The multi-spatial dynamics of niche trajectory: the case of the wave energy technological niche

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Abstract

This paper investigates the role played by processes taking place at different spatial levels in the construction and development of technological niches. It is proposed that niches, as protective spaces where technologies are developed and articulated with societal needs, may transcend territorial boundaries, encompassing communities and actions that span several spatial levels, without losing some local embeddedness. The paper draws on the multi-level perspective and on recent additions to the strategic niche management framework, to support an exploratory case study of the highly internationalised wave energy niche. The objective is to investigate the implications, for the conduction of niche internal processes and for niche-regime interactions, of the increased complexity introduced by this multi-spatial dynamics.
The case study addresses the formation, development and (transitory?) decline of the wave niche in Portugal, that was among the pioneers in the field and whose core actors have consistently been engaged in activities conducted at transnational and supra-national levels. The analysis confirms that niche development is shaped as much by local/national processes as by processes taking place at a diversity of spatial levels, which are strongly intertwined. But it also shows that niche development at country level - and its contribution to the overall niche trajectory – depends on the quality of interactions and the way these contribute to strengthen local/national processes; as well as on the particular configurations of the energy regime and the on-going transitions processes. These results, although still exploratory, contribute to the debate on the role of space in sustainability transitions.

Keywords: Niche dynamics; space; niche-regime interaction; competition between niches; wave energy technology; multi-level perspective; strategic niche management

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1. Introduction

The development of wave energy conversion technologies is part of a wider process of emergence of a set of new technologies – the renewable energy technologies – that shown to have the potential for destabilising the dominant energy socio-technical regime (Verbong and Geels, 2010). The renewable energy label encompasses a number of different technologies whose development processes have been unfolding at different paces (REN21, 2013). Wave is one of the less mature renewable technologies: no dominant design has emerged yet, and there is a variety of competing conversion systems, still in the prototype or test/demonstration stage, being developed in different locations, none having gone beyond pre-commercial applications (Falcão, 2010, IRENA, 2014). However, wave advocates have been able to set-up a protected space for the technology, based on a vision of future benefits (EU-OEA, 2010). Despite its slow development, as compared to other renewable energy technologies, wave actors have managed to build and sustain expectations over a long period, creating and expanding a network of actors prepared to commit attention and resources and to engage in learning processes (Lewis et al, 2011).

Thus, wave energy can still be described as a technological niche (Kemp et al, 1998; Schot and Geels, 2007) evolving in a protected environment. However, the development of this niche occurs in particular conditions. In fact, wave activities take place in a context of growing involvement of regime actors in renewable energy technologies, which is likely to influence the niche trajectory (Geels, 2002). Moreover, wave energy technologies evolve in interaction with other renewable technologies, in the context of a "shared" regime (Sandén and Hillman, 2011), resulting in complementarities but also competition between them. Finally, the activities being conducted for the development of the technology and its articulation with societal needs, combine local/national with transnational and supra-national elements, generating what can be described as an "overall niche space", that transcends narrow territorial boundaries.

Given these features, the wave energy niche offers a relevant setting for investigating the (non-linear) processes along which a technological niche is constructed and sustained over relatively long periods of time (Geels and Raven, 2006; Verhees et al , 2013), and for addressing a number of questions under discussion in niche research. It provides an opportunity for examining the implications, for niche development, of the involvement of regime actors (Raven, 2006; Smith, 2007), as well as the potential impacts of the presence of competing technologies (Mautz, 2007). It also provides the opportunity for investigating how niche construction and development is shaped by processes taking place at different spatial levels. Thus, it enables us to explore the issue of space in niche development, which has recently been pointed out as requiring greater consideration (Coenen et al, 2012; Raven et al, 2012).

The objective of this research is to conduct an assessment of the nature of processes taking place in technological niches that clearly transcend the local boundaries often associated with niche activity (Raven et al, 2012). In this paper, we start by looking at the particular case of a "country niche", but locate its evolution in the wider context of the "overall niche space", of which it is an element. Thus, we attempt to understand the relative importance, for the emergence and development of the niche: i) of processes within the country territorial/ jurisdictional boundaries and shaped by the country's institutions and policies; ii) of a variety of interactions between country actors and actors operating in other locations (e.g. other country niches) or at other levels (e.g. transnational activities); iii) of processes taking place at a supra-national level (whether or not involving country actors), often concerned with the structuring of the niche in socio-cognitive terms (Geels and Raven, 2006) and its consolidation in institutional terms (Coenen et al, 2012). For this purpose, the paper conducts an in-depth

analysis of the emergence and early development of the wave energy niche in a country – Portugal - that was among the pioneers in this field, and whose actors have been, from very early stages, engaged in the activities conducted at various spatial levels (Hamawi and Negro, 2012; OES 2002 to 2010;).

The research is expected to offer some insights into the effects of this multi-spatial scope in the development of a technological niche, including its impact on the performance of niche internal processes and its implications for the interaction between niche and regime. While the focus will be on the effects observed from a "country niche" standpoint, it is also expected to offer some first insights into the functioning of the "overall niche space", which will be addressed in subsequent research.

2. Conceptual framework

2.1 Energy transition

The research on the roles played by new renewable energy technologies in the transition to a sustainable energy regime has recently gained some momentum, due to the changes underway in the energy system (Verbong and Geels, 2010). Transformations in a major socio-technical system as energy – or socio-technical transitions - have been conceptualised by Multi-Level Perspective (MLP) scholars as the product of interrelated processes at three levels: niche, regime and landscape (Geels, 2002, 2005). Radical innovations that may come to play a role in regime transformation are developed in niches that act as protected spaces, temporarily shielding them from the selection pressures exerted by the dominant socio-technical regime. Changes at the landscape level may introduce tensions in the prevailing regime, challenging it and eventually destabilising it, creating opportunities for niche innovations, which may break through and profoundly transform or even overthrow the dominant regime.

The way these transformation processes unfold may vary (Geels and Schot, 2007; Haan and Rotmans, 2011; Smith et al, 2005). In the case of energy, a process that involves interaction and integration between regime and niche actors and their technologies and practices, potentially resulting in some basic reconfigurations in the regime architecture, appears to be more probable (Verbong and Geels, 2010). The energy system has already undergone profound changes, which introduced some tensions in the established socio-technical regime, leading some actors to doubt the long term viability of the "fossil-fuel based" regime configuration. This created a growing space for a variety of substantially different technological options – the renewable energies - that were being developed in niches. These technologies had reached diverse levels of maturity, and the respective niches also displayed differences in terms of internal stability and level of articulation, thus their development process was dissimilar (Verbong et al, 2008). Some of them have achieved considerable market diffusion (e.g. wind energy:), supported by favourable policies and also attracting the interest of regime actors (Bergek et al, 2013).

But interest and investment on more "laggard" technologies has also been sustained (REN21, 2013). This is namely the case of wave energy conversion, where the technology is far from being stabilised. Wave has been particularly slow in achieving the extensive benefits promised (Jeffrey et al, 2013; Lewis et al, 2011), but wave advocates have been able to create and sustain a protective space where the development of the technology and its alignment with societal needs and conditions is being enacted (EU-OEA, 2013; Hamawi and Negro, 2012). Its "laggard" position means that the wave niche has to withstand competition for attention and

resources from other renewable technologies, in particular the ones that have already created a market and achieved a reasonable diffusion (Mautz, 2007). But it also benefits from the creation of a growing space for the alternative sustainable path they collectively entail (Geels, 2005; Bergek et al, 2008).

2.2 Niche construction and development

In this paper we are interested in the formation and development of technological niches, that is, spaces where promising but still underperforming technologies are protected against the selection pressures of the dominant regime (Kemp et al, 1988). These spaces are expected to provide an environment that not only shelters the technology but also nurtures it. That is, they allow for experimentation in a societal context that permits improvements in technological performance and enables the alignment of the technology with user needs and institutional structures (Geels, 2002; Kemp et al, 1998; Smith and Raven, 2012). Thus technological niches can be defined as protected spaces where technologies and user specifications are still unstable and where the technology-specific structures (actors, networks, and institutions) are still in the process of being created and aligned (Schot and Geels, 2007). According to these authors "technological niches act as 'proto-markets' for new technologies, allowing interaction between users and producers in protected spaces" (Schott and Geels, 2007: 616). The final goal of these processes is enabling the technologies to become competitive, break out of the niche and trigger changes in dominant regimes. Such outcome and the ways in which it may be achieved depend both on processes internal to the niche and on the way niche developments link-up with developments taking place in the regime and also at landscape level (Raven, 2006; Schot and Geels, 2007).

The type of internal processes that are critical for the formation and development of technological niches have been put forward by the early proponents of the Strategic Niche Management (SNM) approach (Hoogma et al, 2002; Kemp et al, 1988). These authors identify socio-technical experiments as the locus for niche formation and development and outline three main processes whose interplay might lead to niche upscale and eventual breakthrough: i) voicing and articulation of expectations, i.e. of visions of future functionalities and benefits that provide directions for development and permit to attract resources and enrol new actors; ii) formation of networks of supportive actors, thus creating a constituency behind the technology and enabling the interaction between technology developers and a variety of other actors prepared to invest attention and resources in the technology; iii) enactment of learning processes, about both technical and non-technical aspects, that permit to adjust or reconfigure subsequent work. Consistent policies are an important sheltering element in technological niches and stability of support has been pointed out as critical for achieving long-term results (Jacobsson and Lauber, 2006; Verbong et al, 2008)

Subsequent developments, have attempted to fill some gaps identified in this approach (Schot and Geels, 2008). Research has namely put greater emphasis on the actual process of niche breakthrough and on the implications, for niche development, of its linking-up with the regime within which it emerges (Raven, 2006, 2007; Smith and Raven, 2012).

The interaction between niche and regime actors and institutions has received some attention (Raven, 2006). The presence of powerful regime actors can be important for the development of the niche, since they convey resources and legitimacy and can make it attractive to other key actors, such as capital providers (Schot and Geels, 2007). Niche innovators may namely opt for engaging in processes of "hybridization", whereby niche technologies are partly adapted to match incumbents' competences and interests (Raven, 2007). While the involvement of regime actors can be a strategy through which niche actors profit from regime tensions to

“infiltrate” their novel technologies and practices, translating them into ways acceptable by regime actors (Smith, 2007) and thus gaining their support, it also has risks, inevitably leading to a “niche reconfiguration closer to the regime” (Smith, 2007: 447). In fact, novel developments and approaches may end-up being captured by powerful regime actors, that use their insider intervention to prevent radical transformations or to steer the processes towards their specific interests (Kern and Smith, 2008; Smink et al, 2013). In any circumstance the involvement of incumbents is always likely to influence the development trajectory of technologies (Geels and Schot, 2007).

In the case of the energy system, the ongoing transformations put increasing pressure on established companies to take into account new technologies that can threaten their assets and competitive position (Hekkert and Negro, 2009). Thus regime actors have become increasingly engaged with niche innovations, being even able to absorb and integrate some of them (Bergek et al, 2013). Even in the case of more immature technologies, regime actors may wish to keep an eye on new developments, in order to follow-up their evolution and/or to guarantee an early position, once a dominant design starts to emerge (Sine and David, 2003). Thus, regime actors are increasingly involved in niche activities.

One further contribution to SNM concerns the learning processes and the way they can effectively contribute to strengthening the niche trajectory. Advancements in this field led to the introduction of a distinction between local experiments (individual projects enacted by local networks) that generate contextualised knowledge, and a global niche level (an emerging community) where abstract, generic knowledge is generated, taking the form of shared cognitive rules (problem agendas, heuristics, abstract theories and technical models) (Geels and Raven, 2006). The transformation of contextualised knowledge from individual projects into generic lessons and cognitive rules is not straightforward. It requires dedicated aggregation activities, conducted by community level networks that bring together lessons from multiple projects, codifying them and articulating field-level agendas. These will need to be subsequently translated to local projects, in a process that also requires dedicated efforts (Raven et al, 2011). These processes are facilitated by the circulation of knowledge and actors and the by comparison of outcomes and their collective discussion in a variety of arenas.

This approach also clarifies the relation between learning and expectations and contributes to explain the non-linearity of niche processes (Verbong et al, 2008). In fact, outcomes from experiments give rise to learning processes that are confronted with expectations. If expectations are confirmed, new developments can be pursued along a given trajectory that shows increasing stability, making it easier to extend the supportive network and obtain additional resources. If results fail to meet expectations, support declines and it is necessary to conduct some “repair work”, which eventually results in redirection of the trajectory and in new promises being made (Geels and Raven, 2006). This non-linearity in niche development has been addressed in detail by scholars who studied the role of expectations and discussed the presence of cycles of “hype” followed by disappointment (Bakker and Budde, 2012; Borup et al, 2006; Konrad et al, 2012; Verbong et al, 2008).

2.3 Space and niche development

One further development concerns the greater consideration of geography and space in transition processes (Coenen et al, 2012; Spath and Rohracher, 2012). Two questions raised by this literature are relevant for our discussion. One is the need to contextualise transitions, that is, to put greater emphasis on the territorial and institutional embeddedness of the processes taking place. This would permit to explore and understand the diversity in transition processes that derives from the “variety in institutional conditions, networks, actor strategies and

resources across space" (Coenen et al, 2012: 976). The other is the need to consider that transitions take place at different spatial levels (assuming space in territorial and relational terms) and thus, that "localised" activities are in fact subject to local and non-local influences through the position of actors in networks operating at (or spanning) diverse levels (Binz et al, 2014), as expressively coined in Gertler and Levitt (2005) "local nodes in global networks".

This spatial perspective was applied to the SNM approach, in order to provide a more adequate framework to understand the process of niche development, and thus to explain "how combinations of institutional, entrepreneurial and innovative processes and heterogeneous networks co-evolve and coalesce into more stable configurations that can challenge existing regimes" (Coenen, 2010: 296). Particular emphasis was put on the role of proximity in local niche experimentation, conceptualising proximity as encompassing social, cognitive or institutional aspects (Boschma, 2005) and stressing their importance in the conduction of niche internal processes. This approach had the advantage of permitting to understand the critical role played by the specific circumstances - institutional environments, policies, actors – and agglomeration effects of a given location. But it also implicitly associated niche to local experimentation and, therefore, tended to confine the niche to a territorially bounded place and to the local network formed around it.

A recent theoretical paper aiming at incorporating a spatial scale in the MLP, moves beyond this association, explicitly acknowledging that "there is no reason to conflate the MLP levels with specific territorial boundaries" since they "refer to processes with different temporal dimensions and modes of structuration that could each have a variety of spatial positionings and reach" (Raven et al, 2012: 64). This is namely the case for niches: even if "social networks are less extensive, less stable, expectations more fragile and learning processes are less institutionalized", it is recognised that they are not necessarily only local.

This wider approach – that is in line with debates on the variety of levels and scales at which transitions occur – emerges as the most adequate to address the processes taking place in some technological niches, of which wave energy will be presented as an illustrative case.

2.4 The multi-spatial dynamics of niche trajectory

Raven et al (2012: 71) suggest that "spatially situated niches can become (inter)nationally connected through existing or new networks, and reconfigure the flows constituting them and the institutions developed to regulate them". Drawing on the case of wave energy, we go a little further and propose that some technological niches may have a multi-spatial dynamics from the very early stages. In these cases, the development of the technology and its articulation with societal needs is a process that takes place simultaneously at different spatial levels, considering space from a relational perspective (Coenen et al, 2012).

This appears to be the case of the wave energy niche. In fact, the activities taking place as part of the development of the wave energy technology combine local/national with transnational and supra-national elements. The national element is grounded on the local availability of natural resources and on historical developments that led to emergence of activities in particular geographical locations, and shaped the particular configurations they assumed in these locations, given the country/region set of actors, institutions and policies (Hamawi and Negro, 2012; Lawrence et al, 2013). The transnational element is based on the development, from very early stages, of extensive international networks among niche actors from different locations (Elliot and Caratti, 1994), and on the growing actor involvement in activities taking place in other countries (Løvdal and Neumann, 2011). The supra-national element is related to the presence of a variety of supra-national networks, and increasingly of institutions, which

perform aggregation activities (Geels and Raven, 2006) and act as transnational advocacy networks (Bulkeley, 2005) (e.g. EU-OEA, 2013; OES, 2002 to 2012). Thus the development of the wave energy technological trajectory effectively takes place at different levels and scales, which are interdependent and influence each other. These dynamics may be part of the behaviour of some technological niches, potentially associated with the characteristics of the socio-technical regime in which they emerge and with the strategies of key actors[1]. In these cases the niche emerges as a changing (but increasingly structured) multi-spatial structure, that transcends narrow territorial boundaries.

Thus we propose that the "niche" – as a protected space where a variety of technical and societal processes unfold, with a view to achieve niche upscale and breakout – can effectively encompass the activities of actors and constituencies operating at and spanning different spatial levels, as well as the diversity of the interactions between them. This does not mean that it is not possible identify "country" or "regional" niches, that is, specific configurations of actors/networks that are influenced by specific (territory related) institutional and political environment. But they should be regarded as elements of the "overall niche space" and their behaviour can only be fully understood when viewed as part of that space.

It can be argued that the multi-spatial dynamics of these technological niches – i.e. the fact that niche activities are being enacted at a multiplicity of levels and along a variety of interactions, which are frequently reconfigured and produce a diversity of outcomes with varying degrees of structuring - is likely to be conducive to an increased complexity in the niche dynamics. This is will have implications for the conduction of the niche internal processes identified by the SNM literature - articulation of expectations, network building and learning processes, in particular learning that leads to generic lessons. Similarly, it is likely to have implications for the nature of interactions between niche and regime.

The objective of this paper is to offer a first assessment of the nature of the processes taking place when niche communities and activities effectively span territorial boundaries. It focuses on the wave energy niche and addresses its formation and development from the standpoint of a country – Portugal - that was among the pioneers in the construction and attempted upscale of a niche around wave energy conversion; and where niche development activities were closely intertwined with the transnational and supra-national trajectory of the emerging community. The research will examine the process of construction and development of the Portuguese "country niche" over time, with a view of investigating : i) whether and how niche development is shaped by processes taking place at different spatial levels; ii) the implications for the performance of niche internal processes and for the interaction niche-regime.

3. The case of the Portuguese wave "country niche"

3.1. Approach and methodology

The empirical research on the formation and early development of a wave energy niche in Portugal is based on the analysis of the documented actions enacted over time by actors operating in the niche, drawing on documentary data and on a small number of exploratory interviews with key actors. This preliminary analysis focuses on the identification of the actors

[1] For instance, in the case of wave energy, scientists, who have a strong position in the technological niche, tend to be highly internationalized (Wagner and Leydesdorff, 2005), energy regime actors are often global players (Kolk et al, 2014), European visions and policies for energy are at least partly defined at EU level (EC, 2014; EU-OEA, 2010).

that have been involved with the niche over time, on the mapping of formalized activities they have conducted in or on behalf of the niche and on a first assessment of the main outcomes of these activities and their implications for niche development.

While we are aware that a complete understanding of the processes of niche formation and niche development can only be achieved on the basis of an more in-depth appreciation of the expectations, motivations and decisions of the various actors involved in the process (Verhees et al, 2013), we will start by considering some of their most visible results, i.e. documented actions these actors conducted along the process. Data include information on research projects and research outputs, experimental projects, organization creation, business investments, research or business partnerships, participation in collective activities, policy instruments, and draws on a variety of sources, including archival data from a diverse set of organisations (from government and funding entities to the actual participants); databases; websites; technical and policy reports; specialised magazines; press releases, etc.

This enabled us to address the process from the standpoint of the actors, i.e. to identify the main actors and the timing, nature and degree of their involvement in the niche, as well as to make a preliminary assessment of the type of strategies they adopted and the relationships they established. It also enabled us to address the process from the perspective of the system, namely to gain some insights into network formation and expansion (or contraction), the type of actors the niche is able to attract, the resources it can mobilise and its capacity to influence the launch of favourable policies; and into the impact on niche evolution of developments taking place outside the niche – i.e. in the energy regime, in competing niches, in adjacent fields and in the economy as a whole. Although the focus will be on the process of niche formation and development in Portugal, the analysis will be conducted at the light of the developments taking place at the global niche level.

Combining information on the nature of the actors involved and on the formal outcomes of their decisions, we can build a dynamic map of "what happened" at a visible layer. This is expected to offer insights into the processes taking place over time, as well as enable us to devise some patterns in niche evolution and to raise some questions on why and how they come to be. This will be the basis for subsequent research, involving more detailed interviews with key actors, which will support a more precise answer to these questions.

3.2 The formation and evolution of the niche

The empirical analysis involved building a detailed map and chronology of actions (actors, activities, relationships, outcomes) that served as basis to investigate the niche trajectory. The analysis attempted to identify the main patterns that emerged over time, concerning the specific configurations assumed by the niche internal processes and niche-regime interactions - considering both activities conducted at country level and at various spatial levels of interaction - and their implications for niche development. For analytical purposes these patterns were organised in six main "periods" that are presented in some detail below.

Period 1 – Antecedents – Before 1988

The first period corresponds to a "pre-history" of wave development in Portugal. An embryo of research group in this field started being formed in the late 1970s, based on a small number of scientists from an engineering university (IST). Most of these scientists, who would become central actors in the development of the niche, did their PhD abroad (mainly in the UK) and maintained extensive contacts with the emerging international wave community. In the early 1980s the first government policy towards renewable energies is set-up (a system of generic

fiscal incentives) and in 1988 there is the first great transformation in the Portuguese energy system – a law that establishes the liberalisation of the electricity market, terminating the monopoly of the energy utility (EDP) and authorising the independent production of energy, opening the space for renewable energy development.

Period 2 – Raising Awareness (1988-1993)

This period combines the first steps towards electricity market liberalisation with the set-up of the first government programme specifically targeting the energy sector. However, the research projects launched in the wave field are mostly conducted in the context of European programmes (which start including wave energy in the early 1990s), profiting from the international networks of Portuguese scientists. One of them involved resource evaluation for building an experimental site, led by IST in collaboration with a government laboratory that had also started developing competencies in the field and would equally become a central actor (LNEG). These actors also participate in similar activities in other locations (e.g. UK and Ireland). The development of university level competences pursued with new PhDs in the field (now conducted in Portugal and abroad). A first spin-off from IST was formed offering services in wave modelling.

Period 3 – First Experiments (1994-1999)

Following the very positive results from the resource evaluation, it was decided to pursue with the development of the world first experimental site – the PICO pilot plant in the Portuguese Azores islands – still funded by European programmes. The scientists behind the project were able to involve two important regime actors: the energy utility EDP (ex-monopoly) and the main national energy equipment manufacturer. This was the first move of the energy utility into the field where it would play an important role in the future. IST also participated in a similar project, started in 1998, to install an experimental site in the UK (Limpet plant). The group of pioneer IST and LNEG scientists were now a key element of the international scientific community being created in the field, largely centred in North Atlantic countries. They went on conducting research - fundamental (modelling) and applied (e.g. turbine development, resource assessment) - still mostly in the context of collaborative European projects. Despite the fact that a dedicated "Operational Programme for Energy" had been launched by the government in 1994, only by the end of the period (1999) we find wave projects supported by national funds.

Period 4 – Early Niche Expansion – 2000-2005

The 2000s represent a major turning point in the Portuguese policies towards renewable energies. Ambitious targets are established in response to the EU Directive on renewable energies (2001/77/CE) and a new Programme (E4 – Energy Efficiency and Endogenous Energies) is launched, establishing the objectives for the development of renewable energy production and mechanisms to support it. Among these is the introduction of feed-in tariffs, including a special tariff for wave energy, and support to investment projects.

In spite of this, the number of wave projects supported does not increase substantially, with the largest amount of investment going to wind energy, which is starting to diffuse widely in the country. But Portuguese wave actors continue participating in international projects, including collaboration in EU funded experimental projects, led by foreign firms in different locations. The lead actors also participate in projects and other actions that start being launched at EU level with more "infrastructural" objectives: drawing generic lessons from experiments conducted in different projects and from the experience from different countries

(aggregation activities), providing guidelines for future developments, feeding the formulation of a vision for the field and also informing policy making at EU and country level. This type of activities continued over time, often crystallising in the creation of stable networks or even organisations, with Portuguese actors occupying an important position in several of them. Among these can be mentioned the creation in 2001 of the first supra-national organisation – the Implementing Agreement on Ocean Energy Systems (OES), of which Portugal was a founding member and first chair. In some cases niche actors bring other local organisations into those projects, both regime actors involved in the field and policy actors.

The structuring of the country niche also increases with the creation, in 2003, of a wave energy association – WAVEC - involving research organisations and firms. WAVEC starts launching awareness and lobbying actions and participating in infrastructural and diffusion/training EU level projects, joining and sometimes replacing the two research organisations that traditionally led the Portuguese participation in these activities.

This period registered another important set of events – the choice of Portuguese locations, by several foreign technology developers, to test their technologies. Three main reasons can explain this decision. First the country natural conditions that elected it as a promising location for wave energy production. Second the favourable policies for renewable energies. Finally, the extensive international connections and reputation of the main wave actors, who not only were able to gain the interest of these foreign actors, but could also offer strong scientific and technical competences and local experience. Thus, by the end of the period, one experiment has been launched and a couple of others are announced. These projects assume the form of joint-ventures between the foreign technology developer and local large companies prepared to invest, but are highly subsidised, usually involving a combination of national and European funds. This model will continue being adopted in subsequent periods.

Despite the intense activity of scientific actors and the growing interest in foreign technologies shown by non-niche actors, technology development conducted by local firms is limited. One spin-off is created to exploit technology originating from the university and one large company (already operating in the wind area) starts developing its own technology, in collaboration with universities. One experimental project involving only local actors is announced, but does not pursue. At the same time the PICO plant experiences problems and a recovery project is launched involving the same and new actors.

It is possible to argue that at the end of this period a local constituency is already being formed around wave energy. Because R&D activities are still critical, scientists remain central actors. But other actors have now joined the network, both those that were gained to invest resources and those that are also involved in the development of the technology. Among these, assume growing importance: a small group of regime actors, given their investment capacity and also the legitimacy that their presence bestows to the field; and foreign technology developers, since their presence creates the opportunity for the setting-up of new learning processes from experimental activities. But it is also possible to argue that a substantial part of the niche activity is in fact taking place beyond the country level. That is, that the emerging local constituency is complemented with transnational networks that connect local actors to projects conducted elsewhere; and with the supra-national networks to which they also belong. Finally, while the creation of the collective organisation provided some glue to the country network, it also contributed to reinforce the transnational and supra-national interactions and thus the integration of the country level niche within the overall niche space. This permitted to strengthen the position of country niche actors and increased their capacity to enrol local actors and to influence the setting-up of favourable policies. This will become particularly evident in the next period.

Period 5 – High Expectations – 2006-2010

The government bet in renewable energies was reinforced with the launch, in late 2005, of a National Strategy for Energy. Renewable energy is presented as a priority and described as a driver of country development. Country targets are revised upwards. The ocean also becomes a focus of policies that aim at the development of an Ocean Cluster, involving several economic activities, among which energy. This generates a renewed interest in wave energy.

There is a growing consideration of the country potential for attracting foreign technology developers to test their technologies in the Portuguese coast. These are a mobile set, highly dependent on favourable policies, availability of infrastructures and of investors that enable them to endure the high costs of the sea level experimental projects (Løvdal and Neumann, 2011). The government is pressed by niche actors to create conditions to attract them, as competing locations (namely in the UK and Ireland) are also moving in this direction. Thus a decision is made to create a Pilot Zone that admits both experimental projects and small early stage commercial projects, thus occupying a space not yet covered by the experimental facilities set-up in other locations.

The announcement of the Pilot Zone leads several foreign technology developers to express interest in testing their technologies there, adding to the small group already active in the country. The message put forward by these firms is that their technologies are approaching stabilisation and that these experiments, which move them from the relatively sheltered test environments to real sea conditions, will swiftly lead to commercial installations. This expectation raises the interest of established local companies - both companies that had already moved into renewable energies and others that saw a business opportunity in a field now expected to experience future growth – and new joint ventures are prepared. Among these companies stands the utility EDP that is engaged in several projects and becomes a very proactive advocate of the field. A couple of these companies also invest in projects taking place in other countries. On the other hand, experimental projects start involving firms located along the value chain (e.g. metalomechanicals, shipyards, sea equipment and logistics).

Research organisations and a few firms continue participating in European projects - R&D, infrastructural and experimental. Some of the latter are expected to create opportunities for future deployments in Portugal. There is a small increase in R&D projects funded by national programmes and also in wave patenting, mostly by universities, but also by new ventures. However, the number of local entrepreneurial companies developing proprietary systems remains small, even considering those involved in auxiliary technologies. Despite the availability of public funding, that cover the very early stages, these firms experience difficulties in upscaling their technologies, given the high investments involved and the limited interest of local private investors, who prefer the more mature and (potentially) closest to market technologies presented by foreign developers. This reduces the scope for local development and also for the emergence of radically new designs being pursued by new firms, which can be an important element when technologies are still far from stability (Jeffrey et al, 2013). Venture capital companies are mostly absent from the field.

The period started with very high expectations for the development of wave energy in Portugal. The network around the technology had extended, involving a growing number of actors prepared to invest in the field. Moreover, wave advocates had been able to capture the interest of both the government and regime actors to a narrative that stressed the country particularly favourable conditions, and described the opportunities opened by a first mover advantage in a new field full of potential and with strong synergies with other ocean activities, also being promoted. The implicit strategy was that the country could profit from the capacity

to assist experimental projects and, sooner or later (depending on the pace of development of the technology), would be positioned for becoming a central location for wave energy production. The creation of a supportive industry around this activity (a "wave cluster") was also part of this vision, and the "rejuvenation" of traditional sectors (such as shipyards) and fishing communities was seen as one important outcome. Several elements appeared to be in place: strong international networks led by reputed scientists; a favourable energy policy; a Pilot Zone being installed and a number of experimental projects being negotiated or already starting.

However, things did not progress as expected. There were two main problems. First the Pilot Zone, a central element of this strategy, registered severe delays and, by the end of the period, its set-up was not yet completed. Thus several projects ended-up being diverted to other locations (or did not pursue at all) frustrating the expectations of the local companies that had invested or proposed to invest in them. Second, the expectations about the development of the technology grossly underestimated the problems to be faced in the harsh conditions of real sea experiments. Thus, the outcomes of the few projects that did advance were much below expectations.

Perhaps the most damaging was the case of the Pelamis "wave farm", which was presented as the first pre-commercial demonstration project, potentially leading to energy production in the near future. It was regarded by various players as a basis for the promised "wave cluster" and, based on this expectation, EDP promoted a consortium involving various companies, investing heavily in the project. It was also a presented as a flag project by the government. The visual image of the device (the "red serpents") was taken over by the media that followed up the progress of the project. The quick failure of the system – also widely reported in the media - led some investors to walk out, and later to the abandon of the site by the foreign technology promoter.

For the utility EDP this corresponded to the third negative outcome in wave projects in which it was involved. Thus EDP abandons wave projects and moves the focus to deep-water offshore wind, launching a prototype of a floating offshore system, in joint venture with a US technology developer and several local companies, a few of which are also moving away from wave. The rationale behind EDP decision combines the interest in entering an area that registered fast expansion in recent years (Kern et al, 2014) with a perception of lower uncertainty. In fact, even if floating systems are still at an experimental stage, the project brings the sea environment a technology - wind conversion – it already dominates.

By the end of the period only one experimental project involving a foreign company is pursuing as planned, registering some success and advancing to a second phase (Waveroller). But this is an exception. The disappointment follows the "hype" and the supportive country network dwindles. It is nevertheless relevant to notice that this happens, at country level, at a moment when, in the international arena, large companies start investing more heavily in wave projects, and supra-national networks, where Portuguese actors continue participating, are developing an intense activity (EU-OEA, 2010; REN21 2010 to 2013).

Period 6 – Disappointment & uncertainty (2011 onwards)

The problems experienced by the niche are suddenly aggravated by the economic crisis, which leads to the country bailout. This also drives a change of government and of policy: renewable energies stop being a priority, targets are revised downwards and there is an explicit divestment from "less competitive energy technologies", which includes wave.

For the niche, the abandon of EDP and its partners is a strong blow in the credibility. Combined with continued delays in the Pilot Zone and consequent abandon of the few waiting projects and with the gradual withdrawal of policy support, it definitively clouds the high expectations created around wave energy. No new experimental projects are launched. Investment by local companies stops, financial problems adding to disappointment. Wave projects disappear from national funding programs. New ventures experience increasing difficulties in obtaining private financing for developing or testing their technologies. Some suspend activity, or move to alternative areas, when their technology allows.

The exception to this bleak picture is still the Waveroller project, which was installed, successfully connected to the grid and started producing energy, although still in an experimental way. This project, whose promises were less spectacular, and thus registered much less government interest and media attention than Pelamis, had a different genesis. It largely resulted from the proactiveness of a municipality from a declining fishing town, which was attempting to move to new areas related to the sea. When the country emerged as an attractive setting for experimental projects, it was able to attract a foreign entrepreneur to start conducting his early technology tests there, in joint venture with a large company originating from the region and already involved in renewable energies. It was also instrumental in linking between the technology developer and a local shipbuilding firm and other suppliers, which become increasingly involved as subsequent versions of the device were developed and installed. This way, a working network was effectively built, which is producing positive results that match the more modest but realistic expectations[2].

The move of EDP and some of its partners to offshore wind triggers, at country level, a movement already visible at international level – the focus is now increasingly on "ocean energy" (that encompasses wave, tidal and offshore wind). In Portugal, the "offshore energies" label now prevails and wind offshore effectively supersedes wave, attracting attention and investments, largely due to EDP power and the early success of its floating offshore prototype. Although EDP still mentions wave as a "future target", it stopped being a driver of the wave niche development and effectively became a competitor. Wave niche actors attempt to compensate for the difficulties in wave, by adhering to the "offshore" label (e.g. the collective centre WAVEC even changes its name) and, when possible, by extending the scope of their activities to integrate with offshore wind. There is also an attempt to link to other ocean-level activities, profiting from the continuity of policy focus on the "ocean cluster".

Research activities continue nevertheless being developed at universities. The surviving core actors remain involved in foreign, transnational and supra-national projects, which sustain their activities while they attempt to do "repair work". In fact, while activity dwindles in the country niche, we observe a continued capacity of the overall niche advocates for sustaining visions of an enormous future potential – even if promises point to a longer term – maintaining political support and attracting large regime actors (EU-OEA, 2010, 2013). This is namely the case at European level. While activity increasingly extends beyond the traditional Atlantic region towards the Pacific and Asian countries start investing heavily, European supra-national actors stress the need to maintain the "European leadership" and obtain favourable conditions in the new Horizon 2020 framework programme (EC, 2014). Thus, to some extent country actors are back to the early stages, where transnational networks sustained their attempts to develop a country niche…

[2] In July 2014 the project was awarded substantial financing from NER 300, the largest European funding system in the low-carbon energy area, whose aim is "to establish a demonstration programme comprising the best possible CCS and RES projects" (http://ec.europa.eu/clima/policies/lowcarbon/ner300). The funding will support the construction a large-scale wave farm in the Portuguese coast.

3.3 An overview of the wave niche evolution

This evolution is graphically illustrated in Figures 1 to 4 that present quantitative data on the (documented) actions conducted, over time, by the actors involved in the niche. Figure 1 documents first entry (through formal activities) and new actions by actors already in the niche, distinguishing, for the latter, between those corresponding to performance of same type of activities (repeat activities) and the performance of new ones. Figure 2 presents the number of actors performing each type of activity, by period. The activities were categorised in four types: research, experimental activities, business investment (including firm creation) and structural activities. Figure 3 shows the type of actors active in the niche in every period. These were aggregated in four categories: research organisations; new firms, including technology developers and other firms created for developing activities within the niche (e.g. joint ventures); existing firms, including regime incumbents operating in the niche and companies in complementary activities along the value chain; other, including collective actors, government bodies and local authorities and funding bodies. Figure 4 focus on foreign firms, identifying both direct entry and the establishment of joint-venture with a local firm, and repeat activities of both.

The figures show a clear pattern of slow growth, take off, hype and decline, whereby new entry of supportive actors, as well as the variety of actors and activities they perform, grow more or less steadily during the first three periods, register a sudden explosion and fall again, leaving only a “core” network active. However a closer inspection also confirms that different types of actors and different activities show slightly diverse dynamics over these periods.

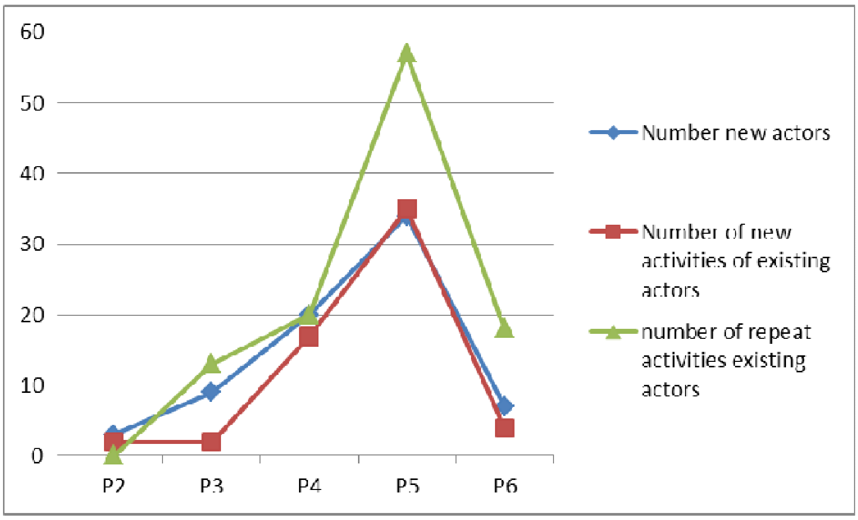

Figure 1 – Number of actors involved in formal activities, in each period

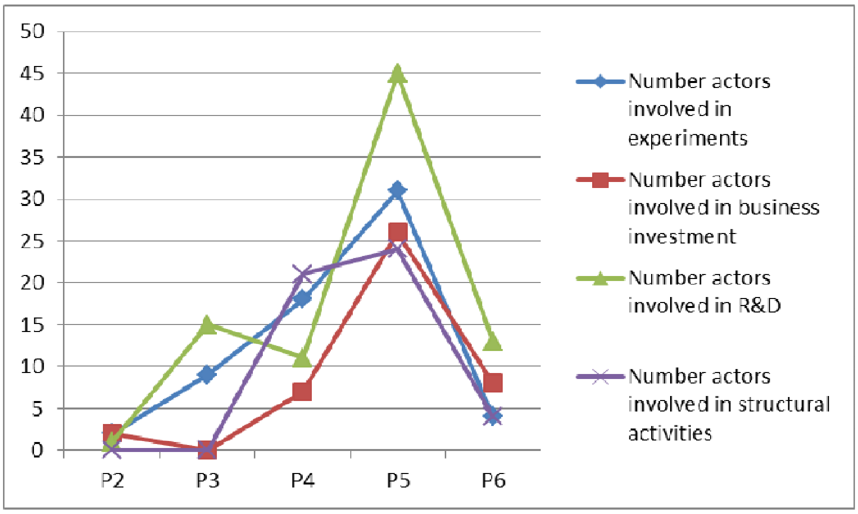

Figure 2 – Type of activities: number of actors in formal activities by type in each period

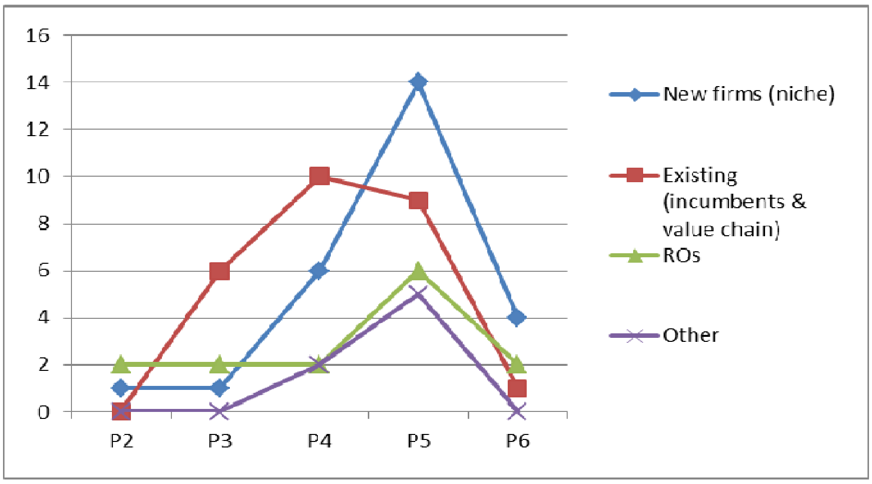

Figure 3 – Type of actors: number of formal activities performed by each type, by period

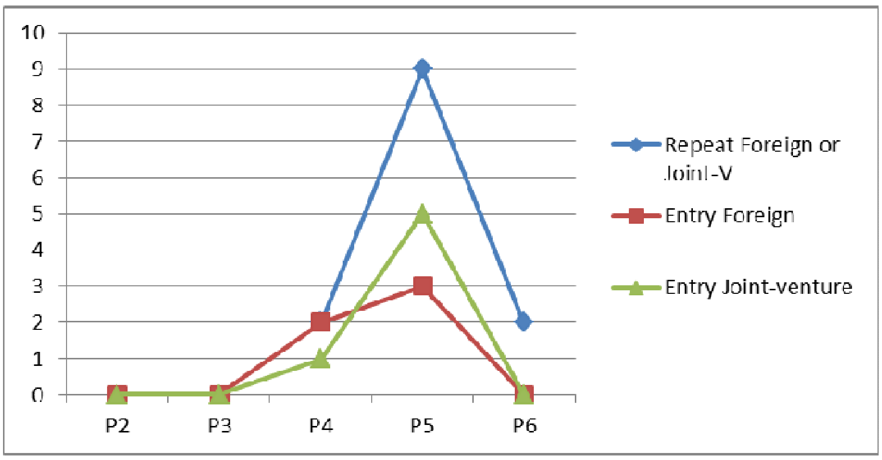

Figure 4 – Foreign actors: direct entry, joint ventures and repeat activities

The transnational dimension of the niche actors' networks can be further documented by data on participation of Portuguese organisations in European joint projects[3] (Figure 5).

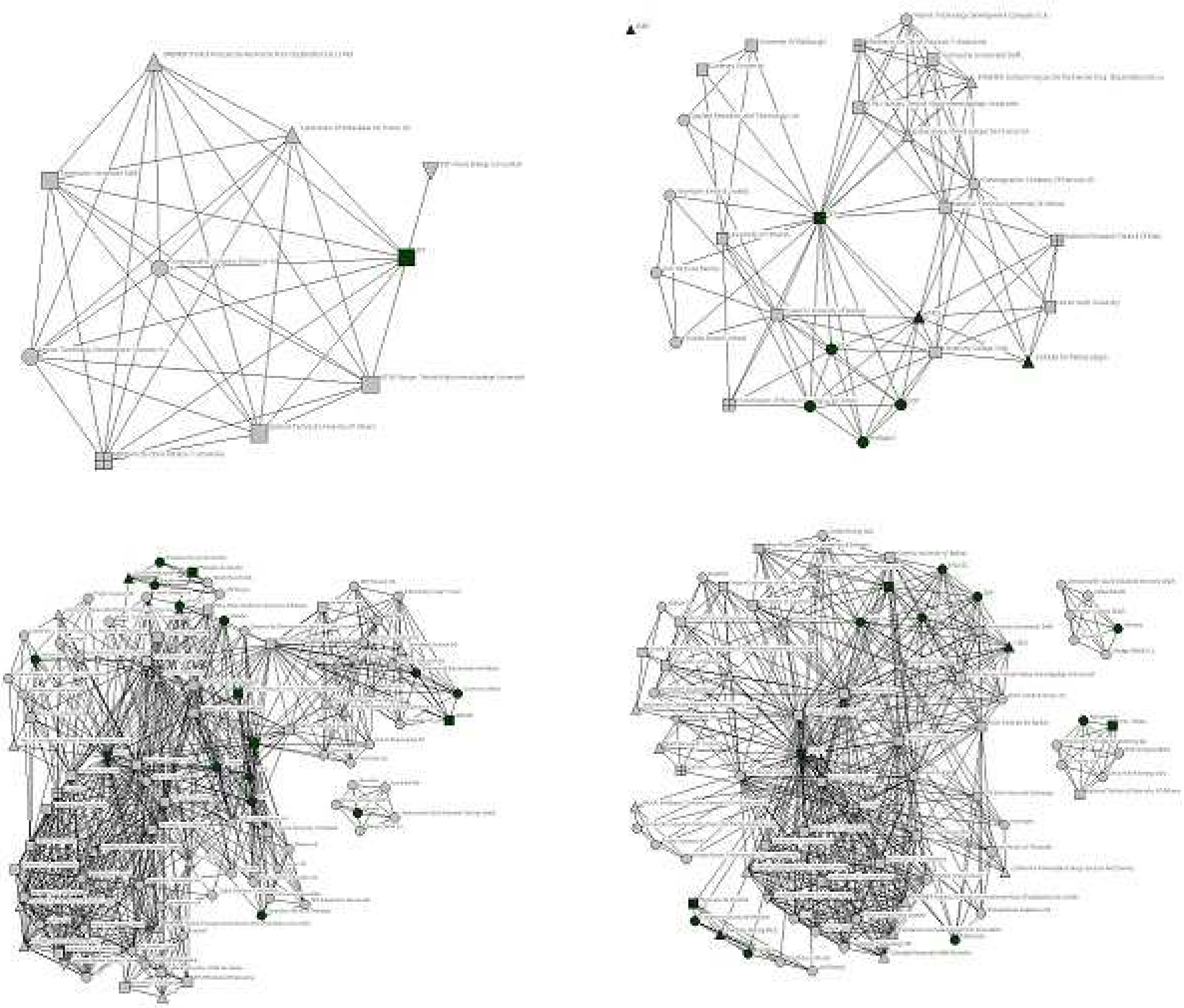

Figure 5 – Transnational networks of country niche actors over time (European projects)
Top – Networks corresponding to Period 2 and 3
Bottom – Networks corresponding to Period 5 and 6
Portuguese organisations are represented in black.

Figure 5 shows the networks formed in two early periods (P2 & P3) and the two latter ones (P5 & P6). They confirm that actors from the "country niche" were, from early stages, involved in transnational networks that expanded over time and played important roles: from the early period, when pioneer scientists built the connections that supported their niche formation activities (P2); through a growing involvement of other local actors (including local regime actors) in transnational activities as local networks expanded (P3); to extensive interactions with actors, with diverse competences and originating from different locations (who may even

[3] The data is based on projects funded by the European Commission (obtained from CORDIS and Intelligent Energy Europe databases). Thus, it only documents a sub-set of the transnational activity, namely missing the participations in supra-national networks (beyond those funded through European programmes) and organisations, for which it was not possible to obtain systematic data. But we believe this already provides a good approximation.

move temporarily, such as when foreign experimental projects are brought-in), which reflect the multi-spatial nature of the overall wave niche, but also contribute to strengthen the country niche (P5). It also shows that the network remains reasonably stable from P5 to P6 (even if some local actors withdraw), suggesting that an effective integration in transnational networks at overall niche level, sustained activities of core actors at a period of dwindling networks at country level.

4. Discussion

The analysis of the formation and early development of the wave energy niche in Portugal has confirmed that the "country niche" was grounded on local conditions. But it has also shown that these "local" conditions were partly shaped by the transnational networks of niche actors and, therefore, by the development of the niche in other locations and the learning processes that resulted from interactions, at different spatial levels, between actors with diverse experiences.

The attempted niche upscale, at country level, can also be understood as based in a strategy that combined favourable local conditions with opportunities arising from the multi-spatial nature of the niche development, and the central positioning of some country actors. In fact, this strategy involved attracting foreign technology developers to conduct experiments with different technologies that appeared to be closer to commercial application. The final goal was creating a strong local competence (including a supportive industry) and profiling the country as a privileged location where these (and eventually other) promoters could establish themselves as energy producers, once the technology stabilised. This strategy was possible, not only because niche activities take place in different geographical locations and spatial levels, but because interaction and mobility between them is an intrinsic feature of the niche development (Løvdal and Neumann, 2011). In addition, the positioning of local actors in the transnational and supra-national networks supported the identification of opportunities, while their reputation in these networks provided credibility.

The success of this strategic approach required that transnational interactions matched and reinforced local activities and networks, contributing to the strengthening of internal niche processes. This depended strongly on the conditions found at country level. But while the outcomes were expected to be particularly beneficial for the development of the country niche, it can be argued that niche strengthening effects might go beyond the country level, not only due to the multi-spatial nature of the actors and activities, but also because there was scope for learning processes that could contribute to improve the stability of rules at global niche level (Geels and Raven, 2006).

The analysis of the way this niche upscaling strategy was pursued enables us to identify some of the local conditions that could contribute to successful niche development, as well to uncover some problems that arose along the process.

In what concerns the local conditions – and besides natural endowments that are an unavoidable feature in this field – two aspects emerge from this case as fundamental. One is the presence of favourable government policies, both generic policies to support renewable energies and specific policies towards wave. But exactly because the country attractiveness for technology developers was at least partly based on favourable policies, the government delays in the implementation of a key mechanism such as the Pilot Zone and the sudden change of policies drove away its very mobile targets and caused major damages (Verbong et al, 2008). This contrasts with the behaviour of other "country niches", such as the UK, which have

maintained a more sustained focus on wave and relatively consistent policies towards it, with positive results (Lawrence et al, 2013).

The other is the particular configuration assumed by the dominant regime and by the transition process at country level. In fact, wave benefited from the previous involvement of Portuguese regime actors in renewable energies, which made them more open to potential opportunities in the wave area. The participation of regime actors was important in a field where technology development requires expensive infrastructures and where operating systems require combining a variety of activities along the value chain (Falcão, 2010). Thus the presence of large established companies prepared to provide resources and offer legitimacy towards capital providers and other firms was particularly important.

However, the role played by regime actors, in particular the central position occupied by some powerful companies in niche networks, emerged as a double-edged sword, because it left the niche vulnerable to their strategic shifts. In fact, the abandon of key regime actors not only drove away resources and relevant alliances, but also redirected the attention of policy makers. In particular, the move of the utility to a competing technology, that combined high promise with lower uncertainty, was particularly detrimental to the field, given its power and influence. Thus the risks inherent to the excessive protagonism of regime actors and, more generally, the vulnerability of niches – in particular less stabilised ones – to developments at the regime level were visible here (Smink et al, 2013; Smith, 2007).

The particular configuration assumed by the transition process at country level also had some role here. In fact, the faster diffusion of other renewables, in particular wind (Bento and Fontes, 2014), created an environment of potential competition between technologies, that was intensified by the utility behaviour. Thus, while at a global level other ocean-related energies are generally presented as complementary to wave and associated within the same vision (e.g. EU-OEA, 2010), in Portugal wind offshore emerged as a competitor, occupying the “ocean” space. This drove a change in niche trajectory, which is evolving in new direction (e.g. greater integration with the various “offshore” technologies and/or an insertion within the wider “ocean cluster”, with cross fertilization with other emerging ocean-based fields, such as marine biotechnology). This type of behaviour has been described for periods of disappointment after a “hype” (Konrad et al, 2012). Finally, developments at the landscape level – in this case the economic crisis - had an additional impact, influencing the behaviour of policy makers and regime actors, and generally reducing the resources available (Geels, 2013).

The strategy followed also had some problems with regard to the conduction of niche internal processes. In what concerns one critical niche process – learning - the excessive focus on foreign technology developers led to a relative neglect of local technology development, preventing the creation of a core set of technology-intensive companies that could support more locally grounded learning processes. This was compound by the fact that, with a few exceptions (mainly in the early periods), the engagement of established local companies in joint-ventures was a business investment, with limited involvement in technology development or in actual learning processes. Thus, the capacity for retaining some activity when foreign actors moved away and/or for absorbing results from experiments was limited, resting almost exclusively on the scientific community or the few entrepreneurs originating from it.

In what concerns another critical niche process – network creation - the absence of a core group of local actors (besides scientists) concerned with the development and local embedding of the technology made networks fragile, since they ended-up being largely composed of highly mobile foreign actors and regime actors. The engagement of the former with the niche

was based on a particular set of conditions and thus their allegiance was weak and they could always move elsewhere. The engagement of the latter was conjunctural and mostly associated with a generic interest in renewable energies. Once it became evident that more stabilised competitor technologies offered better opportunities and, particularly, when landscape developments introduced economic difficulties and forced a choice, they shifted to them. This limited engagement may also have implications for the quality and scope of learning processes.

Moreover, the strong presence of these two types of actors, may have favoured the formation of a hype. In fact, foreign technology developers had a vested interest in raising expectations, to improve the competitive position of their technologies (van Lente and Bakker, 2010), while regime actors had a limited knowledge of the field and thus were more vulnerable to inflated promises (Bakker and Budde, 2012). As a result, voicing of expectations become increasingly dissociated from project outcomes, creating the conditions for disappointment when results were very distant from (unrealistic) expectations (Geels and Raven, 2006). It also made “repair work” more difficult, at least in the medium-term, notwithstanding the efforts made by local niche advocates for translating generic lessons that transcended the scope of national experiences and imposing more long-term visions.

Interestingly, the only project that pursued has avoided several of these problems. Moreover, it effectively achieved, at a local dimension, some of the effects envisaged by policy makers: the local grounding of a foreign technology developer, the formation of a core network of supportive actors spanning two different locations, and the creation of a local value chain harnessing competences from declining sectors. This points to the relevance of local embeddedness (Coenen et al, 2010), which was largely overlooked in other experiments.

Finally, interactions between country and “overall niche” level are also relevant. As the wave niche evolved, structuring activities started taking place in supra-national networks (sometimes crystallised in collective organisations), resulting in higher-level agenda setting and vision building for the field (Geels and Raven, 2006). These were translated into the country level, namely by key local actors positioned in these networks, influencing local trajectories and visions. However, this translation of generic lessons and visions is not necessarily a linear process (Raven et al, 2011). In fact, contrary to the country niche, the global niche has shown to be quite resilient to disappointment: niche advocates retained the ability to attract attention and resources, despite frequent setbacks (EC 2014), even if it required reconfiguring visions and expectations and introducing some modifications in the trajectory (EU-OEA, 2010; Lewis et al, 2011). But these processes did not appear to have real impact at country level, when local learning produced very negative outcomes.

However, it should also be pointed out that when conditions at country level became particularly harsh, transnational networks played a key role in niche survival. They became the privileged locus of action for the core local actors, compensating for the decline of supportive networks at country level. They may also enable the incorporation of lessons from this particular combination of outcomes into generic lessons and cognitive rules at the overall niche level (Geels and Raven, 2006).

5. Conclusions

This paper proposed that technological niche formation and development is not necessarily a local process. Particularly in the case of complex systems - such as energy - it is likely to involve multiple interactions between different spatial levels, resulting in the development of an

"overall niche space" that transcends territorial boundaries. This space, far from being abstract, effectively encompasses the activities and interactions being enacted by a variety of actors in and between the diverse levels, which aim at stabilising the technology, articulating it with societal requirements and achieving niche breakout. Thus, even if the country level can be an important locus of activity - given specific natural endowments and institutional and political conditions – such activity is influenced by (and influences) the actions being performed at other locations and at an increasingly structured global niche level.

The analysis of the formation, early development and (transitory?) decline of the wave energy niche in Portugal confirmed that country niche development was shaped as much by local/national processes as by processes taking place at a diversity of spatial levels, which are strongly intertwined. It has namely shown that multi-spatial networks and learning processes were critical for the conduction of niche processes at country level.

But the research also showed that country niche evolution - and thus its potential impact on the overall niche trajectory - also depends on the way interactions with other spatial levels are integrated with, match and reinforce local processes. In particular, it uncovered the risks of excessive reliance on networks dominated by footloose actors - in this case highly mobile foreign technology developers and local regime actors, with own agendas and limited allegiance to the (local) niche – since this may weaken the already fragile coalitions typical of a technological niche (Raven et al, 2012). This reliance may also limit the extent of the learning processes, especially if it is not associated with the creation a stronger network of locally embedded actors that can both anchor footloose activities, and guarantee continuity in niche processes (Binz et al, 2012). Thus, the research suggests that the quality of interactions at different spatial levels and the attention to the way these effectively contribute to strengthen local/national processes is likely to be determinant. The way these country level processes unfold is not indifferent either from the perspective of the global niche development: given the extensive multi-spatial interconnections the outcomes of these processes are likely to extend beyond country boundaries, potentially influencing the overall niche trajectory.

These results, albeit still relatively exploratory, contribute to the on-going debate on the role of space in niche development and more generally in transition processes (Coenen et al, 2012, 2010; Raven et al, 2012). These conclusions need now to be further explored on the basis of more in-depth analysis of the processes that effectively took place, requiring a more precise understanding of the expectations, motivations and decisions of the various actors involved, which will be the objective of subsequent research. This research will also attempt to move beyond the country niche and explore the implications of the positive and negative outcomes of its trajectory for the overall development of the wave energy niche.

References

Bakker, S., Budde, B., 2012. Technological hype and disappointment: lessons from the hydrogen and fuel cell case. Technology Analysis & Strategic Management 24, 549-563.

Bento, M., Fontes, M., 2014. The construction of a new technological innovation system in a follower country: wind energy in Portugal, DRUID Society Conference 2014 on Entrepreneurship - Organization - Innovation, 16-18 June 2014, Copenhagen. [http://druid8.sit.aau.dk/druid/ acc_papers/iu4yovx915h0ceteo9d5nm961xvg.pdf]

Bergek, A., Berggren, C., Magnusson, T., Hobday, M., 2013. Technological discontinuities and the challenge for incumbent firms: Destruction, disruption or creative accumulation? Research Policy 42, 1210-1224.

Bergek, A., Jacobsson, S., Sandén, B.A., 2008. 'Legitimation' and 'development of positive externalities': two key processes in the formation phase of technological innovation systems. Technology Analysis & Strategic Management 20, 575-592.

Binz, C. Truffer, B., Coenen, L., 2014. Why space matters in technological innovation systems — Mapping global knowledge dynamics of membrane bioreactor technology. Research Policy 43, 138– 155.

Binz, C., Truffer, B. Li, L., Shi, Y., Lu, Y., 2012. Conceptualizing leapfrogging with spatially coupled innovation systems: The case of onsite wastewater treatment in China. Technological Forecasting and Social Change 79, 155–171.

Borup, M., Brown, N., Konrad, K., Van Lente, H., 2006. The sociology of expectations in science and technology. Technology Analysis & Strategic Management 18, 285–98.

Boschma, R., 2005. Proximity and innovation: A critical assessment. Regional Studies 39, 61-74.

Bulkeley, H., 2005. Reconfiguring environmental governance: Towards a politics of scales and networks. Political Geography 24, 875-902.

Coenen, L., Benneworth, P., Truffer, B., 2012. Towards a spatial perspective on sustainability transitions. Research Policy 41, 968– 979.

Coenen, L., Raven, B., Verbong, G., 2010. Local niche experimentation in energy transitions: A theoretical and empirical exploration of proximity advantages and disadvantages. Technology in Society 32, 295–302.

EC, 2014. Communication on Blue Energy - Action Needed to Deliver on the Potential of Ocean Energy In European Seas and Oceans by 2020 and Beyond. Brussels, European Commission, [http://ec.europa.eu/maritimeaffairs/policy/ocean_energy/documents/com_2014_8_en.pdf]

Elliot, G. and Caratti, G., 1994. 1993 European Wave Energy Symposium, Proceedings of an International Symposium held in Edinburgh, Scotland, 21-24 July 1993. Brussels, Commision of the European Communities and NREL – Renewable Energy (Scotland, UK).

EU-OEA, 2010. Oceans of Energy – European Ocean Energy Roadmap 2010 – 2050. Brussels, European Ocean Energy Association.

EU-OEA, 2013. Industry Vision Paper 2013. Brussels, European Ocean Energy Association [http://www.oceanenergy-europe.eu/index.php/en/communication/publications].

Falcão, A., 2010. Wave energy utilization: A review of the technologies. Renewable and Sustainable Energy Reviews 14, 899–918.

Geels, F., 2013. The impact of the financial–economic crisis on sustainability transitions: Financial investment, governance and public discourse. Environmental Innovation and Societal Transitions 6, 67– 95

Geels, F., 2005. Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective- Technological Forecasting & Social Change 72, 681–696.

Geels, F., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case study. Research Policy 31, 1257-1274.

Geels, F., Raven, R., 2006. Non-linearity and expectations in niche-development trajectories: ups and downs in Dutch biogas development (1973–2003). Technology Analysis & Strategic Management 18, 375-392.

Geels, F., Schot, J., 2007. Typology of sociotechnical transition pathways. Research Policy 36, 399–417.

Gertler, M.S., Levitte, Y.M., 2005. Local Nodes in Global Networks: The Geography of Knowledge Flows in Biotechnology Innovation. Industry and Innovation 12, 487-507.

Haan, J., Rotmans, J., 2011. Patterns in transitions: Understanding complex chains of change. Technological Forecasting and Social Change 78: 90–102

Hamawi, S., Negro, S.O., 2012. Wave energy in Portugal, the paths towards a successful implementation, Proceedings of the 4th International Conference on Ocean Energy, 17-19 October 2012, Dublin, Ireland.

Hekkert, M.P., Negro, S.O., 2009. Functions of innovation systems as a framework to understand sustainable technological change: Empirical evidence for earlier claims. Technological Forecasting and Social Change 76, 584-594.
Hoogma, R., Kemp, R., Schot, J. & Truffer, B., 2002. Experimenting for Sustainable Transport: The Approach of Strategic Niche Management. Spon Press, London and New York.
IRENA, 2014. Ocean Technologies - Technology readiness, patents, deployment status and outlook. International Renewable Energy Agency. [http://www.irena.org].
Jacobsson, S., V. Lauber, 2006. The politics and policy of energy system transformation - explaining the German diffusion of renewable energy technology. Energy Policy 34, 256-276.
Jeffrey, H., Jay, B., Winskel, M., 2013. Accelerating the development of marine energy: Exploring the prospects, benefits and challenges. Technological Forecasting and Social Change 80, 1306–1316.
Kaldellis, J.K., Zafirakis, D. (2011) The wind energy (r)evolution: A short review of a long history. Renewable Energy 36, 1887-1901.
Kemp, R., Schot, J., Hoogma, R., 1998. Regime shifts to sustainability through processes of niche formation. The approach of strategic niche management. Technology Analysis and Strategic Management 10, 175–95.
Kern, F., Smith, A., 2008. Restructuring energy systems for sustainability? Energy transition policy in the Netherlands. Energy Policy 36 4093–4103.
Kern, F., Smith, A.G., Shaw, C., Raven, R.P.J.M., Verhees, B., 2014. From laggard to leader : explaining offshore wind developments in the UK. Energy Policy 69, 635-64.
Kolk, A., Lindeque, J. van den Buuse, D., 2014, Regionalization Strategies of European Union Electric Utilities. British Journal of Management 25, S77-S99.
Konrad, K., Markard, J., Ruef, A., Truffer, B., 2012. Strategic responses to fuel cell hype and disappointment. Technological Forecasting & Social Change 79, 1084–1098.
Lawrence, J., Sedgwick, J., Jeffrey, H., Bryden, I., 2013. An overview of the U.K. marine energy sector. Proceedings of the IEEE 10, 876 – 890.
Lewis, A., Estefen, S. Huckerby, J., Musial, W., Pontes, T., Torres-Martinez, J., 2011. Ocean Energy, in IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Cambridge, Cambridge University Press.
Løvdal, N., Neumann, F., 2011. Internationalization as a strategy to overcome industry barriers: An assessment of the marine energy industry. Energy Policy 39, 1093-1100.
Mautz, R., 2007. The expansion of renewable energies in Germany between niche dynamics and system integration – Opportunities and restraints. Science, Technology & Innovation Studies 3, 113-131.
OES, 2002-2012. Annual Report of the Implementing Agreement on Ocean Energy Systems, Executive Committee of Ocean Energy Systems. [http://www.ocean-energy-systems.org/oes_reports/annual_reports/]
Raven, R. Verbong, G., Schilpzand, W., Witkamp, M., 2011. Translation mechanisms in socio-technical niches: a case study of Dutch river management. Technology Analysis & Strategic Management 23, 1063-1078.
Raven, R., 2006. Towards alternative trajectories? Reconfigurations in the Dutch electricity regime. Research Policy 35, 581–595.
Raven, R., 2007. Niche accumulation and hybridisation strategies in transition processes: towards a sustainable energy system. Energy Policy 35, 2390-2400
Raven, R., Schot, J., Berkhout, F., 2012. Space and scale in socio-technical transitions. Environmental Innovation and Societal Transitions 4, 63– 78
REN21, 2010-2013. Renewables Global Status Report (GSR), Renewable Energy Policy Network for the 21st Century. http://www.ren21.net/REN21Activities/GlobalStatusReport.aspx

Sandén, B.A., Hillman, K.M., 2011. A framework for analysis of multi-mode interaction among technologies with examples from the history of alternative transport fuels in Sweden. Research Policy 40, 403–414.
Schot, J., Geels, F.W., 2007. Niches in evolutionary theories of technical change: A critical survey of the literature. Journal of Evolutionary Economics 17, 605–622.
Schot, J., Geels, F.W., 2008. Strategic niche management and sustainable innovation journeys: Theory, findings, research agenda, and policy. Technology Analysis & Strategic Management 20, 537–554.
Sine, W., David, R.J., 2003. Environmental jolts, institutional change, and the creation of entrepreneurial opportunity in the US electric power industry. Research Policy 32, 185-207.
Smink, M., Hekkert, M., Negro, S., 2013. Keeping sustainable innovation on a leash. Exploring incumbents' institutional strategies. Business Strategy and the Environment, DOI: 10.1002/bse.1808.
Smith, A., 2007. Translating sustainabilities between green niches and socio-technical regimes. Technology Analysis & Strategic Management 19, 427-450.
Smith, A., Raven, B., 2012. What is protective space? Reconsidering niches in transitions to sustainability. Research Policy 41, 1025– 1036.
Smith, A., Stirling, A., Berkhout, F., 2005. The governance of sustainable sociotechnical transitions. Research Policy 34, 1491-1510.
Spath, P., Rohracher, H., 2012. Local demonstrations for global transitions - Dynamics across governance levels fostering socio-technical regime change towards sustainability. European Planning Studies 20, 461-479.
Van Lente, H., and Bakker, S. . 2010. Competing expectations: The case of hydrogen storage technologies. Technology Analysis & Strategic Management 22, 693–709.
Verbong, G., Geels, F., 2010. Exploring sustainability transitions in the electricity sector with socio-technical pathways. Technological Forecasting & Social Change 77, 1214-1221.
Verbong, G., Geels, F., Raven, R., 2008. Multi-niche analysis of dynamics and policies in Dutch renewable energy innovation journeys (1970-2006). Technology Analysis & Strategic Management 20, 555-573.
Verhees, B., Raven, R., Veraart, F., Smith, A., Kern, F., 2013. The development of solar PV in The Netherlands: A case of survival in unfriendly contexts. Renewable and Sustainable Energy Reviews 19, 275–289.
Wagner, C.S., Leydesdorff, L., 2005. Mapping the network of global science: comparing international co-authorships from 1990 to 2000. International Journal of Technology and Globalisation 1, 185–208.