the form of supplying existing products or services or undertaking adaptation-oriented innovation rather than developing entirely new offerings. While such activities may appear incremental, they can represent important entry points for longer-term diversification and upgrading trajectories (Sousa et al., 2023). Policy can support these processes by explicitly linking emerging technology strategies with broader industrial transformation and skills policies that can enhance the capacity of firms in mature sectors to progressively move from peripheral supply roles towards more innovation-intensive activities, while retaining some of their core capabilities (Onufrey & Bergek, 2021).

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Declarations

Competing Interests The authors report there are no competing interests to declare that are relevant to the content of this article.

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