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Artigo

ON THE CREST OF A WAVE:
THE VARIETY OF PLACE CONFIGURATIONS AROUND AN EMERGING ENERGY TECHNOLOGY IN EUROPE (1992-2019)

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ABSTRACT – The study investigates the variety in place configurations around a sustainable technology, in its early phase of development. Adopting a systemic and multi-scalar approach to technology development, this article proposes that the spatially distributed nature of technology emergence leads to the formation of different place configurations of actors and networks around the technology, which can contribute in different ways to its development. Using the case of wave energy technology and a methodology that permits to encompass and compare emergent processes unfolding across Europe, the research uncovers five place profiles, which denote different positions in the emerging system and thus need to be jointly considered to fully understand the process of new system development. The article adds to knowledge on the multi-place and multi-scale systemic processes that are at work in the early phases of technology development, contributing to a better understanding of global system construction around a new sustainable technology.

Keywords: Place configurations; sustainable technology early phase; multi-scalar interactions; global system construction; wave energy technology.

RESUMO – NA CRISTA DA ONDA: A VARIEDADE DE CONFIGURAÇÕES DE LUGARES FORMADOS EM TORNO DE UMA TECNOLOGIA ENERGÉTICA EMERGENTE NA EUROPA (1992-2019). Este estudo investiga a variedade na configuração dos lugares em torno de uma tecnologia sustentável, na sua fase inicial de desenvolvimento. Adotando uma abordagem sistémica e multiescalar ao desenvolvimento da tecnologia, este artigo propõe que a natureza espacialmente distribuída do processo de emergência de uma tecnologia conduz à formação de diferentes configurações locais de atores e redes, que podem contribuir de diferentes formas para o desenvolvimento dessa tecnologia. Com base no estudo de caso da tecnologia de energia das ondas e utilizando uma metodologia que permite integrar e comparar os processos emergentes que vão tendo lugar na Europa, a investigação revela cinco perfis de lugares, que ocupam diferentes posições no sistema emergente e, portanto, devem ser considerados no seu todo para compreender plenamente o processo de desenvolvimento do novo sistema. O artigo contribui para o conhecimento sobre os processos sistémicos multilocais e multiescalares que têm lugar nas fases iniciais do desenvolvimento tecnológico, contribuindo para uma melhor compreensão do processo de construção de um sistema global em torno de uma nova tecnologia sustentável.

Palavras-chave: Configurações de lugares; fase inicial das tecnologias sustentáveis; interações multi-escalares; construção de um sistema global; tecnologia de energia das ondas.

RESUMEN – EN LA CRESTA DE LA OLA: LA VARIEDAD DE CONFIGURACIONES DE LUGARES FORMADOS ALREDEDOR DE UNA TECNOLOGÍA ENERGÉTICA EMERGENTE EN EUROPA (1992-2019). Este estudio investiga la variedad en la configuración de lugares en torno a una tecnología sostenible, en su fase inicial de desarrollo. Adoptando un enfoque sistémico y multiescalar para el desarrollo tecnológico, este artículo propone que la naturaleza espacialmente distribuida del proceso de surgimiento de una tecnología conduce a la formación de diferentes configuraciones locales de actores y redes alrededor de la tecnología, que pueden contribuir de diferentes maneras a su desarrollo. Utilizando el caso de la tecnología de la energía de las olas y una metodología que permite abarcar y comparar los procesos emergentes que se desarrollan en toda Europa, la investigación descubre cinco perfiles de lugares, que denotan diferentes posiciones en el sistema emergente y, por lo tanto, deben considerarse en conjunto para comprender completamente el proceso de desarrollo de nuevos sistemas. El artículo amplía el conocimiento sobre los procesos sistémicos multilugar y multiescala que están en funcionamiento en las primeras fases del desarrollo

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tecnológico, contribuyendo a una mejor comprensión de la construcción de sistemas globales en torno a una nueva tecnología sostenible.

Palabras clave: Configuraciones de lugares; fase inicial de tecnología sostenible; interacciones multiescalares; construcción del sistema global; tecnología de energía de las olas.

I. INTRODUCTION

Climate change and unpredicted crises, due to pandemics and war, make it particularly urgent to accelerate the process of sustainability transition. Such acceleration requires the contribution of sustainable energy technologies that have not yet reached the commercial stage but can have an important role in the decarbonisation of the energy system (International European Agency [IEA], 2023). This is namely the case of wave energy technology, which exploits a still untapped but extensive resource and can contribute to the development of coastal communities, often reliant on traditional or declining industries (European Commission [EC], 2020; European Technology & Innovation Platform for Ocean Energy [ETIP Ocean], 2020). However, research on the factors that shape the early process of technology development is still limited (Andersson *et al.*, 2018). It is thus important to gain a better understanding of these early stages, with a view to speeding up technology development, with economic and social benefits.

The development of a new sustainable technology requires the construction of a new system (Bergek *et al.*, 2008). Therefore, in the early phases it not only the technology that is emerging, but also the actors, networks and institutions that support it (Markard, 2020). It is also at this stage that the fledgling system is more dependent on the context structures within which it emerges and that can provide resources for its development (Bergek *et al.*, 2015; Markard, 2020).

The new technology can emerge, simultaneously, in various geographical locations. As a result, processes of early system building around the technology are likely to be conducted in different places (Binz & Truffer, 2017; Sengers & Raven, 2015) some of which may connect (Fontes *et al.*, 2016; Heiberg & Truffer, 2022).

Places differ in the conditions they offer for these processes to unfold, due to their specific structures (actors, networks, institutions) (Binz *et al.*, 2020; Hansen & Coenen, 2015). Place specific conditions will namely influence the nature of the interactions between the still weak system and critical context structures. However, research on these interactions, while acknowledging the differentiating effects of geography (Bergek *et al.*, 2015), has tended to focus on specific countries or on comparison between a few countries (Hojckova *et al.*, 2020; Makitie *et al.*, 2018; Ulmanen & Bergek, 2021).

As a result, extant research does not capture the variety generated by processes that are occurring, simultaneously, in and across different places, as part of technology emergence. That is, it does not capture the variety in the formation of the configurations of actors, networks and institutions that support technology development in different places and at different scales. This is an important gap. On one hand, because the consideration of such variety is necessary for better understanding the process of technology development, as local factors are important in the emergence of a global innovation system (Heiberg & Truffer, 2022). On the other hand, because such variety has implications for the places where these processes occur, as some place configurations may be better equipped to benefit from the technology (Andersson *et al.*, 2018).

The objective of this article is to address this gap. It adopts a comprehensive approach to investigate variety in place configuration in the early phase of development of a technology. More precisely, it investigates whether the processes occurring in different places lead to a variety of configurations of actors and networks formed around the technology; and whether different place configurations correspond to diverse positions in the system under development.

For this we combine contributions from the technological innovation systems theoretical approach and from the geography of sustainable transitions, in particular the global innovation systems approach. At the empirical level, we conduct a pan-European analysis of the spatial trajectory of wave energy technology, supported on three decades of data from European funded Research and Technological Development (RTD) projects, which have been critical in the development of this technology (Magagna *et al.*, 2018).

Wave energy technology provides a good empirical setting for this analysis as it still is at pre-commercial stage, having experienced a slow and non-linear progress (ETIP Ocean, 2020; Guo & Rowling, 2021). A great variety of competing conversion systems have been developed over time, but a dominant design has not yet emerged. Nevertheless, an intense activity has taken place over time across a diversity of places (Fontes *et al.*, 2016) creating several nuclei of development around the technology. Wave energy is a complex technology, requiring contributions from different technological fields (ETIP Ocean, 2020). Experimental activities at increasingly larger scales are necessary to test and improve performance and survivability. They require the manufacturing and assembling of the various components of a complex system, as well as its installation, operation, and maintenance at sea (Bjørgum & Netland, 2017). As a result, technology development needs the involvement of a diversity of actors from research, industry, civil society, and government (Fontes *et al*., 2022).

The article is organised as follows. Section 2 reviews the relevant literature and outlines elements for an analytical framework. Section 3 presents the methodology for the empirical analysis. Section 4 explores place configuration in the case of wave energy technology and presents the results. Section 5 concludes and derives implications and directions for future research.

II. THEORETICAL BACKGROUND

1. The early phase of technology development

The early phase of technology development is described by technology lifecycle theories as a period when several variations of the original breakthrough appear and compete (Anderson & Tushman, 1990). It is usually a lengthy period, characterised by high variety and great uncertainty, along which the conditions for the technology to develop and become established in the market are created (Bento & Wilson, 2016).

A recent approach to the technology lifecycle (Markard, 2020), grounded on the Technological Innovation Systems (TIS) approach to technology development (Bergek *et al*., 2008; Jacobsson & Bergek, 2004), has moved the focus from the technology to the co-evolution between the technology and the system – actors, networks, and institutions – that needs to be built to supports its development. Therefore, in the early phase of development, it is not only the technology that is emerging but also the organisations, networks and institutions that support it. The interaction between the new system and the context structures – technological, sectorial, geographical, political – within which it emerges (Bergek *et al*., 2015) is a key element of these processes (Markard, 2020).

The early, "formative phase" is described by this literature as a period of intense variety creation and experimentation (Markard, 2020). Diverse technology designs emerge and compete. The new system is still being formed, its constitutive elements being put in place (Bergek *et al*., 2008). System development will involve an increase in the entry (but also exit) of actors, an expansion of networks and early processes of institutional structuration (Bergek *et al*., 2008; Markard, 2020).

It is in this early phase that the emerging system is more dependent on the context structures, which can provide important resources – such as knowledge, finance, material and human resources, institutional resources – but also constrain its development (Markard, 2020; Ulmanen & Bergek, 2021). Thus, it needs to create ties with context elements in order to access resources and build legitimacy (Markard & Hoffman, 2016).

2. Role of interaction with context structures

Recent literature focusing on the interactions between a TIS and its context structures (Bergek *et al*., 2015; Ulmanen & Bergek, 2021) can offer some relevant insights on their nature and effects. Context structures are defined as "all other structures and relevant factors outside of the TIS" (Bergek *et al*., 2015, p.52) and the literature distinguishes between two types of interactions: "external links" and "structural couplings". Structural couplings, defined as shared elements (actors, networks, institutions, technologies) between a TIS and specific context structures (Bergek *et al*., 2015), emerge as particularly relevant. Empirical research has shown that structural couplings can lead to the development of interdependences (Ulmanen & Bergek, 2021) and thus have an important influence in the further development of the technology and the system.

Recent empirical research has given some attention to the previously less explored interactions between the new system and existing sectors that can contribute to the new technology value chain, examining the associated benefits and risks (Andersen *et al*., 2020; Bento *et al*., 2021; Makitie *et al*., 2018). But this research has tended to address technologies close to or having already reached the commercial stage. In earlier phases, such interactions may be less frequent and often assume the form of knowledge relationships that enable the generation of new combinations between diverse knowledge bases (Arts & Veugelers, 2015; Stephan *et al.,* 2019). However, for some complex technologies early experimentation will already entail the use of production and business capabilities present in existing industries (Bjørgum & Netland, 2017), and the establishment of connections with firms that act as suppliers or co-developers at that level (Fontes *et al*., 2021).

Close interactions between actors from the emerging system and actors from context structures can be regarded as building blocks in the formation of configurations of actors and networks that support the construction of the new system. Thus, the capacity to attract actors from context structures to engage with the system is critical in the early phase (Bento *et al*., 2021). But it can also be complex due to the uncertainty still surrounding the technologies (Ansari & Kropp, 2012) and the potential competition with the core activities of these actors (Fontes *et al*., 2016; Ulmanen & Bergek, 2021).

3. Spatial dimensions

Research addressing the spatial dimensions of technology and system emergence has shown that the emergence of a new technology may occur simultaneously in different places (Binz & Truffer, 2017).

The recent literature on global innovation systems (GIS) (Binz & Truffer, 2017; Heiberg & Truffer, 2022) proposes a multi-scalar conceptualisation of technological innovation systems. According to this approach, a GIS consists of sub-systems that create key resources – knowledge, market access, financial investment, and legitimacy. These sub-systems are interconnected through structural couplings, i.e., actors, networks or institutions that can span different spatial scales, enabling resource flows.

Building on this framework Heiberg and Truffer (2022) address the process of emergence of a GIS, based on a case study of experimental activities in innovative wastewater treatment technologies. They show that the process starts with several localised individual subsystems that are still incipient and may have loose connections among them. The system develops both mobilising resources locally and accessing missing resources from non-local sources through networks, creating complementarities among different subsystems at different spatial scales. They also stress the importance of actors that play a coordinating role at the trans-local scale.

According to the geography of sustainable transitions, places differ in the opportunities they offer for these processes to occur, due to their specific dynamics (Hansen & Coenen, 2015). Places "are produced relationally" (Binz *et al*., 2020, p. 2), which generates place-specific conditions in a given moment, i.e., actors, cultures, histories, structures, institutions, natural resources, and multi-scalar connections with other actors in other places (Binz *et al.,* 2020; Hansen & Coenen, 2015).

These place-specific conditions will influence the interaction between the emerging system and the context structures discussed in section 2. The geographical dimension of TIS context structures is discussed in the literature, in terms of the territorial and multi-scalar effects of the TIS-context interaction. Bergek *et al*. (2015, p. 58) refer to links "between a TIS and resources located in a specific territory" and thus "structural couplings that lead to the embedding of TIS structures in a specific territory", but also raises the possibility that links/structural couplings are established between a focal TIS and different territorial innovation systems.

Thus, this conceptual approach already suggests that interactions between the emerging system and the context structures can be conducted beyond the specific place where system actors are located and encompass different geographical scales. However, this multi-scalar view is not yet fully reflected in the empirical research, which has tended to focus on individual territories (mainly countries) or on comparison between them (e.g., Hojckova *et al.,* 2020; Mäkitie *et al.,* 2018; Oliveira & Negro, 2019; Ulmanen & Bergek, 2021; van der Loos *et al*., 2021). Thus, extant research already permits to go in greater depth into the nature and impacts of the processes conducted in particular places. But it misses the variety introduced by the simultaneous occurrence of technology emergence and system building processes in other (different and often connected) places, and the implications of this variety for the development trajectory of the technology.

4. Conceptual framework

Combining contributions from the literature reviewed above, we advance three basic elements that can base a framework to address this gap. One first element is the notion that interactions between system and context structure elements, that are critical for the early development of the technology/system, can be regarded as a process through which specific configurations of actors and networks are formed over time reinforcing the still weak system.

A second element is the view that technology development and early efforts towards system building occur simultaneously in several places; and that these places offer different conditions for these processes to occur, potentially leading to diverse configurations of actors and networks.

Finally, a third element is the notion that, even in early phases (at least some of) these places are likely to connect with each other, enabling a variety of resource flows. Such flows include those resulting from interactions with context structures, that are not necessarily conflated to a given territorial context. Rather, they also encompass the range of places that are mobilised by system actors, through (multi-scalar) networks, to gain access to the resources necessary for system development.

As a result, it is possible to argue that the early development of a system around the technology is not only spatially distributed, but also characterised by variety in terms of the configurations of actors and networks that are formed in different places and the connections established between them. Accounting for and understanding this variety is important, as it will influence the overall development of the global system around the technology.

These processes can also be relevant when considered from the places' standpoint. In fact, uncovering such variety may offer insights into the types of opportunities that can be created in different places, enabling them to capture the benefits from the technology, when it reaches the market (Andersson *et al*., 2018; Rohe, 2020).

III. RESEARCH METHODOLOGY

1. Research approach

Following from the previous theoretical discussion, the study investigates the variety in the formation of technology-related place configurations, in the early phase of development of a technology (table I).

Extant research has tended to focus on what happens in particular places, even when accounting for the multi-scalar connections established by these places. In this paper we propose that to effectively capture variety it is necessary to have a more comprehensive approach to the overall process of place configuration around the technology. This will permit to uncover: i) the spatial distribution of the process of technology emergence, and ii) the potentially diverse configurations of actors and networks that emerge in different places, including eventual regularities among them.

For this, the article empirically investigates the process of place configuration associated with wave energy technology emergence and early development, with a view to answer the following questions:

- Which configurations of actors and networks emerge in the various places engaged in the early development of the technology?
- Is there variety in these place configurations?
- Does variety in place configuration correspond to diverse positions in the system under development around the technology?

To address these questions, the article adopts a multi-location and multi-scale approach to identify, localise, characterise, and follow the evolution of actors and networks active in Research and Development (R&D) and innovation activities across Europe, from the early stages of wave energy technology development.

Table I summarises the conceptual framework, the research questions and the methods adopted to address them.

Table I – Research approach and Methods.
Quadro I – Abordagem e metodologia da investigação.

	Conceptual framework	Research Questions	Data & Methods
TIS – Early Phase	The development of a technology requires the construction of a new system: actors, networks & institutions. In the early phase both the technology and the system are still emerging (co-evolve), and the system is still fragile. Thus, the system is more dependent on interactions with context structures to provide actors and resources. Creation of complementarities (or structural couplings) between them results in the formation of particular configurations of actors and networks that strengthen the system.	Which configurations of actors and networks emerge, i.e., who are the organisations involved in the development of the technology and which are their connections?	Based on data on European funded projects in wave energy (1992-2019): - Identification, localisation and characterisation of organisations involved; - Analysis of interorganizational connections established (Social Network Analysis).
Spatial dimensions of TIS formation	Technology development and early system building are likely to occur simultaneously at various places. Some of these places may connect. Places can offer different conditions leading to emergence of diverse technology-related configurations of actors and networks. System grows through (multi-scalar) interactions that enable both mobilising resources locally and accessing missing resources from non-local sources. Need to consider the variety introduced by processes taking place in different environments and the multi-scalar connections between them.	Which configurations of actors and networks emerge in different places (and at different scales)? Is there variety in these configurations? Does variety in place configuration correspond to diverse positions in the system under development around the technology? How place configurations (actors and connections) evolve in the early phase?	- Analysis of connections established between places (Social Network Analysis); - Multivariate analysis of composition, connections, and centrality indicators: i) for the period under analysis: identify actor & network configurations in places. ii) for different sub-periods: assess evolution of place configurations along the technology trajectory. - Cartographic representation of the places' configurations.

2. Data

We conduct a pan-European analysis, based on data from Research and Technology Development (RTD) projects in wave energy funded by the European Union (EU) between 1992 and 2019. RTD projects are an adequate empirical basis, since EU programmes have a key role in supporting wave energy technology development (Magagna *et al*., 2018). EU projects encompass a broad range of activities that go beyond knowledge production, involving experimentation and institutional work. Accordingly, we classify projects as: research – fundamental and applied research activities; experimental – test of technologies, often in real sea conditions; structural – producing and sharing of generic knowledge to support learning and base technology legitimation, or developing material and immaterial structures (Fontes *et al*., 2016).

Data was collected from the European CORDIS database at https://cordis.europa.eu/projects. Project search was based on relevant keywords (e.g. "wave & energy", "marine & energy", "ocean & energy", "offshore & energy", etc) which permitted to make a first selection. Content analysis of project data (title, description, objectives) permitted to refine the dataset and retain only projects related with wave energy. We ended-up with 119 projects: 24 "research"; 65 "experimental"; 30 "structural". Five temporal phases of technology evolution were established, supported on previous research (Fontes *et al*., 2016) that identified four periods along the trajectory of the technology: early growth (1992-1999), take-off (2000-2005), faster growth associated with high expectations (2006-2010), disappointment and decline following the financial crisis (2011-2014). We added a new period (2015-2019) in which some recovery could be observed (Guo & Ringwood, 2021). The analysis stopped in 2019 as the COVID-19 pandemics introduced profound disruption in the development of activities, which was unrelated with the evolution of the technology, and thus the subsequent period is highly atypical.

The projects involved 496 organisations connected by 13 094 links, based in 300 locations in 35 countries. Information on projects, actors and connections was structured into a database of organisations.

3. Methods

On the basis of the data collected we built several indicators to support the analysis. We first produced indicators to characterise the organisations. Organisations were classified by sector according to the NACE – Statistical classification of economic activities in the European Community and by size using data from the ORBIS database and were georeferenced by location. They were categorised into three types: universities (including other research organisations), firms, and government/collective organisations. Firms were further categorised as: technological, i.e., developers of new wave conversion systems; complementary, i.e., providers of complementary resources and competences, ranging from market suppliers to co-developers; using documentary information (e.g., webpages, technology and sectoral reports, project data, corporate documents). The universe of "actors" under analysis encompasses 165 universities, 267 firms (203 complementary and 64 technological) and 64 government/collective organisations.

We built indicators to characterise connections between organisations. Based on Social Networks Analysis we explored the relational data for each of the five phases of technology evolution. Indicators of centrality were calculated (degree, betweenness centrality, eigenvector centrality, closeness centrality). We also explored the intensity and diversity of interorganisational connections, according to the type of organisation and geographical scales (local, national and international) involved. Diversity refers to the number of different types of organisations to which each organisation is connected in the network; intensity refers to the number of connections between pairs of organisations.

As a result, we obtained a database of organisations with 118 indicators, 27 for actor composition and 81 for connections and centrality. Quantitative indicators were categorised using the quintile method and qualitative data were classified into categories.

These indicators were subsequently aggregated by places, originating five geographical databases, one for each of the five phases of technology evolution, in which lines correspond to places and columns to the indicators.

In order to look for specific configurations of actors and networks in places, the indicators were systematised into *local profiles* by applying Multiple Correspondence Analysis (MCA). The MCA is a factor analysis that classifies the relationship patterns between dependent categorical indicators, grouping the geographical units according to common types (Greenacre, 2017). This analysis allows differentiating places, measured by the attributes of the organisations involved in the projects, as well as by the centrality indicators and the links arising from the interorganisational collaborations.

To identify the local profiles the five databases were aggregated in one global database. The MCA analysis was conducted on this global database. In this database each place appears in as many lines as the number of periods in which it is present. This permits to classify each place according to the specific profile it exhibits in each period. We used Geographic Information System tools to explore the spatial dynamics of the local profiles and their multi-scalar relations. These results are presented in figure 1.

Table II – Place profiles that emerge from wave energy projects (1992-2019).

Tabela. II – Perfis de lugares que emergem dos projetos de energia das ondas (1992-2019).

Domaines	Sub-domaines	Subjects	PLACE PROFILES A	B	C	D	E
Composition	Organisational composition	Universities/ RTO	High	High	High	Very low	Very low
		Government/ Collective	Very high		Very high	Very low	Very low
		Firms: Complementary	Very high	Very low	Very low	Low	Low
		Firms: Technological	Very high	Very low	Very low	Very low	Very low
	Organisation size	Small (1 - 50 employees)	Very high				
		Medium (51 - 250 employees)	Very high	Very low	Very low	Very high	
		Large (251 or more employees)	Very high			Very low	Very low
	Leadership	Coordinate and participate in projects	Very high		Very low		Very low
		Only participate in projects	Very high		Very low		Very low
		Only coordinate projects		Very low			High
	Activities (NACE)	Diversity of economic activities	Very high	Very low	Very low		Low
		Manufacturing (NACE - C)		Very low	Very low		Very high
		Electricity, gas, steam (NACE - D)	Very high		Very low	Very high	
		Education & Scientific (NACE - P & M)	Very high	Very high	Very high	Very low	Very low
		Administrative & Public adminis. (NACE - N & O)	Very high		Low		Very low
	Type of Project	Research	Very high			Very high	
		Experimentation	Very high	Very low	Very low	Very low	Very high
		Structural	Very high	High	High	High	Very low
		Research/Experimentation/Structural	Very high	Very high			Very low
Centrality and connections	Centrality	Betweenness centrality	High	Very high	Low	Low	Very low
		Closeness centrality	High	Very high	Low	Very low	Very low
		Degree centrality	High	Very high	Low	Low	Very low
		Eigenvector centrality	High	Very high	Low	Low	Very low
	Diversity of connections	Homophilic connections	Very high	Very high	Very low	Low	Very low
		Heterophilic connections	Very high	High	Low	Low	Very low
		Local connections	Very high	Very low	Very low	Very low	Very low
		National connections	Very high	High	Very low	Low	Very low
		International connections	Very high	High	Low	Low	Very low
	Local scale	Firm with Firm	Very high				Very low
		University/RTO with Firm	Very high	Very low	Very low	Very low	Very low
	National scale	Firm with Firm	Very high	Very low	Very low	High	Very high
		Firm with University/RTO	Very high		Very low	High	
		Firm with Collective/Government				Very high	Very low
		University/RTO with University/RTO	Very high	Very high		Very low	Very low
		University/RTO with Government/Collective	Very high	Very high	High	Very low	Very low
		Government/Collective with Government/Collective	Very high				
	International scale	Firm with Firm	Very high	Very low	Very low	Very high	High
		Firm with Universities/RTO	Very high	Very low	Very low	High	Low
		Firm with Government/Collective	Very high	Very low	Very low	Very high	Very low
		University/RTO with University/RTO	Very high	Very high	High	Very low	Very low
		University/RTO with Government/Collective	Very high	Very high	Very high	Very low	Very low
		Government/Collective with Government/Collective	Very high		Very high		Very low

Very high | High | Low | Very low

IV. RESULTS: PLACE PROFILES FORMATION AROUND WAVE ENERGY TECHNOLOGY

The longitudinal multivariate analysis permitted to identify five different types of configurations of actors and networks in wave energy that form what we labelled "place profiles". Table II typifies place profiles and figure 1 presents a cartographic representation of place configurations dynamics.

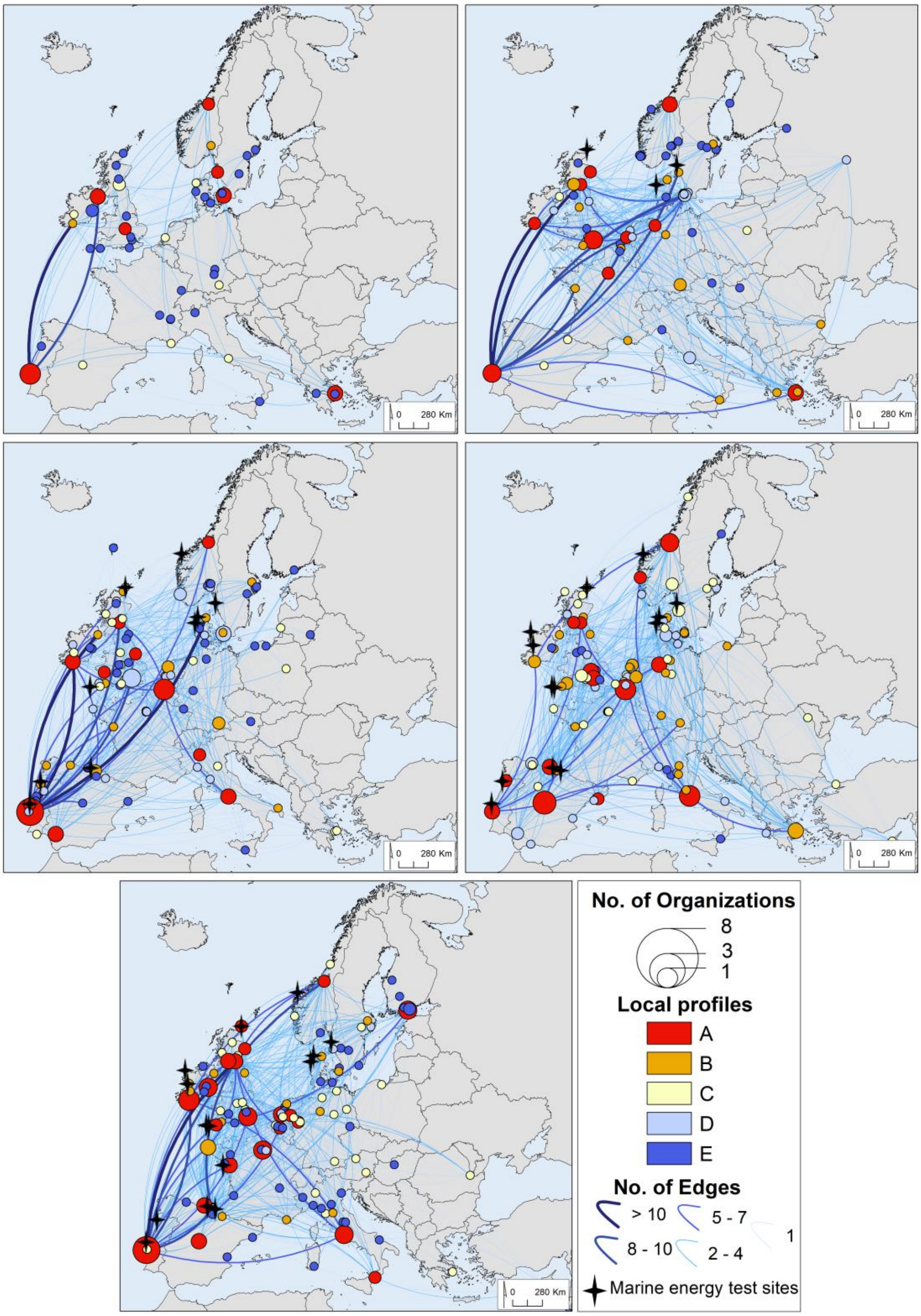

Fig. 1 – Evolution of place configurations by period: 1992-1999, 2000-2005, 2006-2010, 2011-2014, 2015-2019. Colour figure available online.

Fig. 1 – Evolução da configuração dos lugares por período: 1992-1999, 2000-2005, 2006-2010, 2011-2014, 2015-2019. Figura a cores disponível online.

These five place profiles are analysed in detail. The analysis aims at understanding what characterises these profiles, as well as their position in the system being developed around the new technology.

Profile A places are characterised by:

- High density and diversity of organisations (all types);
- Diversity of activities: involvement in research, experimental and structural projects; and coordination of many of them;
- Highly central position in the network;
- Diversified networks, at multiple scales: at local scale mainly among firms or between firms and universities; at national and international scales, heterophilic networks dominate;
- Presence of organisations that connect between different scales;
- Several places are close to the sea, often hosting relevant infrastructures (e.g., test centres).

This place profile shows some evidence of emergence of a local (sub)system based on the activity of a broad variety of actors, and on the multi-scalar networks they establish with a diversity of actors from other places, at different scales. The types of actors involved, through local and non-local networks, and the variety of activities point to interactions between actors from the emerging system and from sectoral, technological and political context structures to access/create missing resources; as well as to the multiscale nature of these interactions.

This configuration of actors and networks signals capacity to produce knowledge, access other key resources and act for technology legitimation. From the technology development perspective, these places may be central to the creation of a global system, both due to their actual strengths and through the resource flows their multi-scalar networks facilitate (Heiberg & Truffer, 2022), namely to places where processes are more incipient (Trippl *et al.*, 2018). From the local development perspective, they may be better prepared to capture the benefits of the technology when it reaches the market. The number of places with this profile increased over time (fig. 1), despite a period of decline (2011-2014).

The other profiles identified concern places where we find less (or no) evidence of local (sub) system emergence.

Profile B places are characterised by:

- Dominant presence of research organisations and very weak presence of firms;
- Involvement in research, structural and experimental projects; frequent project leadership;
- Very prominent central position in the network;
- International and to a less extent national networks dominate, showing little diversity: are mostly between research organisations, or between these and governmental agencies and collective organisations.

The configuration of this place profile points to a “specialisation” in the production of Science and Technology (S&T) knowledge. These places have a central position in technology development through the knowledge flows they foster at national and international level. A central position in international networks and leadership of structural projects also suggest a role in technology legitimation and eventual efforts towards global system coordination (Heiberg & Truffer, 2022). These places increased during the period of decline (2011-2014) (fig. 1); an evolution equally found in the case of Profile C places. This suggests that research organisations were critical for ensuring the continuity of the system during that period.

Profile C places are characterised by:

- Dominant presence of government agencies and collective organisations, combined with more limited presence of research organisations;
- Prevalence of structural and, to a less extent, experimental projects;
- Low centrality in networks;
- Low network intensity and diversity: networks at international scale dominate, national and local ones being much less prevalent; are mainly between government agencies and research organisations.

The configuration of this place profile suggests that such places are still likely to be at an embryonic stage, the activities being mostly conducted by government/collective organisations that attempt to access actors/resources from other places through international networks, inclusive in the period of decline (fig. 1). This hints at the presence of institutional agency (Grillitsch & Sotarauta, 2020) and highlights the role of policy in fostering these processes (Dawley, 2014).

Profile D places are characterised by:

- Dominance of firms from the energy sector; some technology developer firms can also be found; fewer organisations from other groups;
- Mainly involved in research and structural projects, less in experimental ones;
- Some places have a prominent central position in networks;
- High network intensity; networks mostly at international and national scales; mostly among firms and between firms and universities, the latter prevailing at international scale;
- Emerged later in technology trajectory (second period).

The configuration of this place profile reflects the involvement of established energy firms in wave energy, in the periods of take-off (2000-2005) and fast growth associated with high expectations (2006-2010) (Fontes *et al*., 2016). The emergence of these places reflects the capacity revealed by system actors to form structural couplings with sectors that could be critical for technology development. However, their evolution – they almost disappeared after the period of decline (fig. 1) – also shows how the early technology uncertainty and the low commitment of this type of actors (Makitie *et al*., 2018; Ulmanen & Bergek, 2021) make place configurations build around them vulnerable to their strategic decisions.

Profile E places are characterised by:

- Dominant presence of industrial firms, from a variety of sectors, but predominantly from manufacturing; fewer organisations from other groups;
- Prevalence of experimental projects;
- Low centrality in the network;
- Low intensity of networks at all scales; mainly between firms at national and international scale and between research organisations and firms at international scale;
- Various cases of proximity to experimental sites, often hosting test infrastructures.

The actor and network configuration of this place profile, associated with the nature of activities in which actors are engaged, point to a position in the supply of resources related with experimental activities (e.g. manufacturing and sea installation of prototypes) (Magagna & Uihlein, 2015). As knowledge producers rarely possess these competences, they need to establish interactions with actors from context structures that can provide them (Makitie *et al*., 2018). The emergence of these places – that frequently do not coincide with the system actors' location – may be associated to favourable conditions to set-up sea-related experimental sites, which then attract local suppliers (Fontes *et al.*, 2022). However, more specialised assets may be sourced elsewhere, which accounts for places with similar activities not co-located with those sites. This profile shows that interactions and creation of structural couplings with context structures can occur at different scales. From the local development perspective, activities conducted in these places can position them to become part of a future industrial value chain. However, these places are vulnerable to the fate of the technology, which is reflected in their uneven evolution.

V. CONCLUSIONS

The objective of this article was to uncover the spatial variety in place configuration around a sustainable technology in the early phase of technology development. It proposed that the consideration of such variety is necessary for better understanding the overall process of creation of a (global) system around the technology. Thus, the study explored whether processes of technology emergence occurring in and across different locations lead to the formation of different place configurations of actors and networks; and whether different types of configurations – or place profiles – correspond to diverse positions in the system under development around the technology.

For this, the research moved beyond the analysis of specific places and adopted a broader approach and a methodology that permitted to encompass and compare the various processes occurring across space, in the early phase of development of a sustainable technology – wave energy. This enabled us to uncover an extensive set of technology-related configurations of actors and networks in several places across Europe.

An analysis of these places permitted to identify five place profiles that correspond to distinct configurations of actors and networks and to trace their early evolution.

We identified one type of place profile (profile A) in which there is evidence of emergence of a local (sub)system, based on the activities of a high number and broad variety of actors and on the multi-scalar networks they establish with actors from other places at different scales (Heiberg & Truffer, 2022). These places, if they persist and consolidate over time, can contribute to the structuring of a global system around the technology. The other place profiles identified reveal configurations that, although less complete, indicate nevertheless the presence of some strengths – e.g., in terms of scientific and technological knowledge (profile B), or industrial resources (profiles D or E), or institutional agency (profile C) – that give them a specific position in the emerging system. Some of these places may capitalise on these strengths to attract missing resources, through links to other places, and engage in local system building processes (Trippl *et al*., 2018). Profile C configuration suggests agency of institutional actors (government or collective) with that purpose (Dawley, 2014).

Overall, this research contributed to empirically uncover the spatially distributed processes that take place in the early stages of development a technology (Binz & Truffer, 2017; Fontes *et al*., 2016; Sengers & Raven, 2015) and highlight their implications for the emergence of a new system. It showed that the interactions between diverse types of actors involved with the technology, including both core system actors and actors from context structures (Bergek *et al*., 2015), can take place at different scales and result in the formation of a variety of place configurations. It also showed that these configurations differ in intensity and diversity, both in terms of the relative importance of the various types of actors and in terms of their position in multi-scalar networks. The results therefore suggest that these different places occupy different positions in the development of a new system around the technology (Heiberg & Truffer, 2022).

The research offers new insights into the multi-place and multi-scale systemic processes that are at work in the early phase of technology development, adding to the knowledge on system dynamics in this phase. It shows that to understand how to accelerate technology progress it is necessary to uncover the variety introduced by spatially distributed processes of technology development and understand its implications for the development of a supportive system. In addition, the findings for this specific case can inform local policies aiming to capture the benefits of an early involvement in wave energy technology. Policy makers can match places current profile to their ambitions and consider how they may act to reinforce or change it.

The adoption of a pan-European approach was simultaneously a strength and a limitation of this research, as it provided a broader picture but did not allow going in depth into the nature of actors/interactions and their roles in the technology development. Subsequent research can conduct a more detailed analysis and comparison of representative cases of the different place profiles, which will permit to incorporate more data and adopt more qualitative methodologies, enabling a better comprehension of the formation and behaviour of these place configurations.

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Margarida Fontes: Conceptualization; Methodology; Validation; Formal analysis; Investigation; Resources; Data curation; Writing – original draft preparation; Writing – review and editing; Visualization; Project administration; Funding acquisition. **Hélder Santos:** Conceptualization; Methodology; Validation; Formal analysis; Investigation; Data curation; Writing – original draft preparation; Writing – review and editing; Visualization. **Teresa Sá Marques:** Conceptualization; Methodology; Validation; Formal analysis; Investigation; Data curation; Writing – original draft preparation; Writing – review and editing; Visualization.

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