Unleashing the industrial transformative capacity of innovations

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Abstract

This paper investigates the conditions in which the development of new technological systems induces structural change. A literature review reveals three factors that influence the industrial transformative capacity of a technology: context; complementarities; competition. We track the dynamics of these factors, focusing on the extent and nature of induced activities in adjacent sectors. We apply this framework to study marine renewable energy technologies (MRET) in Portugal. Adjacent sector firms active in several MRET exhibited diversified activity, innovation and internal change. Comparing with Norway, where an offshore industry (oil & gas) supports the emergence of offshore wind, the absence of such industry in Portugal raises challenges but also creates opportunities for the transformation of several sectors. We develop a new indicator to identify and compare the transformative capacity of innovations. Finally, we discuss the extent to which context, complementarities and competition contribute to accelerate or hinder transformative change.

Keywords: transformative innovation; context; complementarity; competition; technology policy

1 INTRODUCTION

To accelerate the energy transition, several technological paths are possible, with distinct performances and socio-economic costs and benefits. Benefits could include a greater use of competencies from adjacent activities, the revitalization of declining sectors, or the creation of a larger number of direct and indirect jobs (Arthur, 2009; Pahle et al., 2016). To achieve these goals, 'tweaking' existing innovation trajectories is insufficient and thus 'transformative change' (i.e. structural change) is needed (Grubler et al, 2018). At the same time, aligning environmental and socio-economic goals, such as jobs and value creation, is a key concern to the wider public (Foxon, 2018). The legitimacy of transformative innovation policies would be significantly strengthened if combined with creation of new economic opportunities (Vona, 2019). It is, therefore, important to understand how sustainable energy transitions can contribute to industrial transformation.

The impact of a new technology on existing industrial sectors has been addressed in the literature, via the concept of the transformative capacity of technology. This concept refers to the process of structural change and adjustment in sectors that adopt and use the new technology (Dolata, 2009, 2018). This view of transformation contribute to an understanding of the disruptive effects of transitions on sectors (such as electricity or transport), that increasingly adopt sustainable technologies (Köhler et al., 2019). But it only offers a partial approach, since it does not consider the industrial dynamics of developing, producing and upscaling these new technologies. This is nevertheless an important point if the goal is to combine sustainability goals with industrial development. In fact, most industrial activity and jobs related to new sustainable technologies are likely to be associated with their manufacturing and installation (IEA, 2020) which, in turn, may stimulate activity in the existing industrial structure (Hanson, 2018; Andersen and Gulbrandsen, 2020).

A recent stream in the sustainable transition literature contributes to address the question, by offering some insights into the role of interactions between an emerging technology and the context structures (sectors, institutions, technologies, geography) in which it is embedded (Bergek et al., 2015, Binz and Anadon, 2018; Köhler et al., 2019). Researchers have also illustrated the importance of using a technology value chain approach—that includes the sectors using the technology and the sectors producing it - for understanding the evolution of a focal technology (Stephan et al., 2017, Andersen et al., 2020). This approach highlights the role of the industrial context – conceptualized as adjacent sectors, i.e., sectors outside the technology value chain that can provide resources or be otherwise important to its development – in technology emergence (Andersen and Gulbrandsen, 2020; van der Loos et al, 2012). Interactions with context structures can be complementary or competitive (Bergek et al., 2015). Complementary interactions with adjacent sectors that provide key resources can be crucial for accelerating the development of new technologies (Markard and Hoffman, 2016; Mäkitie et al., 2018).

Competitive interactions, on the other hand, may occur when different technologies dispute the same key inputs and markets (Markard, 2020). Even though this literature improves our understanding of how an emerging technology is affected by its context, it has overlooked the ways in which its emergence affects context elements, such as stimulating activities in adjacent sectors.

Therefore the literature remains scant on the question of how sustainable energy transition can contribute to industrial transformation- i.e., to stimulate (and destroy) activity in adjacent sectors. To address this gap the paper attempts to answer the following question: "*What determines the capacity of a new technology to transform adjacent sectors?*" This is a novel direction of thinking about how to combine sustainable transitions with enhanced industrial activity.

For that, we extend the concept of transformative capacity to also account for industrial transformation related to the production of a new technology. We propose the concept of *industrial transformative capacity of technology,* as an attempt to better conceptualize the effects of technology emergence in the industrial context.

The paper operationalizes the concept of industrial transformative capacity around three main determining factors: context, complementarities and competition. It also develops a set of analytical instruments, including a new indicator to assess in real time the industrial transformative capacity of different technologies.

The framework is applied to analyse the development of Marine Renewable Energy Technologies (MRET). These encompass technologies, such as wave energy and offshore wind, whose growth will require setting-up a new value chain that includes activities associated with technology manufacturing, installation and operation at sea (Bento and Fontes, 2019). A substantial part of these activities can benefit from competences and resources present in existing sectors (van der Loos et al., 2020), including established (e.g., equipment manufacturers), new (e.g. robotics) and declining (e.g., shipbuilding) (Fontes et al., 2016; Bento and Fontes, 2019). The analysis focuses on the development of a local innovation system around MRET in Portugal, a typical follower country that has been very active in the development of these technologies. We include some comparisons with the case of Norway to highlight differences and communalities with another frontrunner in these technologies.

This paper contributes to the literature in three ways. First, we present and qualify a novel concept extending the work of Dolata (2009, 2018) on industrial transformation, to understand the factors that determine how a new technology can have a transformative effect upon existing sectors that provide competences and resources. This adds to the debate on the processes and channels through which a technology and the industrial context co-evolve (Agarwal and Tripsas, 2008; Bergek et al., 2015; Huenteler et al., 2016). Second, we advance the discussion on the interactions between a technology and its context by analysing, for the first time, the impact of emerging technologies on the industrial context. Finally, we show that transition strategies aiming to combine sustainability goals with enhanced industrial activity—i.e. contributing to a just transition (McCauley & Heffron, 2018)—should contemplate which technologies to promote, considering the existing industrial specialization.

The paper is organized as follows. Section 2 articulates the conceptual framework based on a literature review. Section 3 presents the methodology for the empirical analysis. Section 4 explores the results of the analysis of the new sector emerging around MRET in Portugal and Section 5 applies a new indicator to compare the industrial transformative capacity of different technologies.

2 INDUSTRIAL TRANSFORMATIVE CAPACITY OF NEW TECHNOLOGIES

2.1 Economic system transformation and technological change

Technological change can have pervasive effects that lead to the transformation of the established economic system. As Joseph A. Schumpeter noted, at the core of technological change lies "new combinations": "...to produce other things or the same things by a different method, means to combine these materials and forces differently." (Schumpeter, 1934: 64). Schumpeter distinguished between radical and incremental change, depending on the extent to which it transforms the economic system: "... [radical change-led development] is that kind of change arising from within the system which so displaces its equilibrium point that the new one cannot be reached from the old one by infinitesimal steps." (Schumpeter, 1934: 66). Technological change in this sense can lead to a deep transformation of the society such as the one brought by the steam machine in the XVIII century (Freeman and Louçã, 2001).

Incremental change can still have a transformational effect in the economy without provoking a socio-economic revolution. Arthur (2009) suggests the concept of "*redomaining*" for changes provoked by the cross-fertilization of established industries with new industries, resulting in a new industry (e.g. finance and computation leading to financial risk management, computer and telecommunication occasioning smartphones). The author posits that "... the process of redomaining means that industries adapt themselves to a new body of technology..." (Arthur, 2009: 155). These industries do not passively adapt a new technology but "[t]hey draw from the new body, select what they want, and combine some of their parts with some of the new domain's, sometimes creating subindustries as a result" (*idem*). Arthur describes the changes that redomaining operates: "This overall process (...) works outward from changes in the small-scale activities of the economy, to changes in the way business is organized, to changes in institutions, to changes in society itself" (*idem*).

The impact of a new technology on existing industries has been addressed in the literature. Dolata (2009, 2018) introduced the concept of transformative capacity of new technologies to designate the "technology-based pressure to change and adjust the structural and institutional architectures" (Dolata, 2009: 1074), in the sectors that adopt and use a new technology. Thus, transformative capacity describes the extent to which new technology disrupts and transforms the sector in which it is deployed; i.e. technology-using sectors. In the case of sustainable technologies, these transformative effects can be particularly evident in established carbon intensive sectors, such as energy or transport. These sectors can be threatened by the emergence of sustainable technologies and react against them (Geels, 2014), although there is now evidence of an increasingly adaptive behaviour (Turnheim & Sovacool, 2020).

However, by focusing on *technology adopting* sectors, this approach to transformation neglects the effects of the new technologies in sectors that do *not adopt and use* the technology, but rather *contribute with competences and resources to its development and production*. An understanding of whether and how transformation is taking place in these sectors is particularly important for sustainability transitions, not only because they can contribute to accelerate the development of the new sustainable technologies (Markard and Hoffman, 2016), but also because their engagement with the emerging technology value chain can drive changes in the existing industrial structure. It will thus be necessary to extend the concept of transformative capacity of a technology to also encompass the impact of a new technology in technology-producing sectors.

2.2 Technology value chains and industrial specialization

To understand the transformative capacity of technology, we review the main consequences of technological change for the economic system.

The characteristics of technology development dictate the transformative potential of innovations. Technological development typically follows four central tendencies (Grubler, 2003): (i) greater scale, output and productivity; (ii) greater variety and complexity; (iii) greater division of labour; (iv) greater interdependency and interrelatedness. Even though all four tendencies have effects in transforming the economic system, the last one is particularly important. It refers to the fact that technologies are increasingly dependent on one another for production and use (Grubler, 2012, 2003). A single innovation may require simultaneous inputs from several sectors (e.g. internet needs especially dedicated devices, software, telecommunications and electricity networks).

Following this logic, it is important to consider the sectoral configuration of technologies—i.e. the sectors involved in using and producing (i.e. components, subcomponents, and services) a focal technology which constitute its value chain (Malhotra et al., 2019; Sandén and Hillman, 2011; Stephan et al., 2017)—to fully grasp the transformative dynamics of new *technology*. Technology emergence implies the formation of a new supportive value chain (Tushman, 1992, Murmann and Frenken, 2006). The existing industrial specialization can provide inputs (skills, capital, machinery, etc.) that can be critical for the formation and growth of the emerging technology value chain in a particular place (Hanson, 2018; Andersen and Gulbrandsen, 2020). Existing industrial structure is described as a set of *sectors* that are adjacent to the focal technology. In the formative stage, the system is characterized by high uncertainty, few actors, and extensive vertical integration (Markard, 2020; Bento and Wilson, 2016). If the required assets are not available, they must be imported or created via learning and competence building processes that can be long and cumbersome (Bell, 2006, Lall, 1992). In later stages, adjacent sectors can merge with the new value chain through structural couplings (Bergek et al, 2015). This process illustrates development of positive complementarities between the emerging technology's value chain and the adjacent sectors (Andersen and Markard, 2020).

To better understand the transformative capacity of a technology and whether and how it varies across technologies, we propose an analytical framework which we subsequently apply to a case study.

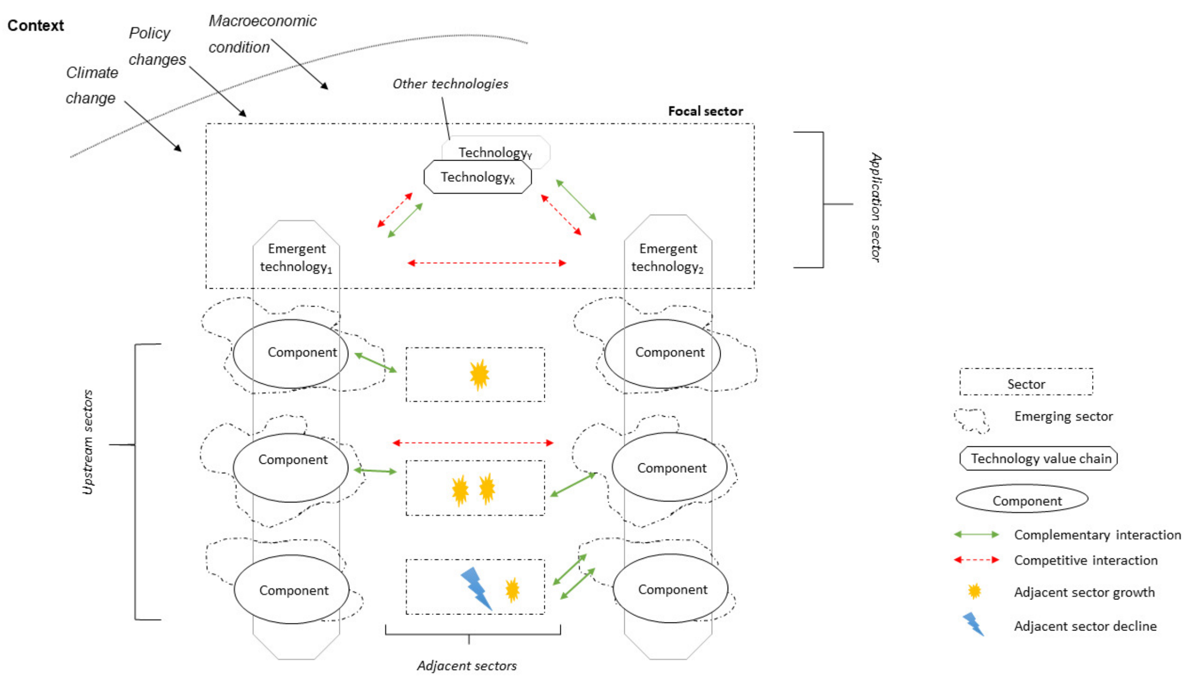
2.3 Conceptual framework

In this section we propose a framework that systematizes how emerging technologies can transform adjacent sectors (Figure 1). We introduce the concept of industrial *transformative capacity of a technology*. This concept draws on and extends the Dolata's (2009) notion of transformative capacity to include the extent to which a new technology value chain transforms (i.e. stimulates and destroys activity in) existing sectors that contribute with competences and resources to its development and production.

The framework outlines the mechanisms of change and the factors that determine whether and how the industrial transformative capacity is realized.

The framework conceptualises the interactions between the technology value chain and the adjacent sectors, under the influence of the broader environment. The interactions between these elements constitute the mechanisms of transformative change. Interactions between adjacent sectors and focal technology value chain are typically uni-directional, from the former to the latter. Interactions between adjacent sectors and technologies can be bi-directional and either competitive or complementary. Below we explain the framework in more detail.

Figure 1. Conceptual framework



A focal sector is at the centre of the framework (Figure 1). It typically undergoes profound transformation (e.g. decarbonization of the power sector) with major changes in the configuration of key technologies (e.g. renewables versus fossil energy). During the technological shift in the focal sector, several emerging and established technologies interact and compete for market shares under the influence of the context[1].

It is proposed that the extent to which these processes bring about transformative changes in adjacent sectors is determined by three main factors: context, complementarities and competition.

[1] Emergent technologies will more likely compete against other new alternatives in the market as they substitute mature technologies. Even if they compete with old technologies in their application sector, they will be complementary in the knowledge base, since the latter is already well aligned/integrated/consolidated with the industrial structure upstream.

Context refers to the context structures within which the emerging technology is embedded and that affect its development (Bergek et al, 2015; Markard and Hoffman, 2016). They serve as a “selection environment” containing both cognitive and material dimensions that shape technology dynamics (Dosi, 1988). Bergek et al. (2015) identify four main context structures for a focal technology: sectorial (interactions with other sectors), political (policies and politics), technological (competing and complementary technologies), and geographical (particular territorial properties). Andersen & Gulbrandsen (2020) also suggests the existence of wider context (macroeconomic conditions, sustainability pressures, among others) that influences the dynamics of the system. The characteristics of the context influence both the likelihood of an innovation to occur or to be adopted, and thereby the impact it can have on its environment (i.e. its transformative effects).

While all types of context structures are important, two have been shown to play a stronger role in the development of a new sustainable technology: sectoral/industrial and political (Van der Loos et al, 2021). The country’s industrial specialisation can facilitate or constrain the gain access to relevant resources, by shaping the configuration of adjacent sectors with which the focal technology can interact (Andersen & Markard, 2019). Supportive policies, on the other hand, provide incentives to invest in still uncertain technologies that are important for the creation of favourable conditions for their development (Verbruggen and Lauber, 2012; Jacobsson et al, 2017). Political support, not only grants easier access to financial resources, but also increases the legitimacy of the technology encouraging the entry of new actors (Bergek et al, 2015). Thus, a favourable context is instrumental to creating the conditions for both attracting and fruitfully interacting with adjacent sectors.

Complementarities between adjacent sectors and an emerging technology value chain are critical for system transformation, for three main reasons. First, adjacent sectors can boost technology emergence by serving its needs and solving its problems (Mäkitie et al., 2018; Wirth and Markard, 2011; Markard and Hoffmann, 2016). Second, adjacent sectors can serve as repository of capability and knowledge inputs to the formation of new technology, via novel recombinations of existing knowledge (Weitzman, 1998, Arthur, 2009; Hidalgo, 2018). Third, technology emergence can create growth in—or even reinvigorate declining—adjacent sectors, whenever their products and services can support the value chain formation for the new technology (Andersen and Gulbrandsen, 2020; Weber and Rohracher, 2012).

Complementarities can create socio-economic benefits as the adjacent sectors respond to the opportunities raised by the emerging technology. These benefits may be higher the greater the knowledge proximity between adjacent sectors and the emerging technology (Hidalgo et al., 2009). However, the status of the sectors involved may influence the intensity and nature of complementarities. For example, adjacent sectors that are declining or growing are likely to provide more resources and interact more heavily with the emerging value chain sectors than more stable ones. Sectors' adaptability may also vary (Dolata, 2009), thus the gains accruing from these interactions depend on how an adjacent sectors respond to the new opportunities. Benefits are higher when sectors' engagement is stronger, resulting in innovation dedicated to the new area (Laurens et al., 2018).

Competition is also a key element in these processes. In the focal sector, different technologies may compete to become the dominant design (Abernathy and Utterback, 1978; Anderson and Tushman, 1990). Along this process, actors supporting the alternative technologies compete for attention and resources from firms in adjacent sectors that are already serving other markets (see red arrows in figure 1). Actors' capacity to attract resources (Garud et al., 2002) will depend on the power of each actor vis-a-vis complementary products/services and users. Ultimately, actors' ability to induce investments can have increasing returns (Arthur, 1989; Gustafsson et al., 2016). The industrial transformative capacity of emerging technologies depends on their strength in these competitive relationships.

Therefore, the *industrial transformative capacity of a technology* can be enhanced whenever there are *complementarities* between emerging technology value chains and adjacent sectors, low *competition* between technologies in the attraction of resources from these sectors, and a favourable industrial and political *context*.

3 METHODS

3.1 Assessing the interactions with adjacent sectors

This paper aims to understand how the development of new sustainable technologies can contribute to transform adjacent sectors. That is, to unleash their industrial transformative capacity.

The main question of the study is: 1) What determines the capacity of a new technology to transform adjacent sectors? To answer it, the research addresses two sub-questions:
2a) How do complementarities (between emerging systems and adjacent sectors), competition (between technologies) and contextual conditions determine the industrial transformative capacity of a technology?;
2b) How do the characteristics of the technology influence the effect of these factors?

Table 1 operationalizes the determinants defined in the literature review – context, complementarities and competition – whose effects are assessed in the case study.

Table 1 - Determinants of industrial transformative capacity– concept and measure

Factor	Measures	Rationale
Context		Industrial and political context structures play stronger role in emergence of new technologies (Van der Loos et al, 2021)
	1.Policy support available	1. support mechanisms improve the incentives to invest in new energy technologies (Verbruggen and Lauber, 2012)
	2. Industrial specialisation	2. industrial specialization provide inputs critical for formation and growth of technology value chain (Andersen and Gulbrandsen, 2020)
Complementarities	3. Scope of interactions: number of sectors mobilized	3. interaction with adjacent sectors increases transformative capacity (Markard and Hoffmann, 2016)
	4. Contribution to value chain: levels of value chain targeted	4. proximity to existing knowledge increases opportunity gains (Hidalgo et al., 2009)
	5. Dedicated innovation activities	5. development of new products/services signals engagement (Laurens et al., 2018)
Competition	6. Attractiveness to suppliers: Internal changes to answer to new opportunities	6. capacity to divert firm's resources has increasing returns in production and scope (Arthur, 1989)

3.2 Case selection

Marine renewable energy technologies (MRET) are a good example of innovation that promotes synergies between sectors. They encompass both ocean energy, i.e. energy derived from the sea, namely mechanical energy from waves and tides; and energy produced on the sea, in particular offshore wind, fixed or floating.

The development of a system around MRET implies the performance of a heterogeneous set of activities. These include the development, manufacturing and assembly of the various elements of the conversion systems, as well as their installation, operation and maintenance at sea. These activities engage with competences and resources present in a variety of sectors, both established (e.g.: metalwork, shipbuilding, sea transport) and new (e.g.: new materials, underwater robotics). MRET complexity is already manifest at experimental stages, since the test of whole systems in real sea conditions is costly and implies putting together these different activities at a period of technological and market uncertainty (Bento and Fontes, 2019).

The growth of MRET depends on the capacity to develop complementarities with adjacent sectors. The diversity of activities and sectors imply that the extent and nature of the relationships vary. Adjacent sectors can become suppliers of existing products and services, but also co-developers of new components, systems, methods and/or partners in new business models. These interactions can lead to the creation of new types of activities, which may remain in the initial sector or become part of a new “marine energy industry”. Thus, the analysis of this process permits to understand not only the influence of adjacent sectors in the development of the emerging technologies, but also the transformative effect of the latter in existing industries.

3.3 Empirical strategy

We investigate the extent and nature of the involvement of adjacent sectors in experimental activities conducted in marine renewable energies in Portugal, a country that has more than 20 years of experience in research, development and deployment of MRET (Fontes et al, 2016). In order to account for context-related specificities we briefly contrast the case of Portugal with that of Norway, which is equally a forerunner in MRET, but has a substantially diverse industrial structure. We conclude with the proposition of a synthetic indicator to compare the transformational power of emerging technologies.

A national focus permits to highlight the activities of and the effects on the sectors whose activities can be transformed by MRET, considering the specific industrial context. The type of adjacent sectors that may become involved in MRET and the effects that interaction with MRET can induce in adjacent sectors depends very much on the industrial specialization, which differs between countries. Therefore, although we are aware of the international scope of the MRET value chain, we opted for focusing on the processes that take place within the national boundaries to better capture those effects.

The empirical analysis of the Portuguese case relies on two main methods: an historical analysis of the involvement of actors from adjacent sectors, based on desk-based research complemented with interviews with key actors; and a questionnaire survey targeting firms from adjacent sectors. Supplementary Information (SI) explains in detail the procedures followed for mapping the actors and for the questionnaire survey.

The historical analysis aimed at identifying firms from adjacent sectors that were either (i) *partners* in Research, Technological Development and Demonstration (RTD) projects or (ii) *suppliers* in the context of experimental activities.

For the identification of partners in RTD projects, we looked into the 52 national and European funded projects with Portuguese firms as participants, launched between 1992 and

2018. These projects involved a total of 43 firms: 10 technology developers; 33 firms performing complementary activities.

To identify firms that had acted as suppliers to experimental projects we selected, based in previous research (Fontes et al., 2016; Bento and Fontes, 2019), technologies that had known experimental activity in Portugal and are still active: the floating offshore wind technology and three wave energy technologies. The data collected permitted to detect an additional 32 firms that had not been formally involved in MRET projects: 21 in the offshore wind project and 11 in the wave energy projects. In both cases, a stable relationship was created with some suppliers[2].

The second step in the analysis was the questionnaire survey. It targeted the firms previously identified in the historical analysis, and firms selected from sectors that are actual or potential contributors to MRET, in a total of 349 firms. These firms were inquired about their MRET-related activities and/or perspectives. From the 111 respondents, 31 mentioned to be currently active and 3 that they had been active in the past. Another 49 indicated the intention of entering in the future and 29 referred no interest in the field at all.

From the group of 34 firms that referred to be/have been active, 6 were technology developers and 28 were from adjacent sectors. These 28 firms are the focus of our analysis. 11 had been previously identified as project partners or suppliers and 17 were new.

In order to assess the role played by each technology in the attraction of firms from adjacent sectors, we classified the projects/experiments in which they participated according to the technology or technologies targeted. In the questionnaire, an open question about firms' activities permitted to associate them to the technologies. Firms active in both areas or in projects encompassing both technologies were classified under the label "marine energies".

Overall, it was possible to identify 82 firms from adjacent sectors that had been involved in MRET over time: 33 as formal projects partners, 32 as more or less occasional suppliers and further 17 that declared to be/have been active in their answer to the questionnaire (Table 2).

[2] Some of the projects / experimental activities identified also included foreign partners or suppliers that were not included in the research for the reasons explained above. In some cases transnational linkages might have been a way to compensate for the absence or limitations of local sectors as suppliers of competences and resources. This is likely to have implications for the national industry, precluding future involvement or, on the contrary, creating additional opportunities as foreign companies become involved in Portuguese projects. While this is an interesting question that can have impact upon the opportunities for transformation of the national industrial structure, it is beyond the focus of this paper.

Table 2 - Firms in adjacent sectors identified as involved in MRET and technologies targeted

Source	Nº Firms*	Main technology area		
		Wave energy	Offshore wind	Marine energies
Project partners	33	17	7	9
Suppliers	32	11	21	0
Questionnaire (new)	17	1	5	11
Total	**82**	**29**	**33**	**20**

3.4 Transformative Capacity Indicator

The Transformative Capacity Indicator (TPI) gauges the eventual effect that the development of a certain new technology can have in the economy. TPI aims to measure the extent to which the innovation creates activity in a large number of sectors and engages a diversified (rather than concentrated) number of sectors.

TPI is a composite indicator with two main components. It has a parcel with the number of engaged sub-sectors (in %, relative to the total number of sub-sectors). Another parcel uses the Shannon Diversity Indicator (S) to account for the diversity of engaged subsectors. That is, the pervasiveness of the induced activities and the way those are more dispersed (or concentrated) in few sectors. More transformative technologies provide more opportunities to change a higher number of sectors (more even impact) from the industrial context, by creating more complementarities with other industries or by being competitive and attractive for more sectors to diversity their activities. This sub-indicator is also reported in percentage of the maximum (Smax) given the number of categories. The final result is conveniently expressed in relative terms, evolving from 0% to 100% for respectively null and very high transformative Capacity of the technology i. The formula is as follows:

$$TPI_i = \frac{N^{\underline{o}}\ engaged\ sub-sectors_{\ i}}{Total\ n^{\underline{o}}\ of\ sub-sectors} * \frac{Shannon\ Diversity\ Index_{\ i}}{Smax}$$

We use the NACE classification which provides a picture of the economic context. The distribution of activities through the different sectors (NACE codes) reveals the relative capacity of the technology to attract resources against the competition. The use of the 2-digit NACE (2nd revision) guarantees a manageable complexity while allowing the analysis of the existing sectoral complementarities. Data come from sectoral analysis which uses available innovation reports, scenarios or roadmaps (more details in SI) – a literature typically abundant for several technologies across countries.

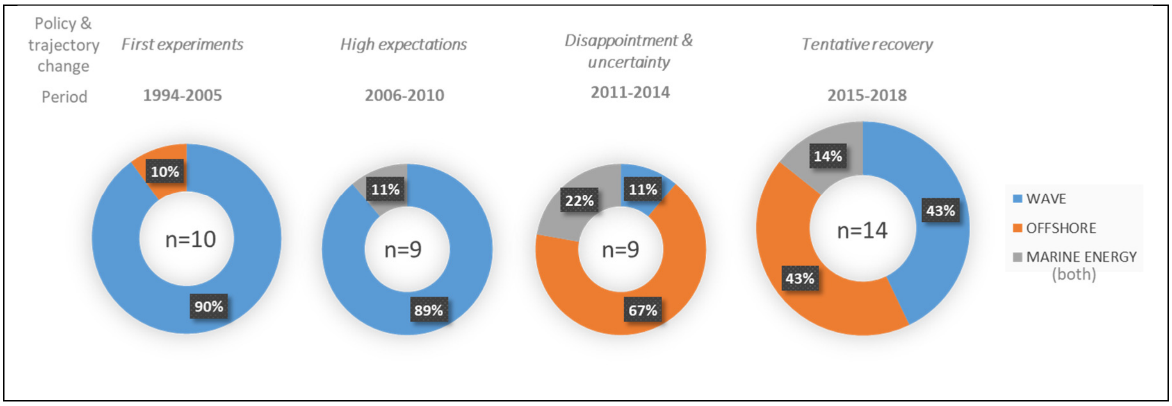
4 THE INFLUENCE OF MARINE RENEWABLE ENERGY TECHNOLOGIES IN ADJACENT SECTORS

4.1 Context

Two features of the context are particularly relevant for the ability of emerging technologies to attract firms from adjacent sectors to the new value chain being formed: the presence of supportive policies and the industrial specialisation.

We analyse the effects of *policy changes* in the participation of adjacent sector firms on RTD projects. For this analysis we consider four major periods, which were identified in previous research (Fontes et al, 2016; Fontes and Bento, 2018) as corresponding to alterations in the trajectory of MRET associated with changes in policy behaviour: 1) 1994-2005 – First experiments; 2) 2006-2010 – High expectations; 3) 2011-2014 – Disappointment & uncertainty; 4) 2015-2018 – Tentative recovery (Figure 2).

Figure 2 Adjacent sector firms in MRET, by period and technology



In the early years, wave energy technology was able to attract a few adjacent sector firms to experimental projects, taking advantage of the government support to this technology. This support was later removed, in the third period, in the context of a financial crisis, reducing the opportunities offered by wave energy. This period sees the launch of the floating offshore wind project, which despite the financial crisis was able to maintain policy support, and provided new opportunities for adjacent sectors. Finally the fourth period corresponds to a renewal of government interest in marine energies, encompassing both technologies. Offshore wind maintains its attraction, while wave energy recovers it with the arrival of several new technology developers.

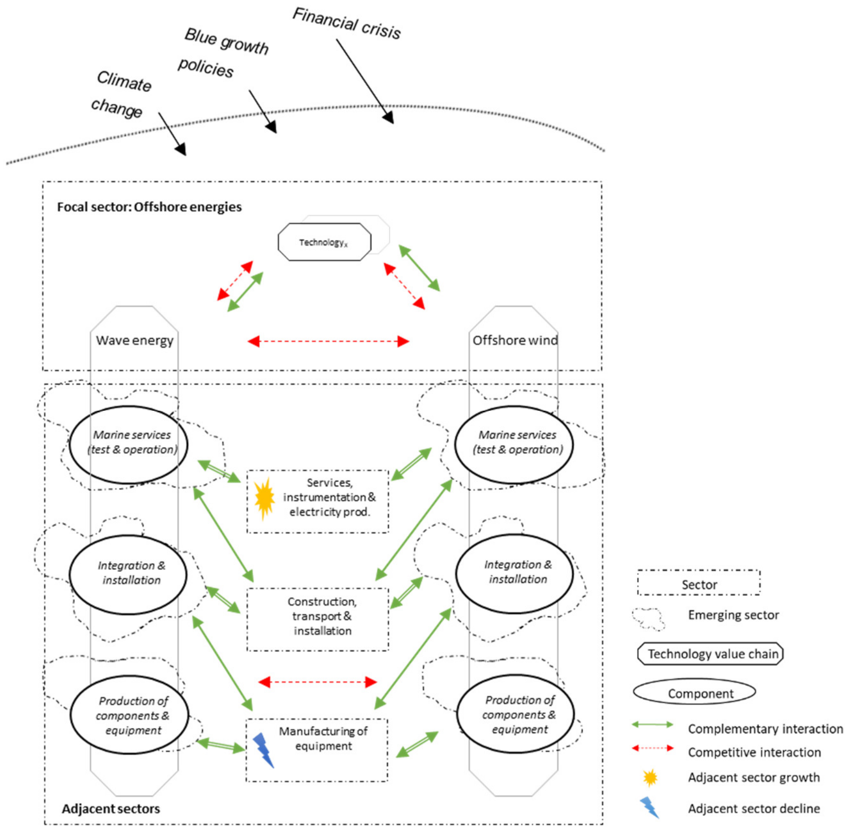
Thus, the presence and changes in policy support, by imposing opportunities and constraints to the development of emerging technologies, have a strong impact on the involvement of firms from adjacent sectors. But such impact was found to differ between technologies. Wave energy, the less mature technology, promoted by new entrepreneurial firms, was more vulnerable to policy changes, which affected both project funding and suppliers' perceptions of the technology potential. Conversely, floating offshore wind, closer to commercialization and promoted by large companies with established reputations and less dependent from external funding, was less affected, maintaining its attractiveness.

The existing *industrial specialisation* is another important element, which not only determines the type of sectors (and thus resources) that are available in the economy, but also influences the nature of the complementarities that can be established and thus the scope for transformation.

In Portugal, there is no dedicated offshore industry (Bento and Fontes, 2019). Although there are several well established sea-related sectors, firms tend to have a limited experience in specialized areas sought by MRET. Such competence gap can lead to hesitancy in getting involved, especially with an uncertain technology.

In this context, the formation of a value chain around MRET depends on contributions from other industries. The 82 firms identified in Section 3 were classified according to the NACE (Statistical Classification of Economic Activities) (see Supplementary Information), revealing that MRET activities did in fact involve a great diversity of sectors. These sectors were organised along 3 main categories: Manufacturing of equipment; Construction, Transport & Installation; Services, Instrumentation & Electricity production (Figure 3).

Figure 3 - Portuguese case



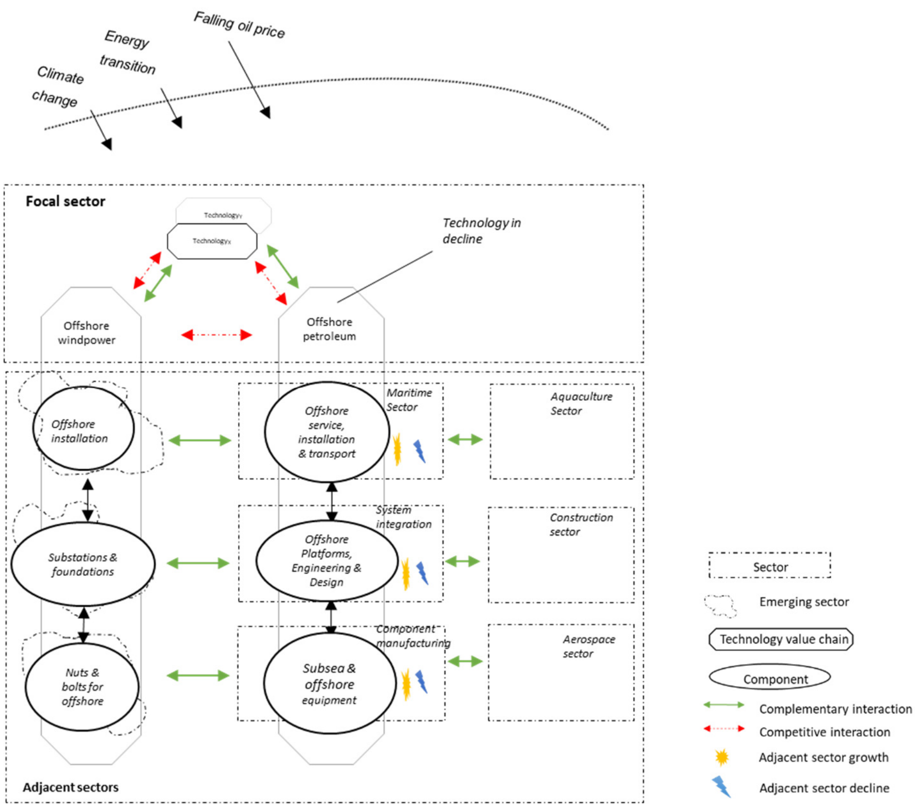
The current sectoral configuration of the technology value chain is shaped by the Portuguese industrial specialisation. The country has developed an industry around onshore wind (Bento and Fontes, 2016), which can answer to some needs of offshore wind. But besides that, both wave and offshore wind technologies draw on a variety of sectors, such as shipbuilding, ports, sea transport and maritime works for activities related to sea installation & maintenance; or metalwork, materials, electronics, computing and instrumentation for the production and operation of energy conversion devices. The fact that both technologies search for resources from the same sectors has advantages, since it increases the opportunities for the development of complementarities.

Overall, the new demands from the emerging technologies pull a diversity of interactions with several adjacent sectors, compensating for the absence of assets in the offshore industry. This diversity can lead to the development of a broad range of complementarities, encompassing established, declining and growing industries.

The impact of the context is likely to be at least partly country-specific, being influenced by the industrial structure and institutional environment. In order to highlight these specificities we compare the case of Portugal with that of another MRET frontrunner country with substantially different starting contextual conditions: Norway.

In Norway (Figure 4), offshore wind is one element of a wider industrial strategy to build new industries based on existing capabilities and knowledge in the ocean economy domain (Hav21, 2012; Maritim21, 2016). In this context, the technology value chain developed since the late 1960s around the offshore petroleum industry, had an important role in the development of offshore wind (Mäkitie et al., 2018). This value chain encompasses: system integration (design engineering, procurement, construction), component manufacturing (from high-tech specialized products to mundane nuts and bolts), and maritime sectors (ship building and specialized transport services) (Figure 6). Most segments of the value chain are technologically mature, being major exporters of technological equipment.

Figure 4 -Norwegian case



In 2015 about 100 supplier firms had diversified and were active in both petroleum and offshore wind (Mäkitie et al., 2018). This move was driven by a combination of decline in their main sector (due to fall of oil prices) and prospects of harvesting complementarities between their primary and emerging sectors by redeploying resources and capabilities (Andersen & Gulbrandsen, 2018; Steen & Weaver, 2017). This suggests that decline in sectors that are proximate to an emerging technology will augment the extent of resource flows redeployed from the former into the latter, enlarging the transformative impact of the new sector. However a majority of diversifying firms have been found to have a rather fickle engagement in the new sector, reducing their activity when oil prices increase (Mäkitie et al., 2019). Therefore, the existing offshore sector has accelerated the growth of offshore wind in Norway, but changes were more limited and indirect in other sectors.

This comparative analysis shows that the extent and nature of the interactions established with adjacent sectors, along the formation of a new technology value chain, are strongly influenced by the characteristics of the country industrial specialisation. In the case of MRET, the absence of industries that can be directly redeployed (which accelerated the formation of the system in the early years in Norway) led Portuguese MRET had to engage with a wider variety of less related sectors. Since such option is likely to require greater adjustments in the activities of the existing firms, it may create more opportunities for actual change in the respective sectors. Thus, different contextual conditions can affect the functioning of the other determinants of transformative capacity, introducing variety in the modes in which transformation may occur.

4.2 Complementarities

Complementarities here refer to the ways the interaction between the emerging technologies and firms in adjacent sectors can induce new activities in these sectors, potentially contributing to their transformation.

As shown above, the number of sectors mobilised by the experimental activities conducted by MRET was high (36 sectors, considering the 4 digits NACE classification), which increases the scope for interactions and thus opportunities for the creation of complementarities.

We analyse the contribution of adjacent sector firms to the technology value chain being formed (Table 3), using the information provided by the 24 firms that answered to the survey about their areas of activity. This permitted to position these firms in the three value chain levels proposed in the framework, which in the case of Portuguese technology value chain comprise: Production of components and equipment; Integration and installation; Marine services for test & operation (see Figure 3).

Table 3 shows that while adjacent sector firms contribute to all value chain levels, they are more frequently active in downstream activities related with installation and operation. Several firms are active at more than one level. There are no great differences between technologies, but the possibility of operating in both ("Marine") attracts relatively more firms than activity directed exclusively to one of them, not only to the more downstream *Marine services* level, but also to the *Production of equipment* level.

Table 3 – Positioning of adjacent sector firms' activities in the technology value chain levels (VCL)

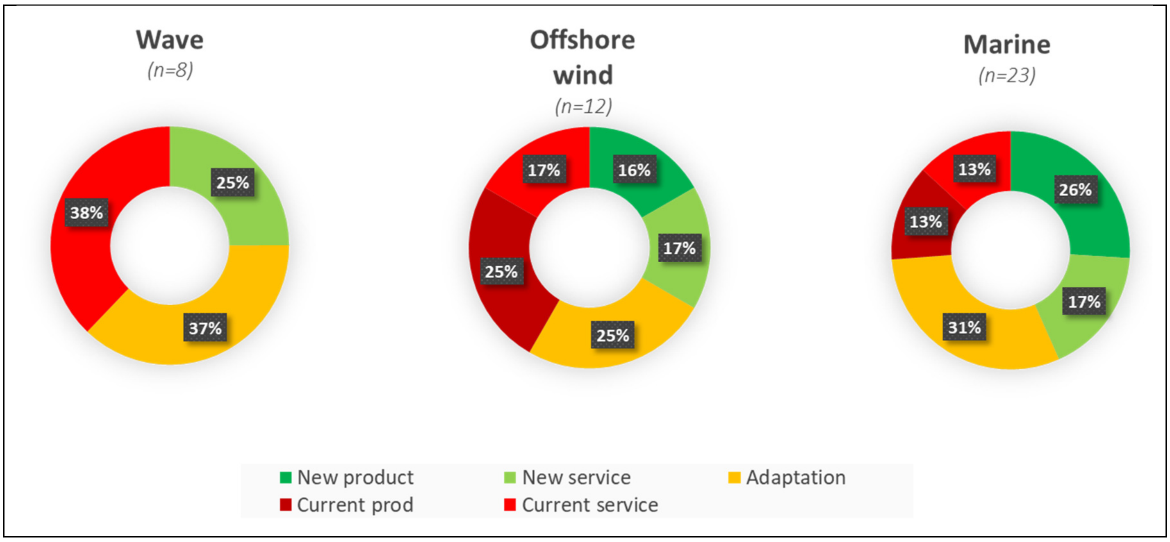
	Nº Resp.*	Nº firms			
		Total	Wave	Offshore	Marine
VCL1 - Production of components & equipment	13	**11**	3	3	**5**
Development of components, subsystems, materials, methods for conversion systems	6				
Production of components, subsystems, materials, methods for conversion systems	7				
VCL2 - Integration and Installation	16	**14**	4	**5**	5
Infrastructures for test and demonstration	5				
Products or services to support installation at sea	**11**				
Equipment, products or services related to grid connection	0				
VCL3 – Marine services (test & operation)	20	**13**	3	3	**7**
Products or services for systems operation and control	7				
Maintenance services	6				
Other services (e.g. environmental impact, licensing, regulatory issues, …)	7				

*Number of responses is higher than number of firms because some firms indicated more than one activity

We investigate whether the involvement of adjacent sectors in the new technology induces the performance of innovation activities by firms in these sectors. Since innovation activities create conditions for more intense interactions and the development of interdependences, the transformative capacity will be higher when innovative activities are conducted. We use survey information on the innovative nature of the products or services supplied by firms, i.e. whether they developed new products or services, adapted existing ones to new applications or straightforwardly provided current products or services.

Overall, the firms that answered to the survey tend to offer more frequently adaptations of products already in their portfolio to applications in the new area (52%), although several firms mention to develop new products (32%) or services (32%) (see Supplementary Information). Figure 5 compares firms' innovative behaviour across technologies. There are no major differences between technologies regarding the relative weight of innovation activities. But innovation in firms targeting only wave energy concentrates in services or in product adaptations to new applications; while standard supply occurs exclusively in services. In contrast, innovation in firms only active in offshore wind is more distributed across products, services and adaptations; and supply of standard products has a substantial weight. Moreover, firms that operate with both technologies are relatively more involved in new developments and relatively less in standard supply. These results suggest that activity in both areas may offer more opportunities for the development of complementarities associated with innovation.

Figure 5 - Novelty of products or services supplied by adjacent sector firms, by technology



We further assess whether there are differences in innovative behaviour across adjacent sectors. Table 4 shows that only part of the sectors identified have firms engaged in dedicated innovative activities. It also shows that there are more sectors supplying new services than new products. This includes services offered by engineering and other technical sectors, populated by new firms with advanced technologies.

Table 4 - Sectors engaged in dedicated innovative activities, by type of activity

	New products	New services	Adapta-tions
1. Manufacturing of equipment *(3 in 5)*			
Manufacture of metal structures and parts of structures	X	X	X
Manufacture of cordage, rope, twine and netting	X		X
Building of ships and floating structures		X	X
2. Construction, Transport, Installation *(3 in 4)*			
Wholesale of electronic and telecommunications equipment		X	X
Construction of other civil engineering projects		X	X
Trade of electricity		X	
3. Services, Instrumentation, Electricity production *(5 in 6)*			
Other professional, scientific and technical activities	X	X	X
Technical testing and analysis	X	X	
Business and other management consultancy activities	X		X
Engineering activities and related technical consultancy	X		X
Computer programming activities		X	X

N = 15 sectors populated by active firms that answered to the questionnaire

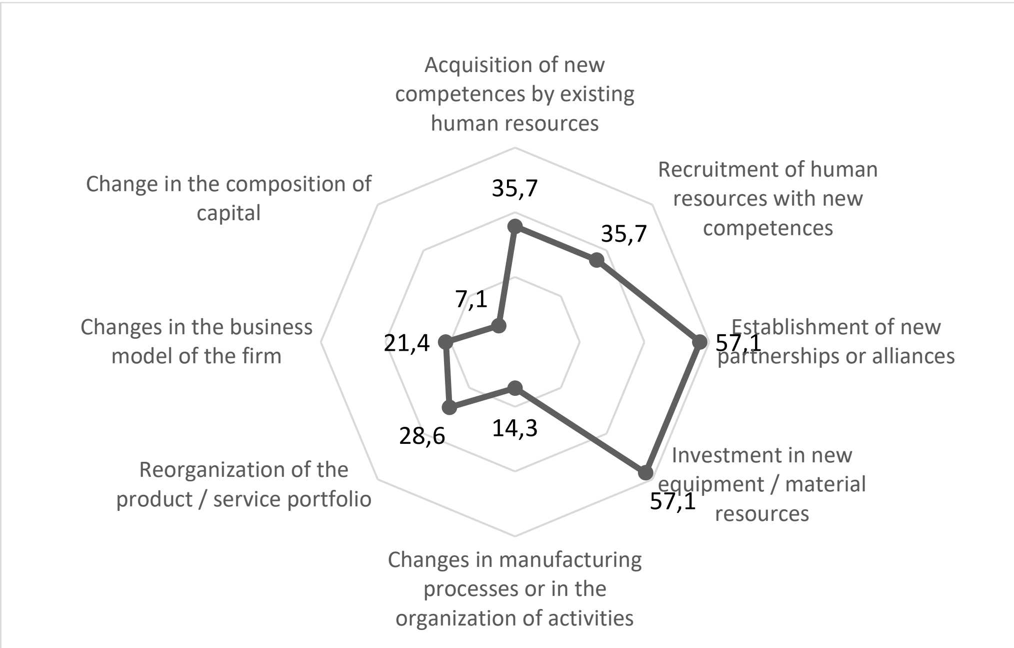
4.3 Competition

The capacity of the emergent technology to divert competitive resources - that is, to convince adjacent sectors to invest in activities that answer to its needs despite the competition from established markets –also determines its transformative capacity.

Internal changes in adjacent sectors firms reflect a willingness to adjust the activities to answer to the new opportunities. Thus they indicate the relative capacity of the technology to attract competitive resources (along with the conduction of dedicated innovative activities, already discussed in the previous section). Therefore, use information from the firms surveyed, on whether they introduced changes in their activity to enter/operate in MRET and which types of changes, according to the categories shown in Figure 6.

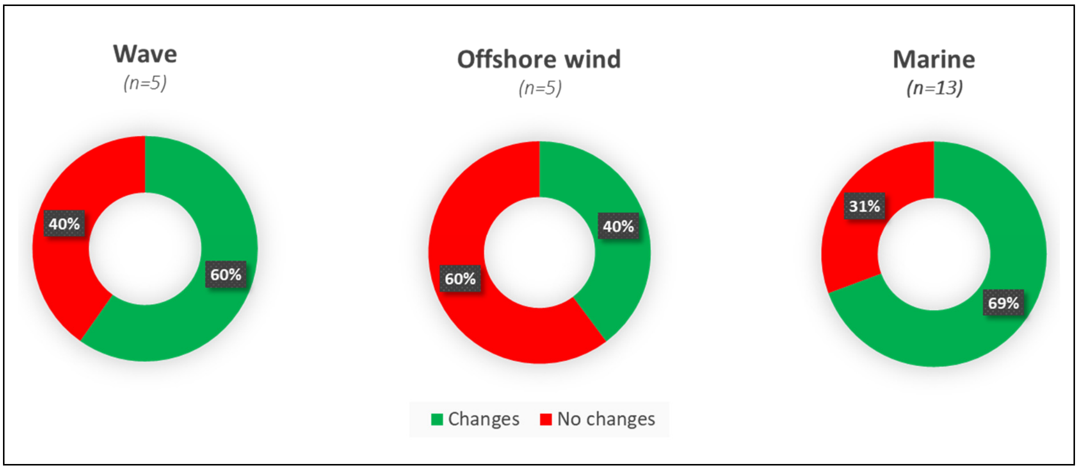
More than half of the firms had introduced changes to enter in MRET. The most important changes concern investment in equipment and other material resources, as well as establishment of new partnerships or alliances. Obtaining new skills – through training of human resources or new recruitment – is also frequent. Of lower importance are changes in company strategic positioning, such as reorganization of its portfolio, or new business models.

Figure 6 – Internal changes introduced by adjacent sector firms to enter/operate in MRET (% of responses)



We also assess whether the two technologies have different impact on the decision to introduce internal changes. Figure 7 shows that firms operating in offshore wind introduce changes relatively less frequently than those in wave. However, firms active in both technologies tend to introduce changes more frequently when compared to those that operate in a single technology. This suggests that the presence in both technologies may require a higher commitment, potentially leading to broader adjustments in firms' activity.

Figure 7 - Internal changes by technology targeted



4.4 Comparing the transformative capacity of technologies

We apply the Transformative Capacity Indicator (TPI) to assess the relative effect of the two technologies under analysis – wave energy and offshore wind – in existing sectors. In the case of two or more technologies, the TPI identifies the technology with the highest transformative capacity. The technology with the highest score in average engages a relatively higher number of complementary activities, which also tend to be more evenly distributed across sectors. Table 5 shows the results for the cases of floating offshore wind and wave energy technology in Portugal. Wave energy has a slightly higher TPI of 9%. It also scores higher in the two component indicators, particularly in the Shannon Diversity Index where it overtakes floating by 5 percentage points. These results say that wave energy has a slightly higher transformative capacity than floating offshore wind.

Table 5 - Transformative Capacity Indicator

Indicator/	Engaged sectors		Shannon Index		**TPI**
Technology	#	%	#	%	%
Floating offshore	13	13%	2.339	52%	**7%**
Wave energy	16	16%	2.599	58%	**9%**

Total number of subsectors in 2-digit NACE (rev.2): 88. Maximum value for the Shannon Diversity Index (Smax) is the natural logarithmic of the number of categories (ln (88)) which is 4.477, corresponding to the extreme case of equitability under which all the events are evenly distributed by the categories. Engaged sectors from the 82 firms identified in Table 2.

The transformative capacity indicator has some inherent limitations. The multiplicative form has the advantage to produce more comparable results and standardized results. But alternative specifications are possible, such as the mean of the two base metrics, with or without different weights. On the other hand, technologies need to be in similar stages of development to better understand their capacity to create change in other sectors and sub-sectors. In our analysis, floating offshore wind is slightly more advanced than wave technology, but both are in the pre-commercialization stage. Finally, TPI says little about the forecasting of exports or job creation. However, it is less complex than the Economic Complexity Index for international specialization (Hidalgo, 2018), or less controversial than the estimation of green jobs. All in all, we propose an indicator that assesses in a simple, but solid way, the industrial transformative capacity of new technologies in order to enable policy-makers to unleash the maximum potential for the same public effort.

5 DISCUSSION AND CONCLUSIONS

The paper contributes to a better understanding of how the development of new sustainable technologies can enhance industrial activity, thus filling a gap in transitions research (Andersen et al, 2020). It investigates the conditions that can stimulate the industrial transformative capacity of sustainable technologies, understood as the ability to produce effects beyond the focal sector, which can contribute to the reorganization and expansion of established sectors, or provide growth opportunities for new ones.

By investigating how the existing sectors can be positively impacted by the transition process, the paper moves beyond research that addresses the context as a means to accelerate the development of the new sustainable technologies (Mäkitie et al., 2018), or that focuses on the destructive effects of transitions upon established activities (McCauley & Heffron, 2018). This is an important change of perspective, as the urgent need to decarbonize the energy system should go along with countries' search for strategies to restructure the domestic industry (e.g. Newell and Mulvaney, 2013; Lamperti et al., 2019).

The conceptual framework proposed addresses the industrial transformative capacity of sustainable technologies by looking at the interactions that occur between the focal technological system and the context, the complementary (adjacent) sectors, and other competitive technologies, along the formation of its new value chain.

We defined measures for these factors and studied their effect in the case of MRET in Portugal, based on an exhaustive mapping and a survey of the actors from adjacent sectors engaged in the value chain of floating offshore wind and wave energy.

The results show that the *context* constrains the industrial transformative capacity of emerging technologies. Changes in policies had a critical impact upon the capacity of MRET in Portugal to attract resources from adjacent sectors. The impact was stronger in the case of the more immature technology (wave energy). This confirms the importance of institutional alignment for promoting sustained interactions between emerging technologies and relevant sectors as pointed in other studies (e.g. Bergek et al., 2015). The industrial specialisation was also critical, influencing the type and nature of the relationship with adjacent sectors, as was highlighted by a comparison with Norway. In the case of Norway, offshore wind can take advantage of the resources from an established offshore industry (oil & gas) (Mäkitie et al, 2019). In contrast, in the case of Portugal, where such industry is absent, both offshore wind and wave energy are forced to compete and collaborate for the resources of several less proximate sectors. This can slow down the flow of resources, but also creates greater opportunities for more sectors, and for increasing the scope of "redomaining" (Arthur, 2009).

Therefore, the country's industrial and political context offers a set of starting conditions that affect the formation of complementarities and competition, resulting in variations in the way the industrial transformative capacity unfolds.

Complementarities are key for expanding the socio-economic benefits of innovations. The study confirms previous research that points to the importance of the different types of complementarities (e.g., technological, institutional, infrastructural) (Markard and Hoffman, 2016). The analysis uncovered the participation of firms from a wide range of sectors in MRET and their role in the formation of the new value chains. A substantial number of firms had engaged in dedicated innovative activities, more frequently adaptations of existing products to new applications, but also products or services developed for the new area. The effects may be stronger in firms operating with both technologies, which offered a greater variety of activities and were relatively more innovative.

Competition – here expressed as the ability to divert scarce resources from established activities to the new area - affects the capacity of the emerging technology to create new activities in the existing sectors. The fact that a substantial number of supplier firms had already introduced some internal changes to answer to the new demands – particularly concerning human and material resources and new partnerships - suggests that the new technology was able to compete with the markets that adjacent sectors usually supply. However, trade-offs exist, depending on the relative competitive power of each emerging technology (Garud et al., 2002). Firms operating in offshore wind (closer to commercialization) were more likely to supply standard products and introduced organizational changes less frequently. This suggests that the more advanced stage of the technology may result in less intense interaction with adjacent sectors, which is consistent with the notion that the need to create links with context structures is stronger in the early stages of development of a technology (Markard, 2020)

We develop an indicator to assess the industrial transformative capacity of technologies. The TPI takes a step forward in relation to the qualitative analysis by showing that, in this case, the more immature technology (wave energy) has a higher capacity to diversify the activities in the economic structure. This confirms the qualitative results that point to the technology characteristics as a source of variation in industrial transformative capacity. The indicator compares the industrial transformative capacity of technologies in real time, providing crucial information to policy-makers, which could be of interest to the emergent literature on transformative innovation policy (Janssen, 2019).

Overall, to understand how sustainable energy transitions can contribute to industrial transformation, this paper introduced a new concept – industrial transformative capacity of a technology - and operationalized it along three main determining factors: context, complementarities and competition. The application of this conceptual framework permitted to conclude that the capacity of emerging technologies to spur new industrial activities in adjacent sectors is an important effect and allowed us to uncover the mechanisms behind such capacity. The research also produced an indicator to assess the industrial transformative capacity of different technologies. These results provide important insights into processes that can result on a positive (rather than destructive) effect of sustainable energy transitions upon existing activities and jobs.

The paper contributes to shade light on the channels through which lead to transformational change. To our knowledge this is the first attempt to analyse technology emergence in terms of its impact on other sectors. Concerning the generalization of the findings, and even though based on a country case study approach, the comparison with Norway permits to identify regularities that can support recommendations to other countries aiming to combine sustainability goals with enhanced industrial activity. They indicate that the country industrial specialisation needs to be taken into account when defining strategies to promote new sustainable technologies with socio-economic goals. In particular, policies should consider how to bring together the requirements of the technology value chain being formed and the competences of the local industry. More theoretical and empirical analyses will improve the understanding about the effects of each one of the determinants (context, complementarities and competition) and their interplay.

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