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Winds of change: the potential path disturbing effect induced by the offshore wind energy technology

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Abstract Path development literature focus on path creation or on changes in mature paths but gives limited attention to early path evolution. The paper addresses this gap by investigating the disturbance, in the early trajectory of technology-driven regional industrial paths, that results from the emergence of new generations of technology. We propose that changes in actor composition and purposeful resource modification actions by path actors are important elements of disturbance and develop an approach to investigate their effects. The ongoing changes in the wind energy regional industrial path, associated with the development and diffusion of offshore wind energy technology, are empirically investigated. The research finds evidence of path disturbing effects at the level of actors and resources. As onshore wind actors start engaging in offshore activities and new actors enter the wind business, the composition and industrial structure of the wind energy regional path and its spatial distribution start to change. There are equally important effects upon the process of resource formation, at the level of knowledge, market, financial and legitimacy system resources and across the various phases of the industrial value chain.

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The paper contributes to a better understanding of path disturbance and offers an instrument to assess deviation in path trajectories and pinpoint its sources.

Keywords Regional industrial path · Path disturbing · Actor behaviour · Resource formation · Wind energy

1 Introduction

The paper addresses the disturbance that new generations of a technology can introduce in the early trajectory of a regional industrial path built around that technology.

While the process of new path creation is widely studied, there is less attention to the evolution of the new path (Fredin et al. 2019; Gong and Binz 2023). However, when the industrial path was driven by a new technology, subsequent developments that result in the emergence of new technology generations can lead, early on, to significant changes in actors and resource configurations—e.g. extensive mobilization of new actors, strategic change among the existing ones and major modifications in the stock of resources. These changes can be sufficiently important to introduce disturbances in the path trajectory, affecting its industrial and institutional structure, with implications for the regions that started building the new path around the technology.

Such disturbances can be equated to what has been recently described in the literature as "critical moments" in a new path cumulative system resource formation process, in which actors are required to strategically re-orient strategies and update or reconfigure resource stocks (Gong and Binz 2023). But, besides requiring strong firm and system level agency (Grillitsch et al. 2018) from path actors, these disturbances may also create opportunities for actors external to the path, which possess resources that are not part of the industry-specific resource stock but are critical for the new resource formation process (Trippl et al. 2018; Mäkitie et al. 2018). It is also important to take into account that these processes are not necessarily uniform and may have a greater incidence in some parts of the industrial value chain more affected by the new technology requirements (Poulsen and Lema 2017).

In this paper, we propose to investigate in greater detail the "disturbance" processes at work in the "critical moments" that result from the emergence of subsequent technology generations in a regional industrial path driven by a new technology. Drawing on the literature, we advance that changes in actors' composition and territorial distribution, and purposeful resource modification actions by path actors are important elements of disturbance and develop an approach to investigate their unfolding. These changes can have consequences for the regions involved, contributing to their densification and diversification as well as to reinforce the regional path embeddedness.

We apply this approach to the case of wind energy, focusing on a wind energy regional path formed within Portugal. Wind energy technology is an interesting empirical setting, as the first technology generation triggered the development of industrial paths in several regions (Bento and Fontes 2015; Rohe 2020; Simmie et al. 2014). But new technology generations that moved the wind energy to the sea—bottom-fixed and later floating technologies—increasingly diverge from the onshore technology, demanding significant changes at industrial and institutional levels and therefore potentially creating disturbance in the existing paths.

The empirical analysis starts by highlighting the areas of the wind energy value chain in which offshore wind substantially differs from onshore wind. Subsequently we map the regional industrial path initially formed around onshore wind energy technology (actors, installed capacity) and uncover the emergence of new activity around floating offshore wind technology. The latter includes actors' movement from onshore to offshore wind and new entry from outside the path, and its spatial distribution.

In a second step, we investigate the path disturbing effects that result from the development and implementation of offshore wind technology, by focusing on the behaviour of a particular group of actors—firms—across the different phases of the industrial value chain. For this we: (i) assess the relative incidence of movers from onshore wind and new entrants in each phase; and (ii) investigate the resource modification processes conducted by the movers from onshore.

The research found evidence of disturbance at the level of actors and resources resulting from the emergence and diffusion of the new generation of wind energy technology. As onshore wind actors start engaging in offshore activities and actors external to the path enter the wind business, the composition and industrial structure of the path and its spatial structure start to change, and there are important effects upon the process of resource formation.

The paper contributes to a better understanding of the disturbance introduced in the early trajectory of technology-driven regional paths by new technology generations. Using microdata on actors' behaviour it identifies factors of disturbance—at the level of actors and resources—and their effects in the existing path and discusses some implications for regional development. This approach can offer an important instrument to assessing deviation in path trajectories and pinpointing its sources.

2 Literature

2.1 Path development and disturbance

The emergence of a new radical technology can create opportunities for the development of new industries. Such development often has a strong territorial component, being at the basis of new regional industrial path creation (Tanner 2016; Simmie et al. 2014).

The concept of regional industrial path captures the evolution and trajectory of industries within a specific region, recognizing that past developments often constrain future possibilities, yet new paths can emerge (Garud and Karnøe 2001; Martin and Sunley 2006). The formation of a new path in a given region was found to require, not only the presence of favourable pre-existing technological and economic conditions (Boschma 2017; Martin and Sunley 2006), but also the individual and collective agency of a variety of actors from within and outside the region, whose activities drive change in organizational practices and institutional arrangements (Binz et al. 2016; Hassink et al. 2019; MacKinnon et al. 2019a).

The literature describes a number of regional structural preconditions on which the new path draws to emerge and develop: natural resources, scientific and technological knowledge, industrial assets, infrastructural assets, institutional assets (regulations, norms). Actors engaged in new path creation mobilize and eventually reconfigure these assets to build the new industrial trajectory (Hassink et al. 2019; MacKinnon et al. 2019a; Trippl et al. 2020). The literature also notes that some relevant assets may not be present in the region but be obtained from non-regional sources through networks or the installation of outsiders (organizations or individuals) (Fredin et al. 2019; Trippl et al. 2018).

Gong and Binz (2023) provide a conceptualisation of the resource formation process, pointing out that an emerging industry resorts to a combination of region-specific resources—that is, the regional assets that can be mobilised by actors for the new industrial path—and industry specific resources. The latter are described as system resources that are formed along the process of development of a new industry or reconfiguration of an existing one (Binz et al. 2016; Musiolik et al. 2020). Binz et al. (2016) and Binz and Truffer (2017) typified these resources in four broad categories: knowledge, market access, financial capital, and legitimacy. The process of resource formation is conducted by system actors over time and can occur endogenously in the region (drawing on regions' resource stocks) or result from bringing-in external resources and anchoring them into the region (Binz and Truffer 2017). Mobilizing resources absent in the local context, through the establishment of resource complementarities at different spatial scales, can be particularly relevant for late mover regions (Heiberg and Truffer 2022).

While the process of new path creation, namely the conditions that lead to its emergence, are widely studied, there is less attention to the evolution of the new path (Fredin et al. 2019; Gong and Binz 2023; Brenner and Jeddeloh 2024). However, when a regional industrial path was driven by a new technology, the subsequent development of that technology—namely the emergence of new technology generations—may raise, early on, new requirements in terms of industrial and institutional configurations, potentially disturbing the industrial trajectory, with implications for the region in which it is embedded.

The literature on path development conceptualized different ways in which industrial path trajectories can evolve and eventually be transformed, through the influx of new knowledge and its combination with the existing one, advancing mechanisms such as path upgrading (major changes within an existing path in new directions) or path diversification (creation of a new sector from within an existing industry) (Grillitsch et al. 2018; Hassink et al. 2019). But the focus tends to be on changes in industrial path trajectories experiencing maturity or even decline (Breul et al. 2021; De Propris and Bailey 2021), rather than on trajectories that are still in relatively early stages and have high growth potential.

It is therefore important to understand these early "disturbances": which processes are at work, which are the possible effects they will have upon the new industrial path, and which are the potential implications for the region.

The “disturbance” arising from the emergence of new technology generations in a new technology-driven path can be conceptually equated to what Gong and Binz (2023: 4) define as “critical moments” in a new path cumulative system resource formation process. The authors characterize them as “endogenous or exogenous crises and shocks, windows of opportunity, perturbations”, which may require actors to re-orient their strategies and update and reconfigure their resource stocks.

The change processes set in motion by the emergence of new technology generations can create a threat to the path, if the technology diffusion renders it less competitive. But they may also open up opportunities for new developments, in parallel to (or in combination with) the current activities. Path-related actors face the choice to opt (or not) for re-directing some of their activities or developing new ones in response to these opportunities (Andersen et al. 2017). In the particular case of industry actors, this can assume the form of diversification into related markets that allow them to redeploy existing resources (Adner and Zemsky 2016; Wiersema and Beck 2017), directly or in support to the creation of new ones (Mäkitie 2020). In the case of a path that is not experiencing particular difficulties, the lack of immediate pressure to change may leave a greater margin for path actors to opt. Indeed, such option may also be influenced by the fact that new activities may interfere with the performance of existing ones, raise conflicts/trade-offs (Levinthal and Wu 2010).

On the other hand, it may be difficult for path actors to create all the necessary new resources, as they may substantially differ from the existing ones (Markard and Petersen 2009; Poulsen and Lema 2017). Thus, the new opportunities may also call the attention of actors from other industries, which possess resources that are not specific to the industry in its current state, but address the requirements raised by the new technology generation (Steen and Hansen 2014). While these new actors may be diversifying towards unfamiliar markets, they are also likely to be redeploying existing resources (Wiersema and Beck 2017; Grillitsch et al. 2018), even if the lower familiarity with the new markets—including customers knowledge and network access—may make entry more complex (Content and Frenken 2016).

An understanding of the change processes that are associated with the emergence of new generations of a technology is relevant because they can have consequences for the configuration of the regional industrial path and therefore for the development of the region (Isaksen and Trippl 2016; MacKinnon et al. 2019b). In fact, while a new technology naturally evolves over time, these particular changes can be sufficiently important to require extensive mobilization or creation of resources not possessed (or fully utilised) by the regional path actors (Fontes et al. 2021). Some of these resources may still be available in the region and, therefore, the expansion of activities of existing path actors or of new actors with new resources will positively affect regional development (Grillitsch et al. 2018). Other resources may need to be obtained outside the region, therefore leading to an increase of extra-regional links and associated influx of some resources (Trippl et al. 2018), and eventually to the expansion of the path to other regions.

Considering the above, it can be concluded that the magnitude of the impact of new technology generations on the existing regional industrial path depends on how much they diverge from earlier ones, and on the nature of the changes in the path trajectory that are necessary to adjust to them, including the amount of changes in the stock of industry specific resources and the extent to which these changes involve entry of new actors with a different set of resources.

It is therefore relevant to understand along which aspects of the evolution of a new technology-driven regional industrial path will the subsequent technology generations introduce disturbance, and how actors' agency is deployed to address them. Such understanding is important from the standpoint of the region as the evolution of the path will have consequences for regional development.

The technology-driven industrial paths formed around wind energy technology provide an exemplary case of potential for path disturbance, as will be discuss below.

2.2 Path evolution in the case of wind energy technology

The first generation of wind energy technology, that resulted in the development and installation of wind energy generation systems on-land—onshore wind—drove the development of new industrial paths in several regions (Bento and Fontes 2015; Rohe 2020; Simmie et al. 2014; Varela-Vázquez and Sánchez-Carreira 2015). This was followed by the introduction of new generations of this technology that moved wind energy generation systems from land to the sea: first bottom-fixed systems to be installed in shallow waters; then floating systems that could be installed in deeper waters. These new technology generations showed some structural continuity in several elements (e.g. the core turbine technology), but increasingly diverged from the onshore technology in others, requiring significant changes in the industry concerned with their production and deployment (Andersen et al. 2017; van der Loos et al. 2020; Wüstemeyer et al. 2015).

The industrial development of the new technology generations, not only demands innovation activity in some of products/services supplied by the existing manufacturing industry (e.g. in the case of the core wind turbine technology) (Wüstemeyer et al. 2015), but also requires the involvement of a new set of actors, often from unrelated industries, whose resources are necessary to deal with the new requirements of operating at sea (Bento et al. 2021; Poulsen and Lema 2017). The location at sea also makes proximity to the natural resource more pertinent, has implications in terms of physical infrastructures, demands regulatory changes and raises new acceptance issues (MacKinnon et al. 2019b; Wüstemeyer et al. 2015).

In terms of industry location, the move offshore represents a significant change: while in onshore wind industry location was influenced by the inland natural characteristics, in offshore wind industry location will tend to be more influenced by the importance of being near the sea. In particular, characteristics of the ports and proximity to them gain a new importance. As infrastructure, port facilities have a strong location effect as they become central to offshore activities (especially for floating offshore), not only to serve installation and/or operations and maintenance, but also increasingly as the setting for some stages of manufacturing (especially assembly of large components) (Wind Europe 2021). For instance, to support the installation and operation and maintenance phases of offshore wind projects, the physical characteristics (ex. bearing capacity), connectivity (distance to the offshore site) and layout of the port (ex. port depth) are determinant (Akbari et al. 2017). At the same time, for firms, location near ports can become an important issue, both for local supply and for exports, given the characteristics of the industry—large sizes that are difficult to move from inland—and the logistics associated with sea installation. All these factors enhance the relevance of geographical location in the proximity to some ports.

It is therefore argued that the emergence of the new wind energy technology generations potentially produces disturbance along several dimensions that could affect the industrial and institutional configuration of the wind energy regional path. For this reason, the ongoing move from onshore to offshore wind can be regarded as a particularly appropriate setting to examine the factors of disturbance in the path early evolution.

3 Methodology

The empirical analysis of path disturbance is based on the case of wind energy in Portugal. The country developed an onshore wind energy industry, that combined endogenous development with importation of some assets and actors (Bento and Fontes 2015). This development was mainly located in the centre and north west parts of the country, where the formation of a wind energy regional path could be observed. Although Portugal missed the first generation of bottom-fixed offshore wind, it has engaged early in experimentation with the new generation of floating offshore wind (Fontes et al. 2022; Vieira et al. 2019), which is still at a pre-commercial stage (Castro-Santos et al. 2020).

The objective of the study is to investigate disturbance in the wind energy regional path, as a result of the ongoing development and deployment of offshore wind, focusing on actors and resources. The actors analysed include the main actors involved in wind energy: firms, universities and research and technology centres, government agencies, collective and civil society organisations. The resources encompass the four categories of resources proposed by Binz et al. (2016): knowledge, market access, financial capital, and legitimacy.

The analysis follows two steps: 1) characterization of the wind energy regional industrial path, as well as the dynamics introduced by the emergence of offshore wind, focusing on the changing actor composition and spatial distribution and identifying the potential for disturbance they drive; 2) more detailed investigation of the disturbance introduced in the wind energy regional industrial path by the development of offshore wind activities, focusing on the behaviour of a particular group of actors—firms—across the different phases of the industrial value chain.

The empirical analysis combines secondary data—on the structure of the onshore wind industry and on the experimental activities aiming at the early development of floating offshore wind—and primary data from a questionnaire survey to firms.

Secondary sources include wind energy technology and industry reports, specialized magazines and websites, directories from industrial associations, data on research and innovation projects in the wind energy field, previous research on wind energy. They were used to support the identification and characterization of organisations involved in wind energy (both already operating in onshore and new entrants in the offshore area) and, in the case of onshore wind, the location of wind parks and the installed capacity. In the particular case of firms, they also provided some indications towards their location in the industrial value chain, which was complemented by extensive analysis of firms' activities as presented in their websites and other documents.

The questionnaire survey was first of all concerned with identifying new firms active in offshore wind, as complete information on this still emerging area could not be found in secondary sources. It targeted three groups of firms: 1) firms active in onshore wind; 2) firms already identified in previous research as active in marine renewable energies (which in Portugal encompass offshore wind and wave energy[1]); 3) firms from sectors identified in various studies as potential contributors to the offshore wind value chain. The contact to this third group of firms was tentative, as we did not expect the majority of them to be involved in offshore wind. But we still expected to be able to identify some that were not captured by the secondary data search. We were also expecting to uncover some potential interest in the offshore wind area by firms not yet active in that area.

The questionnaire also addressed the activities being conducted by these firms in the offshore wind area. The goal was to obtain information about the changes in the organisation of the industrial value chain and in the resource formation process driven by the new requirements of offshore wind.

Therefore, the questionnaire inquired firms about: (i) whether they were/had been involved in offshore wind activities and, if not, whether they were considering the possibility of entering in the near future; (ii) the areas in the offshore wind value chain in which they operate or foresee to in the future; (iii) the changes on their activities/organization that were required, or are expected, in order to enter/operate in the new field; (iii) the obstacles faced or expected to in doing it. For each item the questionnaire offered a comprehensive set of non-exclusive alternatives that were based on the known activities, resources and problems in the offshore wind area. It also provided space for open responses in order to include alternatives not listed or to allow the responds to develop some issues they judged relevant.

The questionnaire was administered online through a survey platform, during 2022 and 2023. A total of 979 firms were successfully contacted (a further 123 questionnaires were returned)[2]. The survey yielded 381 answers: 97 from firms that were or had been involved in offshore wind, 148 from firms not involved but that expressed the intention of entering in the future, 121 from firms that declared to have no interest in offshore wind and 15 from firms exclusively active in wave energy. Given the purpose of this research, we only retained the answers of firms that mentioned involvement in offshore wind (either already active in onshore wind or new entrants), and of firms active in onshore wind that expressed the intention of entering offshore wind.

[1] There is a substantial overlap of part of the sea-related value chains in offshore wind and wave energy. Portugal was a pioneer in wave energy, with a long tradition of organizations operating in this field that in many cases also moved to offshore wind when this activity started in the country (Fontes et al. 2022).

[2] The questionnaire was sent to the e-mail of members of the management team when it was possible to obtain. Otherwise, it was sent to the firm official e-mail.

The response rate (39%) was regarded as acceptable, considering that a substantial part of the firms targeted belonged to the "tentative group", most of which were unlikely to be involved or have interest in offshore wind, thus potentially discarding the survey.

The answers received permitted to considerably extend our initial dataset of firms active in offshore wind. In addition, they also permitted to identify a group of onshore wind firms not yet active in offshore but willing to engage with this activity in the future. The data obtained from the questionnaire allowed, first of all, to locate firms more precisely in the industrial value chain. It also provided relevant microdata to support a first analysis of resource modification associated with the move of onshore firms to offshore.

The online survey was chosen as mode of inquiry as it enabled us to target the known universe of firms active/potentially active in the offshore area. This provided a broad perspective on the range of activities being developed by the variety of firms moving into the new area, permitting to gain some new insights into the change processes underway in that universe, even if at the expense of a more in-depth understanding of how these processes were conducted. Relevant cases of resource modification identified can be subsequently subject to a more detailed analysis through face-to-face interviews, in order to gain such understanding.

Finally, consultation with technology and industry experts, attendance of events in the field and informal contacts with key actors offered opportunities to gain additional knowledge and to validate some of the data obtained.

The analysis in step 1 involved the cartographic representation of wind parks and respective capacity, as well as the identification and spatial distribution of the organisations involved in wind energy (firms, universities and research and technology centres, government agencies, collective and civil society and organisations) according to their activity in onshore wind, offshore wind or both.

The analysis in step 2 addressed exclusively the firms, focusing on the potential of disturbance introduced by their behaviour. It involved, first of all, an assessment of the distribution of the three groups of firms identified (movers from onshore, potential movers from onshore and new entrants) across the different phases of the industrial value chain, in order to investigate which types of activities appeared to be more affected by the new requirements of offshore wind technology. It subsequently focused on the firms moving from onshore and, based on the answers to the questionnaire, analysed the extent of resource modification and the type of resources affected along the resource categories defined in the literature (knowledge, market, finance, legitimacy).

4 Wind energy industrial value chain—from onshore to offshore

As pointed out above, the development and deployment of offshore wind requires more or less extensive changes in the industrial value chain, in particular in some segments—e.g. these related with the installation process—which depend on technologies and competences substantially distinct from onshore ones (Kaldellis and Kapsali 2013; Poulsen and Lema 2017; Wüstemeyer et al. 2015;). But there are different views regarding the actual impact of the new technology generations on the existing wind energy industry. While some authors admit learning opportunities for wind industry actors (at least in some areas), others argue that differences are so great in terms of processes and actors that the industries may start following distinct trajectories (Wüstemeyer et al. 2015).

Extensive changes in the configuration of the industry will have implications for the regional industrial path built around wind energy technologies. It is therefore important to understand where changes are likely to occur, in order to be able to assess the impact of actors' decisions regarding this industry, be it a move from onshore to offshore for actors that were already part of the wind energy path, or on new entry for actors from outside the path.

For that purpose, we compared the phases of the industrial value chains and the respective components for the two main wind technology generations: onshore and offshore. Since our initial document analysis identified different approaches to the organization of the value chain—in particular in the case of offshore wind—we decided to primarily follow those proposed by two main documents, both from industry respected sources. For onshore wind, where there is less variety of approaches, we draw on the layout and description provided by the International Renewable Energy Association (IRENA 2017). For offshore wind, where diverse approaches to value chain organization can still be found, we draw mostly on the Guide provided by the Offshore Renewable Energy Catapult (BGV Associates 2023), which offers a well-documented and comprehensive explanation of the value chain and its components. We have also resorted to complementary documents to better elucidate specific points, especially in more contentious areas, and consulted with two technology/industry experts to help validate our final outline.

While following the above sources, we have made some decisions in terms of the industrial value chain structure. We organize it in terms of four main phases that follow the life cycle of a wind farm: Development and Project management; Manufacturing Core; Installation and Commissioning; Operation and Maintenance (O&M). A key decision at this level was the inclusion of offshore foundations as a sub-group in the manufacturing phase, while this activity is often included in the Installation phase. Our decision is based on the fact that, especially for floating offshore wind (which is the main object of our empirical case), this activity entails significant technological development and is conducted by actors that are distinct from the ones that conduct installation. On the other hand, we included in the Installation phase other activities presented under the "balance of plant" heading in the Catapult Guide that have a strong manufacturing component. This decision is based on the evidence that firms involved in installation are often the producers of the components used in these tasks. However, in the empirical analysis, we will refer to eventual differences between "service" and "manufacturing" sub-groups of Installation. Finally, we do not develop a last phase of Decommissioning, as it still has no relevance for offshore wind.

Figure 1 provides a stylised view of the offshore wind value chain, advancing some proposals on its similarities and differences to the onshore wind one, supported on the extensive literature on differences between onshore and offshore. For that, we highlight the elements where: (i) no changes (unless marginal) are expected—in

DEVELOPMENT & PROJECT MANAGEMENT (D&P)		MANUFACTURING CORE			INSTALLATION & COMMISSIONING	OPERATION & MAINTENANCE (O&M)
		TURBINE		Foundations		
Project planning	Project management	Core	Other componentes			
Feasibility studies; Site selection activities: resource & metocean assessment; seabed surveys; Environmental and social impact assessment; Engineering & design (farm system design & concept dev).	Management of various activities in wind farm development from consent through procurement, contracting and construction up to Commercial Operation Date.	Nacelle; Rotor & blades; Tower.	Transformers; Capacitors; Electric installation; Control equipment; Electric protection equipment; Metering equipment.	Fixed foundation (monopile, tripod); Floating substructure (steel or concrete).	Road transport of components; Maritime transport Port infrastructures: assembly & installation; Offshore logistics On-site assembly and installation of the turbine components (include construction port); Special vessels for installation (turbine & cables); Underwater infrastucture works & construction; Mooring system; Underwater cables installation: array cables (connecter turbines & offshore substation), export cables (connect to onshore substation); Offshore substation; Onshore substation; Installing electrical/ electronic instrumentation and control systems; Grid connection & comissioning.	Commercial and technical control of the facility & monitoring; Maintenance activities; Major repairs: Offshore vessels & Logistics, O&M Port.

Wind energy value chain - moving from onshore to offshore: Substantial Changes; Some changes; Minor or no changes.

Own elaboration from:
(1) IRENA (2017), Renewable energy benefits: Leveraging local capacity for onshore wind, International Renewable Energy Agency, Abu Dhabi.
(2) Ore Catapuly (2023) Guide to a Floating Offshore Wind Farm, Published on behalf of the Offshore Renewable Energy Catapult, The Crown Estate and Crown Estate Scotland, BVG Associates.

Fig. 1 Wind energy industrial value chain: moving from onshore to offshore

black; (ii) some changes are expected, but possibly not disruptive ones—in green; (iii) major changes are expected, creating potential sources of disruption—in red.

The Installation and Commissioning phase (Installation for short) is the one in which most changes are expected, especially due to the requirements raised by the sea context. At this level it should be noticed that some major changes already visible in bottom-fixed offshore systems (e.g. the role of ports) are likely to be intensified in floating systems. Important changes are also expected in the Operation and Maintenance phase (O&M for short), with particular incidence in the Maintenance activities, which can be partly conducted remotely, but will also rely strongly on operating at sea. In the Manufacturing phase, major changes are expected only in foundations, which are a new activity, as pointed out above. Some less disruptive changes are expected in core turbine manufacturing, as technological innovation takes place to answer to offshore requirements in terms of turbine size and stability. In Development and Project management (D&P in short) some changes are expected only in the Project planning sub-set: major changes in activities related with site assessment (sea-related); some changes (but less significant) in impact assessment and engineering & design.

5 The wind energy regional path in Portugal

The process of creation of an industrial path related to wind energy started in the early 2000s with the introduction of a set of policies to promote investment in new renewable energy technologies (Gomes et al. 2014; Guerreiro et al. 2021). These included both support mechanisms and economic incentives, in particular a feed-in tariff system that offered a good remuneration to wind energy production and reduced the risks of what was still a maturing technology. The process took off in the late 2000s (see Fig. 2) following the launch, in 2005, of public tenders that linked the attribution of capacity rights to local industrial development of core technologies,

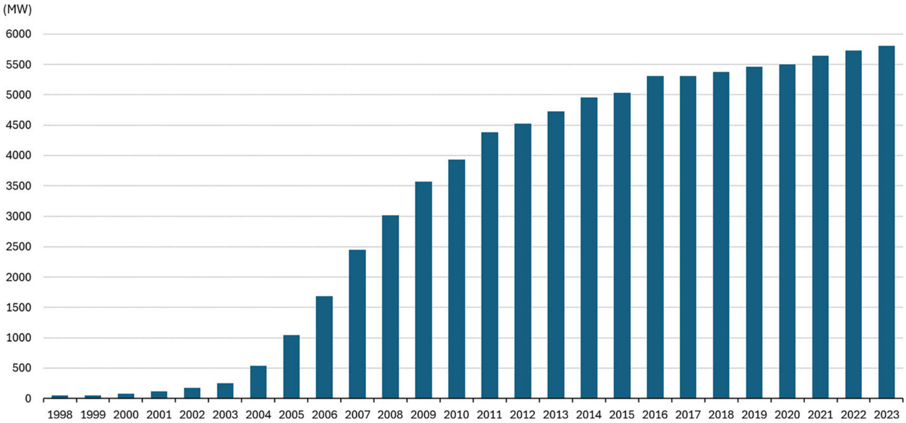

Fig. 2 Evolution of onshore wind installed capacity (1998–2023) (Source: Own elaboration based on e2p (2023))

as wind farm installation had so far been based on imported technologies (Godinho 2013). The tenders resulted in the formation of two international consortia of domestic and foreign companies, including foreign turbine manufacturers, and led to the creation of several new manufacturing facilities. One of these consortia in particular (ENEOP), involved or subcontracted to companies in a variety of sectors relevant for wind energy manufacturing, installation and O&M, leading to the creation of what has then been labelled a "wind cluster" (Bento and Fontes 2015; Guerreiro et al. 2021).

As a result of these efforts wind capacity quickly increased (Fig. 2). Starting from 58 MW in 1999 it reached 4364 MW (21% of total electricity production capacity) in 2011 (DGEG 2013).

The financial crisis and the country bail-out in 2010 interrupted this development process (Araujo and Coelho 2013; Vieira et al. 2024). Wind energy developers started experiencing great difficulties in obtaining credit and slowed down or stopped their projects. The policy focus on renewable energies also registered a sudden halt. In 2012, the government suspended the attribution of new licenses, with a view to reexamine the regulatory framework and later suppressed the feed-in tariff for new contracts (IEA 2016). Thus, wind farm installation practically stopped and most of the production was turned to exports.

From 2013 onwards new capacity installation resumed but remained very limited (e2p 2023), as can be seen in Fig. 2. Companies whose business was centred on component manufacturing or wind farm development had to re-orient a large part of their activities to foreign markets. This process was less complex for international companies, such as the large utilities and technology manufacturers, for whom exporting was always foreseen. Also, several local firms that had developed expertise and gained experience in Portugal were equally able to search for new markets for their products and services, sometimes following the wind developers with whom they had worked. However, firms that entered wind farm installation only as a complementary business redirected again to their core activities and many possibly abandoned the wind industry (Costa and Veiga 2021). But, on the other hand, the already installed wind energy capacity continued offering business opportunities for companies with competencies relevant for operation and maintenance activities. Thus, the wind industry that was created in the 2000s was partly able to withstand this period, albeit with several adjustments.

In the late 2010s, as economic conditions improved, renewable energies started recovering a strategic position in government policies, but new wind capacity installation remained limited. However, in 2020 a new energy program, the National Plan for Energy and Climate (PNEC 2030), set again ambitious targets for onshore wind: 9 GW by 2030, subsequently updated to 10.4 GW, which practically duplicates the current installed capacity (RCM 2020; DGEG 2024). As available space on land is limited and existing wind farms are reaching the end of life, the focus has mostly been on life extension or repowering (Alves 2019; Simões et al. 2019; Vieira et al. 2024).

In terms of territorial distribution, both the new industrial facilities and a substantial number of suppliers were located in a littoral axis from the North region, through Centre region, until the Lisbon Metropolitan Area region (Fig. 3a). This distribution is coincident with the highest density of industry in the country. The wind industry was also parallel to the wind farms (Fig. 3b), mainly located on a more inland axis that follows the natural relief associated with the highest incidence of the wind resource (e2p 2023). Thus, it was mostly in those regions that a new industrial path took form and developed, even if companies from other parts of the country as well as foreign, also contributed to its development.

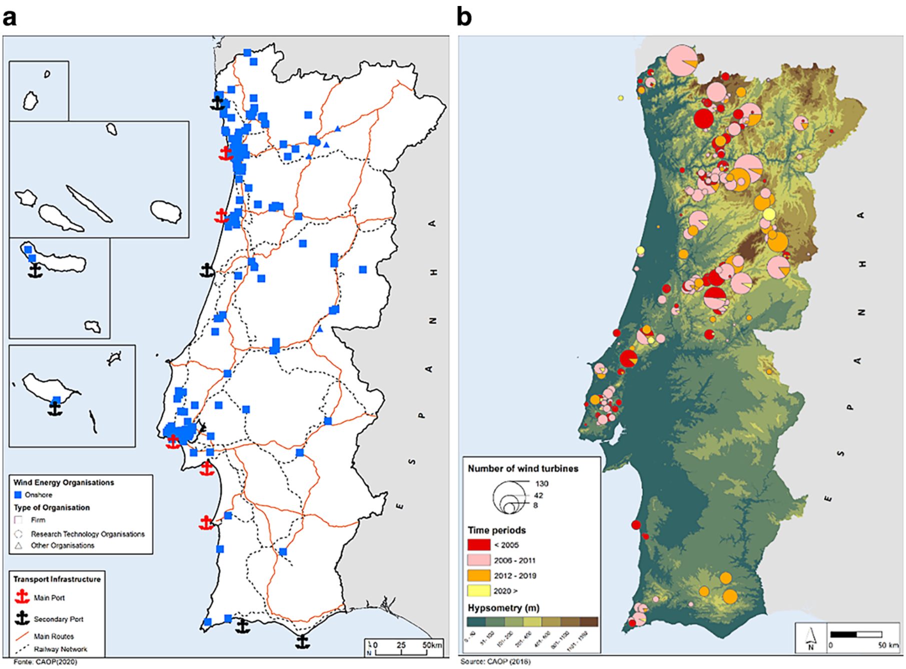

Fig. 3 **a** Organisations in onshore wind energy and **b** Number of wind turbines installed by period

Interest in offshore wind started in the late 2000s, when the large domestic energy utility that had played a key role in onshore wind development launched a pioneer project to develop an emerging technology—a floating system (Windfloat[3]). Although its development coincided with the financial crisis and government divestment in renewable energies, positive results combined with the nature of the developer permitted to pursue the activities and retain policy support. Upon economic recovery the technology also benefitted from a renewed policy interest in the Sea Economy, in which "ocean energies" were presented as one driver (Fontes et al. 2022). Two large floating offshore wind projects were conducted during the 2010s in the northwest coast of Portugal, the most recent leading to the installation of three floating turbines totalling 25 MW, which remain in operation supplying energy to the electrical grid (Vieira et al. 2019). Despite their pre-commercial nature, these projects required an extensive industrial activity concerned with production, installation, operation and maintenance, mobilising a broad range of suppliers. These included firms already active in onshore wind and firms not previously related to the wind industry, in particular firms from sea-related sectors (Bento et al. 2021). Concerning the latter, although the country had no competences in oil & gas activities, it was able to profit from the experience of firms that have been previously involved in wave energy technology experimental activities, in which the country was a pioneer (Fontes et al. 2024). While initially led by a domestic company, those projects had an increasingly international scope, both in terms of the developer partnerships and in terms of suppliers (Fontes et al. 2022). On the other hand, the development potential offered by a future installation of offshore farms attracted the attention of local authorities and planning agencies, which supported these projects and increasingly included this activity in their development plans, often in association with the rejuvenation of declining sea-related industries (Ministério do Mar 2017).

Until recently offshore wind capacity installation was expected to be residual (200 MW by 2030), but the updated PNEC 2030 energy program increased the target to 10 GW until 2030. A process leading to international auctions for a subset of this capacity (2 GW) started in 2022. A first call for interest in 2023 attracted a large set of international developer companies, some of them in partnership with local firms. The launch of these auctions was delayed due to a government change but is now being prepared for 2025.

6 Path disturbing effect of offshore wind technology

6.1 The wind energy regional path and the emergence of offshore wind

The wind energy regional path was formed around the industrial implementation and territorial embedding of onshore wind energy technology, as explained in the previous section. However, the growing engagement with the new technology generation—floating offshore wind—is demanding significant changes in some of the activities conducted for the development and deployment of wind energy technology.

[3] https://www.edp.com/en/innovation/windfloat.

Table 1 Number of organisations by type of involvement in wind energy in Portugal

Type of involvement in wind energy	Total	Firms	RTOs	Other
Organisations only in onshore wind (a)	166	147	10	9
Organisations in onshore & potential in offshore wind (a)	29	Na	Na	Na
Organisations in onshore & offshore wind (a) (b)	71	57	12	2
Organisations only in offshore wind—new entrants (b)	96	76	11	9
Total organisations in wind energy	**362**	**309**	**33**	**20**
Total in onshore wind (a)	*266*	*233*	*22*	*11*
Total in offshore wind (b)	*167*	*133*	*23*	*11*

Thus, we aim at uncovering the possible disturbance in the wind energy regional path that is resulting from these changing requirements. In this section, we investigate whether these changes are having effects in terms of actor composition and territorial distribution.

For that, we started by identifying the organisations that operate in onshore wind and the organisations that become involved in the new activities related with offshore wind (Table 1). The organisations identified included firms, universities and research and technology centres (labelled “research & technology organisations (RTOs)”), as well as government agencies and collective and civil society organisations (labelled “other organisations”). Figure 4a maps the organisations involved in onshore wind. The subsequent figures illustrate the actor involvement in offshore wind, which is also quantified in Table 1. Figure 4b highlights in purple the organisations active in onshore wind that also engaged in offshore wind (71). In addition, the questionnaire permitted to identify a group of firms active in onshore (29) that, although not having yet moved to offshore, expressed the intention to do it in the future, which are highlighted in lilac in Fig. 4c. Finally, Fig. 4d adds a new group of organisations only engaged in offshore wind (96), represented in red.

This data shows that, even at this relatively early stage of industrial deployment, offshore wind is mobilizing a significant number of organisations that were part of the path initially created around onshore wind, as well as significant number of organisations that had no previous involvement with wind energy and entered directly in the offshore area. The entry of new organisations, which tend to be in sectors less represented in the wind energy regional path, changes the actor composition of the path. The move to offshore of organisations already active onshore indicates the decision to engage in a new area that may require changes in their current activity. Thus, both new entry and onshore moves to offshore can be interpreted as introducing some disturbance in the path.

In what concerns the spatial distribution of these organisations, Fig. 4d shows that the new entrants are markedly aligned to the western coast, as they tend to be closer to the sea and to cluster around seaports. The distribution of the organisations that are moving (or willing to move) from onshore to offshore wind follows the same tendency (Fig. 4b, c). In addition, Fig. 4d shows that, while all regions identified in section 5 as involved in the path are experiencing an increase in the number of organisations engaged in wind energy, the expansion is more evident in the Centre

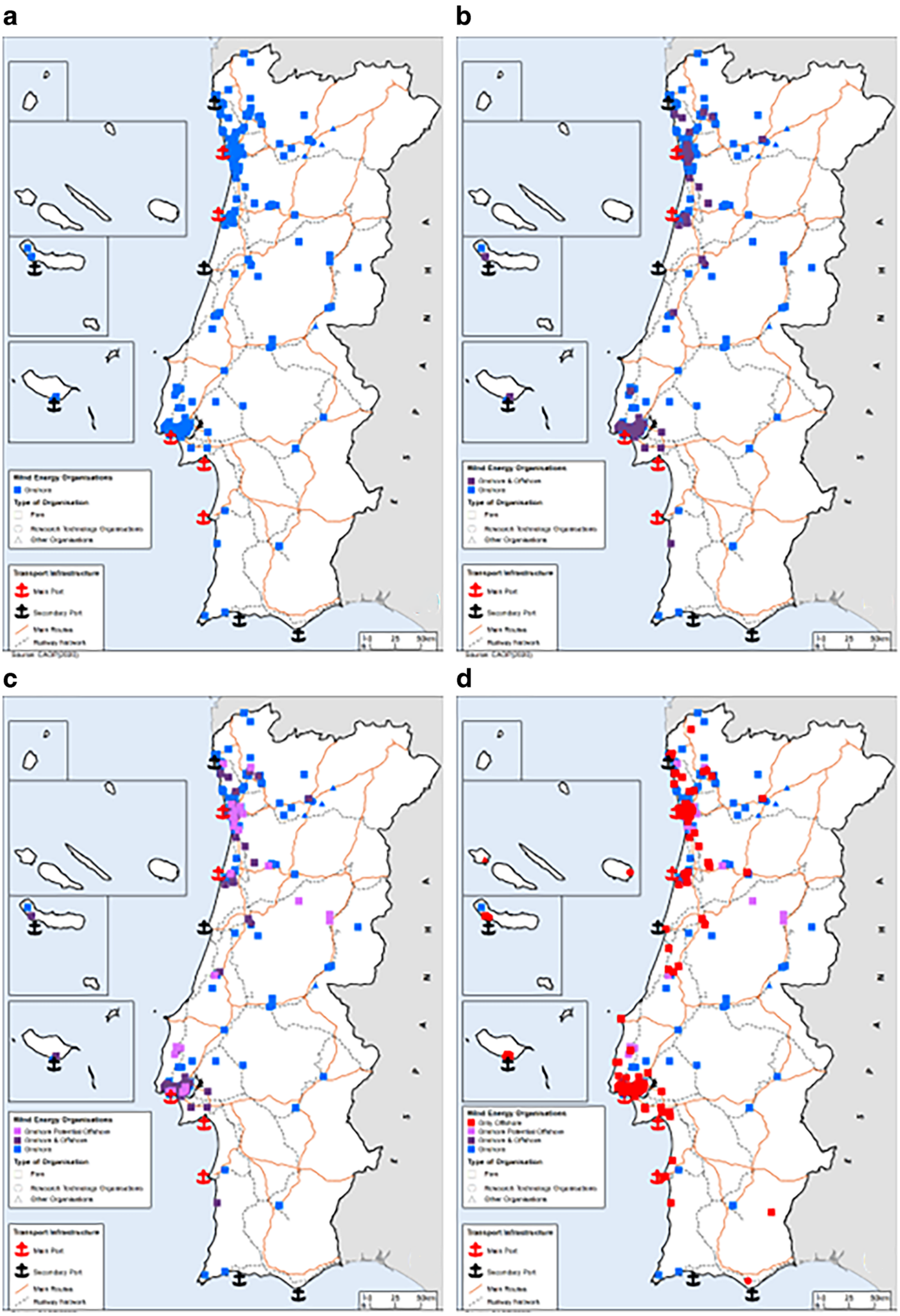

Fig. 4 Spatial distribution of organisations in wind energy: **a** organisations in onshore wind in blue, **b** organisations in onshore wind and also in offshore wind highlighted in purple, **c** organisations in onshore wind potentially in offshore wind highlighted in lilac, **d** organisations in offshore wind only (new entrants) added in red

region, where the density of path actors was lower. There is also some expansion to the south in the Lisbon Metropolitan Area region, around a main port (Setubal). Thus, changes are being already visible in the territorial organisation of the wind energy path, which has now a broader extension and density, as well as greater littoralisation, with some concentrations near the main ports. Noteworthy is the role of ports, which experience a growing pressure to offer space for industrial activities and to develop new infrastructure and functionalities (LNEG 2023), which are likely to stimulate the location of companies within or near them in the future. Thus, these territorial changes may introduce a further level of disturbance in the wind energy regional path.

6.2 Changes in the actor composition of the industrial value chain

In this section we focus on the firms active (or willing to be active) in offshore wind and investigate their position in the industrial value chain.

As discussed in section 4, the development and deployment of offshore wind technology requires new activities, driving changes in the industrial value chain, which tend to be more extensive in some of its phases. These changes can affect the structure of the industry and thus have impacts on the configuration of the regional industrial path. Such impacts are likely to be stronger in the parts of the value chain whose activities are more affected by the new technology. Thus, an understanding of the relative position of firms moving from onshore and new entrants in the various phases of the industrial value chain can provide some first indication of where disturbance in the regional wind energy path is more likely to be taking place.

The distribution of both movers from onshore and new entrants across the various phases of the industrial value chain (Fig. 5) shows, first of all, a concentration in two phases: Installation and Operation and Maintenance (O&M).

The weight of the activity in these two phases mirrors what already existed in onshore wind. In fact, core manufacturing has fewer companies and is centred around the local filials of three foreign multinationals—one in turbine assembly

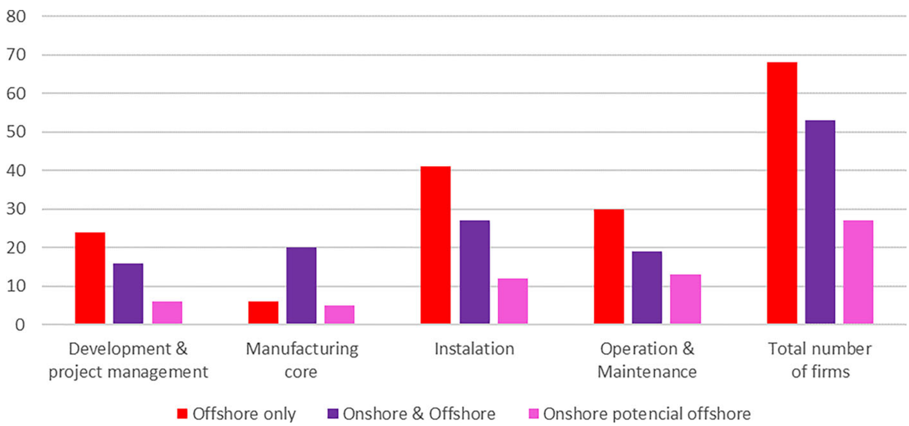

Fig. 5 Number of firms in each category, along the offshore wind value chain

(which does not plan to move offshore); one in blade production (which may move); one in towers and foundations which has been recently acquired from a domestic producer (and also supplies offshore)—and domestic companies are mainly suppliers of turbine components or other components. The weight of Installation and O&M is not unexpected as the activities included in these "downstream" segments of the value chain tend to be more spatially sticky, involving strong client/producer interactions and market specific knowledge (Rohe 2020). Therefore, they provide opportunities for regions that have no or limited involvement in the innovation processes around the manufacture of core technologies (Jolly et al. 2023).

Regarding the position of the three categories of firms under analysis, it was found that new entrants are more frequently in the phases of the industrial value chain identified as potentially more affected by the specific requirements of the new technology: installation (particularly installation services), operation and maintenance and, to a less extent, development and project management. Their entry is an indication of the need for resources that are not part of the industry-specific resource stock. In fact, it can be assumed that these new firms will bring a new set of resources and contribute to new resource formation to answer the new requirements. A strong weight of entry from other industries and a significant process of creation of new resources may induce disturbance in the path trajectory. As was pointed out above, new entrants are more likely to be located close to the coast thus steering the path towards it. Therefore, it can be argued that it is the activity in these phases of the industrial value chain that is more likely to drive the territorial changes in the regional path.

The results show, so far, a strong incidence of new actors with new resources, but an analysis of these resources and their "novelty" in the wind energy path is beyond the scope of this research. We simply assume that the greater the incidence of new actors in a particular phase of the industrial value chain, the greater the potential for disturbance at that level.

Firms already active in onshore wind are found across all phases of the offshore wind value chain, even if they are more prevalent in the phases that are likely to experience less changes—manufacturing of turbines (core or components) or the manufacturing of components for installation. In what concerns these firms, it is to be expected that the stock of industry-specific resources previously built is used, whenever the activities being developed enable it. Thus, in some cases firms may simply redeploy their resources to similar activities, but in other cases the new technology requirements may force them to engage in processes of resource modification, including the creation of significantly new resources.

Thus, the extent to which the behaviour of firms moving from onshore to offshore contributes to introduce disturbance in the path depends on the extent to which their actions, collectively, enact a substantial re-orientation of the resource formation process. In order to assess this, we investigate how onshore firms moving (or willing to move) offshore describe the implications of this move in terms of resource formation.

6.3 Resource modification by onshore wind firms moving offshore

In this section we address in greater detail the implications of a move from onshore to offshore, focusing on firms' resources. The objective of this analysis is to understand, for the actors that were already in the wind path and across the different phases of the industrial value chain: (i) the extent to which changes are required in these actors' resources; (ii) which types of resources are more affected; (iii) the actors' s views on the obstacles to achieve it. By conducting the analysis for each phase of the industrial value chain we can also uncover potential differences between these phases.

The analysis is expected to give some indications on an eventual re-orientation of the resource formation process in the wind energy regional path, resulting from path actors' responses to the emergence of the new technology generation and its specific requirements. While the analysis only focuses on changes resulting from the actions of the actors already active in wind energy—not including the resource changes associated with actors entering *the novo* in the wind business—it is expected to offer some indications of areas where disturbance is more likely to be taking place. That is, to show the type of resources more frequently modified through path actors' agency and the phases of the industrial value chain where these actions more frequently occur.

For this analysis we draw on the responses to the questionnaire survey to firms, focusing on two sets of questions: (i) the changes that were required or expected in firms' activities or modes of organisation in order to operate in offshore wind; (ii) the obstacles they faced or expected to face along that process.

The questions included in the questionnaire were specific, being designed to be meaningful to the actors targeted. The answers were then organized according to the four major system resources proposed by Binz et al. (2016) and Binz and Truffer (2017): knowledge, market, finance and legitimacy, as shown in Table 2. For this, each set of questions was first grouped into more disaggregated categories (also shown in Table 2), which were the object of detailed analysis to gain a more complete understanding of the firms' resource modification focus. They were subsequently combined and subsumed into the four major resource types.

The analysis centres on the two groups of onshore wind firms (Table 3): firms that are already developing activities in offshore wind (43 firms[4]) provide evidence on the actual experience of operating in the new area; firms that answered they were considering entering offshore wind (26 firms[5]) offer insights into how potential entrants perceive the implications of this move.

Table 3 shows that the majority (over 2/3) of the respondents already active in offshore wind mentioned to have engaged in resource modification. The incidence is slightly lower for those in the manufacturing phase of the industrial value chain and slightly higher for those in the Development and Project management (D&P) phase

[4] Respondents correspond to 75% of the firms identified in the "onshore firms that moved offshore" category. Three other respondents did not provide valid answers to the relevant questions.

[5] Onshore firms that answered to the questionnaire, mentioning that intention. Four other respondents did not provide valid answers to the relevant questions.

Table 2 Resource modification categories

Resources	Changes required to operate in new area Which resources are mentioned as requiring modification	Obstacles faced to operate in new area Which resource modification are perceived as more difficult
Knowledge	**Competences**	**New (internal) competences**
	Internal acquisition new competences	*Development of new capabilities*
	Recruitment human resources (HR)	*Recruitment HR*
		(Lack of) Experience with sea
	Organisation (internal)	
	Investment in new equipment	
	Changes in processes	
	Relations	**Relations**
	New partnerships	*Establish partnerships*
Market access	**Positioning**	**Market**
	Reorganize product portfolio	*Lack of opportunities to learn about products/markets*
	New business model	*Lack stable demand*
		Foreign competition
Finance		**Financial**
		Access to funding
		Investment capacity
Legitimacy		**Policies**
		Absence of policies
		Lack of continuity of policies

Table 3 Number of firms and incidence of resource modification by phase of the industrial value chain

	Active in offshore		Potential entrants	
	Total	Resource modification	Total	Resource modification
*All firms**	43	30	26	21
Develop. & Project Management (D&P)	12	9	3	3
Manufacturing	13	8	6	5
Installation	22	15	14	10
Operations & Maintenance (O&M)	16	11	18	15

*Some firms are active in more than one phase, especially in the case of Installation and O&M

and is similar for firms in Installation and in Operations and Maintenance (O&M) phases. Firms expecting to enter offshore tend to perceive an even higher need to modify resources than the ones already active.

We will now look in greater detail into the resources most affected, in each phase of the industrial value chain.

The responses concerning the changes that had to be introduced to operate in offshore wind provide essentially information about resource modification at the level of two types of resources: knowledge—including new competences, changes in organization and new relationships—and market positioning.

In the case of firms already active in offshore wind, Fig. 6a shows that while changes in competences were mentioned by a high proportion of firms in all phases of the industrial value chain, there are differences in the incidence of changes in other resources. Changes in relationships were relatively important in all phases but were particularly relevant for firms in O&M. Changes in organization were much more frequently mentioned by firms in Installation and O&M and were almost irrelevant for firms in Manufacturing. Changes in positioning were the least frequently mentioned, but when they did it was especially by firms in Installation and O&M. It is equally relevant to mention that potentially deeper changes were less frequently mentioned in all phases: e.g. in organization, new equipment and other material resources were more frequent than changes in processes; in positioning, changes in product portfolio prevailed over changes in the business model.

Overall, firms in Installation and O&M are the ones that mention changes most frequently and encompassing the whole range of resources. The contrary can be seen in the case of Manufacturing—here changes are less frequent and mostly focused on competences and relationships. Firms in D&P followed a similar pattern to those in Manufacturing in terms of types of resources, but with a higher incidence of changes. Installation firms exclusively focused on services experienced a greater need to introduce changes, especially in resources and organization.

The pattern is somewhat different in the case of firms that are considering entering offshore wind (Fig. 6b). Perceptions of the type of resources that would require changes are similar across all phases of the industrial value chain, the exceptions being a very low relevance of changes in competences for firms in manufacturing (somewhat contradicting the answers of the active ones) and in organization for firms in D&P. Overall, for these firms, relations emerge as the resource most frequently perceived as requiring changes, above competences, even if the latter remain

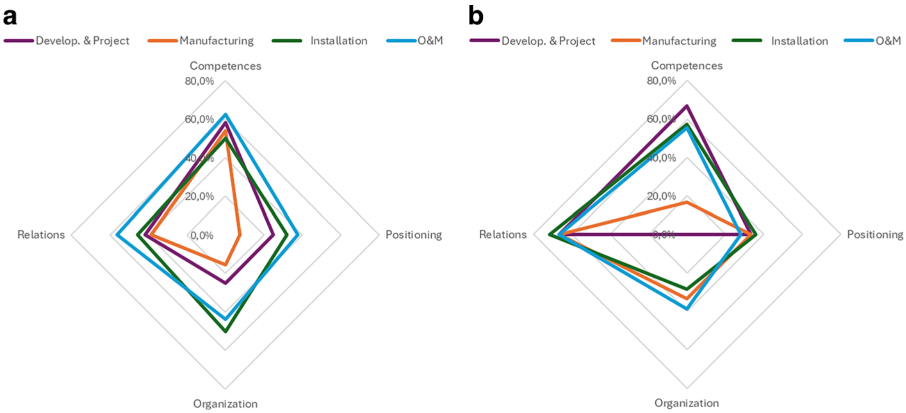

Fig. 6 **a** Changes introduced by onshore firms that operate offshore, by phase of the industrial value chain, **b** Changes expected by onshore firms willing to enter offshore, by phase of the industrial value chain

important. On the other hand, there is a lower perception of a need for changes in organization.

The answers to the question about obstacles (Fig. 7a) permit us to assess which resource modification processes are perceived as involving greater difficulties. They provide additional insights into the changes required in the two types of resources already discussed above, knowledge and market. But they also offer new information about the other two types of resources: finance and legitimacy, the latter indirectly through firms' perceptions of policy attention to the field.

Regarding the types of resources discussed above—Knowledge and Market—the data suggests that most firms, from all phases of the industrial value chain, perceived the resource modification process to entail some difficulties, with firms in Manufacturing being the ones mentioning obstacles more frequently. However, if we disaggregate these two categories into their constituent elements we find a more complex situation. In the case of Knowledge resources, changes in Relations that are important in all phases, are generally perceived as not difficult to achieve (the exception being firms in Manufacturing). But the equally important internal development/acquisition of new competences is frequently perceived as facing obstacles (although less so for firms in O&M and Manufacturing). The data also reveals the relevance that is attributed, by firms in O&M and Installation, to a missing critical but difficult to obtain competence—experience in operating at sea.

In the case of Market resources, the data offer some insights into the difficulties faced to achieve change in market positioning, which was the least frequently mentioned change, in all phases. In fact, obstacles such as limited opportunities to learn about products and markets (mentioned by the large majority of firms in all phases except D&P, and particularly important for Manufacturing) and lack of perspectives of a stable demand (also important for a significant proportion of firms), are likely to hamper resource modification decisions, such as the reorganization of the product portfolio or changes in the business model. These obstacles—and therefore firms' cautious behaviour at this level—are typical of the stage of development of the tech-

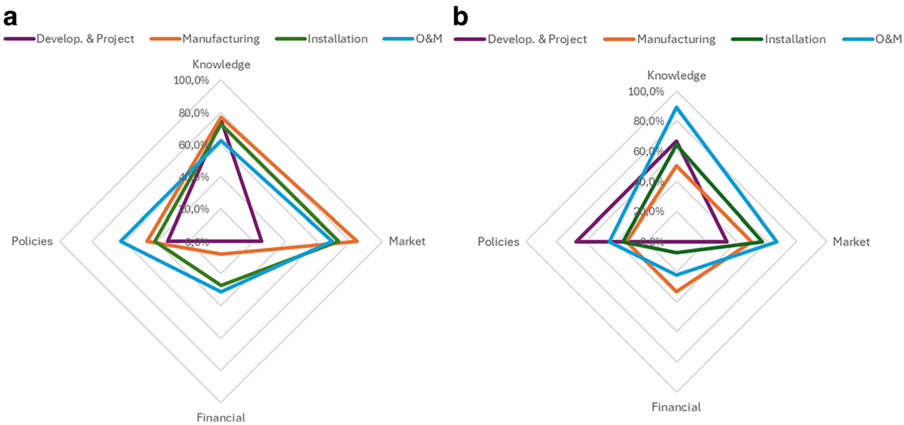

Fig. 7 **a** Obstacles faced by onshore firms that operate offshore, by phase of the industrial value chain, **b** Obstacles expected by onshore firms willing to enter offshore, by phase of the industrial value chain

nology. Finally, the data on obstacles call the attention to the preoccupation of firms in Installation and O&M about the potential competition of foreign firms that have already developed the new competences in their area of activity.

The data also offers some new indications regarding the two other types of resources. Figure 7a shows that Financial resources—i.e. the need to access funding for the new activities and to develop additional investment capacity—are the least frequently mentioned obstacles, only being perceived as relevant for a small subset of firms in Installation and O&M. This suggests that firms possibly have not, so far, engaged in significant investments, which can also be explained by the stage of development of the technology. Conversely, Legitimacy resources, or more precisely their lack—i.e. a perception of limited alignment of policy with the requirements of the new area—emerges as a greater obstacle for firms in most phases and especially for these in the Installation phase. However, the data available does not allow us to go deeper into eventual firms' actions to act upon this resource.

In the case of firms that consider entering offshore wind (Fig. 7b), the overall pattern has some differences. In general, firms in all phases expect relatively less obstacles across the four types of resources. Particularly interesting is the lower weight of obstacles related to Market resources, as they may reflect the "outsider" lack of market exposure. Main exceptions are firms in Installation that expect relatively more obstacles in terms of Knowledge resources, those in D&P that expect more obstacles related to policy and those in Manufacturing than now expect Financial obstacles.

Taken together, firms' answers to the question on changes required to operate in the new field provide information on the extent to which resource modification was taking place, as well as on the type of resources more frequently object of such modification and in which phases of the industrial value chain they occurred. This offers indications of areas where more systemic disturbance in the path activity is likely to be taking place.

Also taken together, the firms' answers to the question on the obstacles faced provide information on which resource modification processes are perceived as involving greater difficulties, while also providing additional information on the actual resources requiring action. This offers additional insights into areas of disturbance and complements it with indications on difficulties being experienced.

Table 4 synthesizes key elements of path disturbance, induced by the behaviour of this particular group of actors, along the various phases of the industrial value chain.

7 Conclusions

The paper investigated the disturbance that new generations of a technology can introduce in the early trajectory of a regional industrial path built around that technology.

The research permitted to identify some factors of disturbance of the wind energy regional path, at the level of actors and resources.

Table 4 Matrix of disturbance considering actors (firms) and resources across the different phases of the industrial value chain

	Development & Project Management	Manufacturing core (Turbine; Foundations)	Installation (Services; Manufacture components)	Operation & Maintenance
New entrants	Stronger weight than movers	None in turbine; few in foundations	Strongest weight; mainly in services	Similar weight to movers; evenly distributed by operation and maintenance
Onshore movers	Lower weight than new entrants; very diversified set (include developers, EPCs & service providers)	Stronger weight than new entrants; manly turbine (components)	Stronger weight than new entrants in manufacturing components	Similar weight to new entrants; evenly distributed by O and M; several firms in both
			Some firms also O&M	Some firms also Installation
Resource modification by movers	Highest overall, but more focused in some resources	Lower than in other phases; in limited range of resources	High and in the whole range of resources (similar weight to O&M)	High and in the whole range of resources (similar weight to O&M)
Knowledge	Important for all; facing obstacles for all. Differences across component elements—most frequent: competences & relationships; less frequent positioning. Obstacles high for competences and low for relationships			
	Resource modification mostly focused on competences	Resource modification lower than in other phases (except competences)	Resource modification higher than in other phases	Modification of organization resources only frequent here (even more than in installation)
			Modification of organization resources only frequent here	Competences less an obstacle except sea experience (high)
			Critical obstacle: sea experience	
Market	Resource modification less frequent; High perception of obstacles in most phases			
	Some resource modification	No resource modification	Some resource modification	Some resource modification
	Reduced perception of obstacles	Highest perception of obstacles: especially opportunities to learn about products/markets	Obstacle: lack opportunities to learn about products/markets & lack stable demand	Obstacle: lack opportunities learn about products/markets & (less) lack stable demand
			Fear foreign competition	Fear foreign competition
Finance	Not perceived as obstacle—limited need for resource modification due to stage of development			
			Obstacle only for a few: need for additional investment capacity	Obstacle only for a few: access to funding & need for additional investment capacity
Legitimacy	Perceived as an important obstacle—need of resource modification (alignment of policies)			
		High obstacle	Highest obstacle	

In terms of actors, factors of disturbance include both the engagement, with the new floating offshore wind technology, of actors that were part of the path initially formed around onshore wind technology, and the entry of new actors that were not previously part of the path.

The entry of new actors is changing the actor composition of the path and, in the case of industrial actors, can also affect its sectoral structure as a several of them come from sea-related sectors not (or rarely) present in the path. It also has implications for the path spatial pattern, by increasing its littoralisation, as new actors tend to be closer to the coast; and by reinforcing the involvement of regions in which the path had less hold.

In terms of resources, the entry of new actors is leading to changes in the industry-specific stock of resources as, in principle, they bring new resources that are not part of that stock. The involvement of several onshore actors in offshore wind activities also has effects at this level. At least in what concerns the industrial actors, the decision to move to offshore was found to frequently require resource modification to answer to the new technology requirements. Moreover, some types of resources were more frequently identified as requiring changes, pointing to resource modification processes that may generate greater disturbance. Taken together the behaviour of new entrants and of onshore movers is introducing disturbance in terms of resources, as they are contributing to modify and expand the path's industry-specific resource stock.

Finally, the differences identified across the industrial value chain—in terms of actor composition and resource modification—confirm that the requirements of the new technology generation affect more strongly some parts of that value chain, which are thus likely to play a greater role in the process of path disturbance.

It is therefore possible to conclude that the behaviour of both onshore actors moving to offshore and new actors entering directly in offshore is introducing disturbance in the wind energy regional path, in terms of actor composition, industrial structure and spatial distribution, as well in terms of the path cumulative resource formation process (Gong and Binz 2023).

However, the industrial development associated with the emergence and diffusion of the floating offshore wind technology is still in a relatively initial phase (Castro-Santos et al. 2020). So, while there is evidence of disturbance taking place at the level of actors and resources, it is not yet possible to assess the extent of their effects in the path, namely whether they will lead to a divergence in its trajectory.

For the same reason, impacts on the development of the regions involved can only be anticipated. Nevertheless, the types of changes already taking place in the path suggest possible implications for the regions, especially once the implementation of offshore wind accelerates through the programmed launch of auctions for installing 2 GW of offshore wind, along the coastal area of the regional path (DGEG 2024).

The fact that the new activity around offshore wind requires resources possessed by regional actors with no previous involvement in the wind energy path is important for regional development, as it provides an opportunity for these actors to expand and/or diversify their activities. It also creates conditions for new connections between activities/sectors previously unrelated (Janssen and Frenken 2019), eventually also leading to interactions with other industrial paths in the region, involving both collaboration and conflict (Frangenheim et al. 2020). On the other hand, the fact that a set of actors already part of the wind energy path engage in the new area is also important for regional development, as it can contribute to stimulate the economic activity enacted by these actors. In terms of resources, changes in the industry-specific resource stock can also contribute to modify/reinforce the stock of regional resources (Gong and Binz 2023). These processes can namely bring about particular resource configurations that emerge from the region-specific actor arrangements. As a result of the expanded activity, the path may become increasingly embedded in the region.

Overall, the involvement of regional actors—both new to the path and already part of it—with the new generation of technology can lead to a densification and diversification of the regional structure, creating new opportunities for development along it. It may also contribute to increase the extra-regional interactions, given the international nature of the offshore wind energy activity (MacKinnon et al. 2019b). However, the fact that even actors already in the path perceive resource modification as frequently fraught with difficulties indicates that these diversification processes are far from being linear (Wiersema and Beck 2017). This will be particularly evident while the new technology is not fully stabilised and may require supportive policies to guarantee that the regions effectively capture the benefits from these processes (Bento and Fontes 2019; Dawley et al. 2015).

In what concerns the understanding of early path evolution (Fredin et al. 2019; Gong and Binz 2023), our approach has proven to be effective at uncovering factors of disturbance and some of their effects at path level. This suggests that it can be a useful instrument to support an assessment, over time, of how a technology-driven regional industrial path is evolving as a result of substantial changes introduced by the emergence of new generations of the technology. It may enable an early understanding of the directions such evolution is taking—e.g. in terms of actors, resources, spatial scope—which can inform actors' decisions. In more advanced stages, it may support a more precise detection of the extent of divergence in the path trajectory, offering an empirical approach complementary to more theoretical approaches to path evolution (Brenner and Jeddeloh 2024).

This research has a number of limitations, namely in what concerns a more detailed examination of the extent of disturbance caused by new entrants. In particular, it did not explore the nature of the resources they bring-in and their implications for the process of new resource formation. In addition, the insights obtained on the process of resource modification conducted by path actors when moving to the new area need to be consolidated through more detailed qualitative research. On the other hand, the research did not consider the potential interactions between path actors and new entrants and the effects of these interactions, namely the implications in terms of the combination of new and industry-specific resources, and in terms of the reconfiguration of intra and inter-path networks. These are likely to be important additional factors of disturbance that will need to be object of subsequent research.

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