Environmental Innovation and Societal Transitions 15 (2015) 158–179

Contents lists available at ScienceDirect

Environmental Innovation and Societal Transitions

journal homepage: www.elsevier.com/locate/eist

Spatial diffusion and the formation of a technological innovation system in the receiving country: The case of wind energy in Portugal

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ARTICLE INFO

Article history:
Received 21 April 2014
Received in revised form 23 October 2014
Accepted 28 October 2014
Available online 25 December 2014

JEL classification:
L2
O33
O38
Q42
Q55
R11

Keywords:
Absorptive capacity
Spatial diffusion
Technological innovation systems
Wind energy

ABSTRACT

This paper investigates how energy technologies diffuse spatially through the examination of wind growth in Denmark (core) and Portugal (follower). The research draws on the empirical historical scaling dynamics to compare patterns of diffusion, and proposes an explanation for these patterns with the help of the technological innovation systems (TIS) theoretical framework. The analysis uncovered an acceleration of diffusion when the technology attained the new market. The mechanisms that allowed rapid adoption were found to be, among others, transnational linkages and an improved absorptive capacity. The latter benefited from past investments in knowledge development, imports of state-of-the-art technology and construction of a local industry assembling available competencies. Targeted policies (e.g. tender-based feed-in scheme) were effective to stimulate technology transfer and boost diffusion. The linkages with the global TIS and the concept of absorptive capacity improve the understanding of the processes involved in the formation of a TIS in receiving countries.

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http://dx.doi.org/10.1016/j.eist.2014.10.003

1. Introduction

The diffusion of low carbon technologies across regions is essential to tackle climate change in the years to come (IPCC, 2014). In the last decade, the electricity sector has witnessed a spectacular investment increase in renewable energy sources, especially wind energy. The global cumulative installed capacity of wind power has reached 282 GW in 2012 (GWEC, 2013), generating 521 TWh, or 2.3% of total gross electricity consumption (BP, 2013). Even though China leads in terms of installed capacity (around 70 GW), the majority of wind plants are still located in OECD countries.

The objective of this paper is to contribute to our understanding of the process of spatial diffusion of wind energy technologies and how it can lead to the development of more sustainable energy systems. It addresses a case of diffusion from a pioneer country (Denmark) to a fast follower one (Portugal), comparing the development of wind energy in both countries and analyzing the processes that enabled fast technology development and the building-up of a wind energy system in the latter. Denmark clearly assumed the leading role in technology developments in the 1990s (see Garud and Karnøe, 2003; Karnøe and Garud, 2012; Bergek and Jacobsson, 2003; Kamp et al., 2004; Neij and Andersen, 2012), especially after the unsuccessful commercialization of early multi-megawatt wind power plants in the previous decade in the US and Germany (Gipe, 1995). A variety of knowledge and technological exchanges took place between Portugal and Denmark since the early stages, even if other countries like Germany also became suppliers of technology and know-how later in the process.

Portugal is an interesting case of study, not only given the speed of wind energy penetration, but also for the modes it assumed. On the one hand, wind energy registered a remarkable growth in the past decade, becoming the second most important renewable energy source after hydropower. In 2011, it produced 17.2% of total electricity consumption, the second highest share among OECD countries, only surpassed by Denmark (EWEA, 2013; DGEG, 2013). On the other hand, the application of a mix of demand "pull" and supply "push" policies resulted in the formation of an industrial cluster and ultimately in a national incorporation of inputs that reached 100% (with exports representing more than 60% of production, cf. Público, 2011). This case reasserts the conclusions of previous studies that pointed to the role of home markets for industry expansion in renewable energy technologies (Lund, 2009; McDowall et al., 2013). Yet, there is still limited knowledge about the process of emergence and development of wind energy in Portugal, which may offer some lessons on the factors that can lead to rapid diffusion of renewable energy technologies in follower countries.

In order to conduct this analysis, the paper draws on the literature that addresses the emergence and growth of new energy technologies, in particular recent conceptualizations that give an increasing attention to the spatial dimension of these processes. It makes use of contributions from historical scaling dynamics analysis (Wilson, 2009; Grubler, 2012) to reveal patterns that are then discussed with the help of theories and concepts from the technological innovation systems literature (Bergek et al., 2008a; Hekkert et al., 2007, 2011).

The diffusion of several energy technologies is well documented by the historical scaling dynamics analysis (Wilson, 2012, 2009; Grubler, 2012), which found strong patterns of market growth in and across regions. This approach centers on the analysis on technology scaling, i.e. technological growth that is both rapid and extensive and occurs at multiple levels: the technology unit size and the industry as a whole (Wilson, 2012). One important contribution of the historical analysis concerns the patterns of international diffusion: it uncovered an acceleration of growth rates when energy technologies move from the initial markets and start diffusing in new regions, i.e. diffusion is faster in subsequent markets (see Grubler, 2012, 1998).

The Technological Innovation Systems (TIS) literature addresses the emergence of new technologies from a systemic perspective, as a process of formation and development of a new innovation system. In contrast with the previous approach, more centered on the technology, it investigates the evolution of the structure in terms of actors, networks and institutions, as the technology evolves over time (Carlsson and Stankiewicz, 1991; Bergek et al., 2008a; Jacobsson and Bergek, 2012). More recent theoretical developments added the notion of core processes or functions of the innovation system that are decisive for the performance of the emerging TIS (Bergek et al., 2008a; Hekkert et al., 2007). Thus the TIS provides a more encompassing framework that permits to *explain* the empirical patterns identified by the historical scaling analysis, offering the theoretical instruments to understand the processes that underlay the development, diffusion and use of innovations.

One of the advantages of the TIS theoretical framework is that it views technology emergence and growth as a global process that transcends sectoral and geographical boundaries (Carlsson and Stankiewicz, 1991; Bergek et al., 2008a). However the majority of empirical studies tends to concentrate on the national level, overlooking the interactions between different regions (Markard et al., 2012; Coenen et al., 2012). That is, they tend to ignore that the formation of a TIS in a given country receives extensive external influences. In this paper, the TIS approach is mobilized in the perspective of Markard and Truffer (2008), considering the local innovation system as part of a global TIS, which influences its formation and growth.

The paper extends the very recent empirical research on the treatment of space in the TIS (Binz et al., 2014, 2012; Vasseur et al., 2013), by looking at the process of diffusion as it unfolds when the technology reaches enough maturity to spill over from the initial markets and start moving into new regions. Furthermore, it examines the relationships between the different regions along this process, and investigates how the performance of system functions in the "receiving" region influences the process of diffusion. This analysis offers new insights on how transnational interactions can contribute to accelerate the formation of a local TIS, enabling the country to rapidly seize the opportunity to participate in a growing market (Lee, 2009; Markides and Geroski, 2005).

The empirical research centers on the spatial diffusion of wind energy technologies, analyzing the development of wind energy in Portugal and comparing it with that of Denmark, in order to answer the following questions: how do energy technologies such as wind power evolve spatially? Which processes take place, as part of the formation of a TIS, that enable a country to bring about rapid transfer of the technology and become a fast follower?

The paper is organized as follows. Firstly, the conceptual framework is presented. Secondly, the methodology and data sources are explained. Thirdly, the spatial diffusion of wind energy from a core country – Denmark – to a fast follower country like Portugal is examined, by analyzing diffusion dynamics and the mechanisms involved in the process.[1] The understanding of the determinants of spatial growth of wind power to a fast adopter country will allow a better design of strategies that can be used to promote the widespread adoption of low carbon technologies.

2. Emergence of new energy technologies and spatial diffusion

Two approaches have recently appeared in the literature that aims to understand the process of emergence and growth of new technology systems. The first is the technological innovation system (Bergek et al., 2008a; Hekkert et al., 2007, 2011) that comes from the more theoretical field of socio-technical transitions (Markard et al., 2012). The second is the recent historical scaling dynamics analysis (Wilson, 2012, 2009) which comes from the tradition of applied systems analysis (Grubler, 2012, 1998).

2.1. Technological innovation systems

2.1.1. Conceptual model: structural and functional dimensions

The model of Technological of Innovation Systems (TIS) focuses on the emergence of novel technologies and the institutional and organizational changes that are needed for the formation and growth of the new technology system (Markard et al., 2012). Innovation is understood as an interactive process involving a network of actors (e.g., firms, users), who act within a particular context of institutions and policies that influence technology development, adoption behavior and performance, and who bring new products, processes and organization structures into economic use (Carlsson and Stankiewicz,

[1] In this paper, terms such as core, center and pioneer, are used as synonymous for markets of first commercialization; whereas (fast) followers refer to the countries that adopt the new technology after the former group. The latter countries are normally (but not exclusively) found among OECD countries other than G7, intermediate economies, or even economies in process of catching up with developed ones.

1991; Bergek et al., 2008a; Jacobsson and Bergek, 2012). This definition highlights the three main elements constituting the structure of the new technology system (Bergek et al., 2008a; Jacobsson and Bergek, 2004): actors, networks and institutions. *Actors* include firms and other organizations (e.g. universities, industry associations) along the value chain (Bergek et al., 2008a). *Networks* are the result of links established between fragmented components to perform a particular task (e.g., learning and knowledge creation and diffusion, standardization and market formation, political and advocacy coalitions). *Institutions* consist of formal rules (e.g., laws and property rights) and informal norms (e.g. tradition and culture) that structure political, economic and social interactions (North, 1990). Institutions have three roles in innovation systems (Edquist and Johnson, 1997): to reduce uncertainty by providing information; to manage conflicts and promote cooperation; and to provide incentives for innovation.

In addition to the structural view presented above, this approach also considers the evolution of the functional dimension of the innovation system (Hekkert et al., 2007; Markard et al., 2012). The literature on TIS focuses on a set of processes, or functions, that are required for the innovation system to start, grow and gain momentum.[2] Bergek et al. (2008b) identified eight key *functions of innovation systems* that support the development, dissemination and use of a new technology.[3]

Development of formal knowledge concerns the way knowledge is developed, diffused and combined in the system, in order to create a knowledge base. *Entrepreneurial activities* relate to the development of a more applied, tacit and explorative knowledge, through the conduction of technical experiments or testing of new markets and applications. *Materialization* refers to the investment in artifacts such as products, factories and physical infrastructures. *Influence on the direction of search* refers to the capacity to attract new supply-side actors and to direct their search and investments toward the TIS. *Market formation* involves the articulation of demand around increasingly organized markets, from demonstration projects to niche markets and, if successful, to large-scale diffusion. *Resource mobilization* refers to how the TIS is capable of attracting human capital, financial capital and other complementary assets from other sectors. *Legitimation* comprises the process of formation of expectations and visions (including the action of advocacy coalitions) as well as alignment of regulation through mechanisms such as market regulations, economics instruments or science and technology policy. *Development of positive externalities* provides insights about the strength of the collective dimension of the TIS, and the dynamics of the system in terms of the extent to which the other functions contribute to the generation of positive externalities.

Previous research on the formation of energy technology innovation systems (e.g., wind, solar, biomass) has called the attention to three important features of change. Firstly, a small number of functions emerged as particularly relevant for sparking system dynamics: “legitimacy”, “influence on the direction of search” and “market formation” (Hekkert and Negro, 2009; Hekkert et al., 2007). It is argued that the first helps to align institutions to the needs of agents and technologies, whereas the second and the third are important for raising entrepreneurial activities. Secondly, key system functions are likely to change over time, with knowledge development and direction of search being crucial in the earliest formative period, whereas market formation become important in a more advanced stage of TIS formation (Bergek et al., 2008a). Thirdly, interactions between functions – also called ‘motors’ of innovation (Suurs and Hekkert, 2009) – may lead to “virtuous cycles” that accelerate system emergence and growth (Hekkert and Negro, 2009). This is likely to happen later in the formative phase, when more functions are fulfilled, leading to stronger internal dynamics and to system growth.

[2] Bergek et al. (2008a) distinguish between a formative phase and a growth phase. The formative phase is when “... constituent elements of the new TIS begin to be put into place, involving entry of some firms and other organizations, the beginning of an institutional alignment and formation of networks.” (p. 419), while in the growth phase “... the focus shifts to system expansion and large-scale technology diffusion through the formation of bridging markets and subsequently mass markets.” (p. 420).

[3] Researchers at Utrecht University have developed an alternative list of innovation functions that is relatively close to the one used in this paper (see Hekkert et al., 2007).

2.1.2. Spatial dimension

The TIS approach has the advantage of moving beyond sectoral and geographical boundaries to analyze how a technology develops, diffuses and is used (Hekkert et al., 2007; Bergek et al., 2008a). This means that the process of construction of a TIS at country level can be conceptualized as part of a larger, 'global' TIS development (Markard and Truffer, 2008). However, most empirical studies have tended to concentrate on the national level (Coenen et al., 2012; Markard et al., 2012), and only recently this spatial dimension has started being integrated explicitly in the TIS analysis.

The treatment of space in TIS was done through the analysis of the national TIS as a subsystem of the international TIS, which includes globally operating actors as in the "geography of transitions" (Binz et al., 2012). Another approach focused on transnational linkages, involving technology, actors, knowledge, etc., which allow the mobilization of local as well as international capabilities (Wieczorek et al., 2013). The transnational contacts established between different TIS levels and the resulting activities have namely been associated to system functions (Vasseur et al., 2013; Gosens et al., 2015). These attempts to include space in TIS have offered new contributions, by uncovering mechanisms that have an important role in the growth of innovation systems, as well as by enabling the identification of "prime movers" (Jacobsson and Johnson, 2000; Markard et al., 2011), who are decisive for the fulfillment of the early formative processes (e.g. creation of formal knowledge, entrepreneurial experimentation, etc.).

The integration of the spatial dimension in the TIS analysis opens a promising research avenue in what concerns an understanding of the diffusion of technology across regions, in particular the processes that occur when technology achieves enough maturity to spillover from the initial markets and start diffusing in new regions. Firstly, because it allows the contextualization of transition studies at different spatial and institutional levels (e.g. local structures or global networks) (Coenen et al., 2012). Secondly, because it permits to take into account differences between regions in what concerns the stage of development of the TIS, and to assess how this affects the process of technology transition. Finally, because it enables the analysis of actors' strategies (e.g., creation of networks) to stimulate the transfer of a successful innovation (Wieczorek et al., 2013; Markard et al., 2011).

2.2. Patterns and drivers of the historical growth of energy technologies

A more empirical literature, which comes from the tradition of diffusion of innovations and system analysis (Rogers, 1995; Grubler, 2012, 1998), analyzed the historical diffusion of several energy technologies, focusing on the effect of scaling to draw lessons about technology development (Wilson, 2012; Wilson and Grubler, 2011). Scaling refers to the growth that is both rapid and extensive, as well as occurs at multiple levels of individual technologies (increases of unit scale like larger turbines) and of entire industries (industry scale) (Wilson, 2012). The substantial cost reductions permitted by economies of scale following technology scaling-up further drives the dynamics of energy transition. This methodology enables the analysis of patterns of diffusion over time and spatially, through the study of technology scaling.

The importance of scaling in the past diffusion of technologies has been widely demonstrated in Wilson (2012, 2009) and Wilson and Grubler (2011). Firstly, it has been shown that the speed of diffusion is influenced by market size, so that innovations with a higher potential should take longer to diffuse. Secondly, previous analyzes of several energy technologies have revealed that growth typically evolves in a three-phase sequential process (cf. Wilson, 2012): formative phase, unit scaling and growth phase. The *formative* phase is normally a long period of experimentation and learning with small unit-scale technologies but a diversity of designs and producers. The technology improves over the period in terms of costs, performances and designs, which tend to stabilize into a small number of technology design(s) that became standard(s). The *up-scaling* phase (in case scaling is technologically feasible) is characterized by the rapid increase of the size of individual technologies in order to significantly lower costs by the effect of economies of scale, until the gains saturate as the technology approaches the scale frontier. Finally, the technology enters into a period of industry *growth* and globalization, when there is an increase in the sales of large unit-scale technologies in the first markets. The growth of the industry allows further cost reductions through economies of scale in manufacturing, leading to consolidation and concentration of production in larger firms that have cost advantages. When the first signs of market saturation in the innovation core appear, further industry growth is driven by diffusion in other regions.

Thirdly, the analysis of international patterns of diffusion pointed to an acceleration of growth rates as innovation penetrates into new areas (Wilson, 2012; Grubler, 1998; Bento, 2013). In other words, the rhythm of penetration becomes faster as the new technology transits from initial to subsequent markets – the diffusion in new regions enlarges the market potential and improves the technology attractiveness by continually reducing costs and improving performances, but typically saturates more rapidly requiring the expansion to the next, more peripheral areas, before the technology reaches global saturation.[4]

The fact that new technologies (get out from the core and) start diffusing abroad when they become sufficiently mature may explain why adoption is faster in the subsequent markets, as they benefit from the learning investments previously made by the lead countries in R&D and in early deployment of the technology (Perkins and Neumayer, 2005; Nemet, 2009). Indeed, other regions take advantage of the knowledge and technology spillovers created during the previous diffusion in the core (Jaffe, 2005). The literature of international diffusion and economic catching-up shows that the typical channels for international technology transfer after the post-war have been capital imports, foreign direct investment (FDI) and licensing (Mowery and Oxley, 1995; Mowery et al., 1996; Keller, 2010). Keller (2010) emphasizes the role of international trade and FDI in the capture of technology spillovers. In this perspective, the local capacity to exploit these externalities can be enhanced by importing technology or with the physical presence of international companies.

However, international technology diffusion is not automatic from the existence of a knowledge base in the core, but requires the recipient to have the capacity to absorb and assimilate such technology in order to take the maximum benefit from it (Mowery and Oxley, 1995; Teixeira and Fortuna, 2010). The term “absorptive capacity” was coined by Cohen and Levinthal (1989, 1990) in order to designate the ability of organizations (and ultimately their countries) to exploit external knowledge.[5] At the macro level, enhancing local absorptive capacity refers to the institutional and organizational changes that are needed to adopt more rapidly new technologies (Fagerberg and Godinho, 2005; Mowery and Oxley, 1995).

This concerns particularly the ability to absorb external knowledge and the efficient use of imported technology in traditionally laggard countries, such as Portugal, which depends on a minimum level of human capital and of local R&D efforts (Teixeira and Fortuna, 2010). It is also subject to non-technological factors related with the social and institutional set-up of the country (Caragliu and Nijkamp, 2012), and the way these enable or constrain the development of a coherent and integrated innovation system. These socio-technical processes are extensively dealt with by the TIS literature, as we saw above.

The concept of absorptive capacity has also been applied in the TIS context in terms of the construction of capacity needed to transfer and implement a new technology in the receiving country (cf. Van Alphen, 2011), with repercussions for the nature of system functions. This was namely the case of knowledge development, which became more centered on the creation of domestic conditions for the implementation of a new technology, namely through the absorption of imported technology and its adaptation to local needs.

[4] A similar conceptualization of innovation growth by phases was suggested by Bergek and Jacobsson (2003) in their study of the emergence and growth of the wind innovation system in Germany, Sweden and The Netherlands: “The first [stage] is characterised by substantial technological variety (and uncertainty), underdevelopment of the market and entry of many firms. The second is characterised by a considerable turbulence, driven by rapid growth in the market and an up-scaling of the turbines (corresponding to a set of minor technological discontinuities), as well as by many exits but also some new entrants, including some larger firms. [...] we will therefore distinguish between a phase of experimentation (roughly 1975–1989) and one of turbulence and growth (roughly 1990–1999).”

[5] The authors point out that “...while R&D obviously generates innovations, it also develops the firm’s ability to identify, assimilate, and exploit knowledge from the environment...” (Cohen and Levinthal, 1989, p.565). See Todorova and Durisin (2007) and Zahra and George (2002) for more refined models of firms’ absorptive capacity comprising recognition of the value, acquisition, transformation/assimilation, and exploitation of external knowledge and Narula (2004) and Criscuolo and Narula (2008) for an attempt to extend the concept to the national and “innovation system” level. Empirical studies are surveyed in Lane et al. (2006), Volberda et al. (2010) and Ebers and Maurer (2014).

The above discussion suggests that a more "spatialized" technological innovation systems perspective can provide an appropriate conceptual framework to address and explain the patterns uncovered by the historical analysis of diffusion. The TIS approach permits to move beyond an explanation for the acceleration of diffusion largely focused on the stage of development of the technology,[6] to one that centers on an understanding of the core activities that allow the rapid construction of a successful innovation system in the receiving country. That is, the TIS approach permits to uncover the mechanisms that intervene in the adoption of a new technology by the follower and in the building up of a local innovation system.

3. Methodological issues

This research aims to analyze patterns of spatial diffusion and explaining them with the help of concepts issued from the technological innovation systems literature (Markard et al., 2012; Bergek et al., 2008a; Hekkert et al., 2007, 2011). Instead of studying the strategies pursued in core countries only (e.g. Garud and Karnøe, 2003; Kamp et al., 2004; Hendry and Harborne, 2011; McDowall et al., 2013), our analysis examines the conditions under which rapid transfer of technology is possible from the core to other regions.

The paper compares the case of wind development in two countries: Denmark (representing the "core" of the innovation) and Portugal (a "fast follower" country). The comparison of the dynamics of growth of wind energy in these two countries may reveal historical patterns, providing a ground for a discussion on the possible determinants of spatial technological diffusion.

The diffusion analysis applies the historical scaling methodology developed in Wilson (2009) and Wilson and Grubler (2011). Logistic growth models are used to fit actual numbers – either in turbine size and in installed capacity – and to (eventually) distillate historical patterns in the growth of wind power (Grubler, 1998, 2012; Marchetti and Nakicenovic, 1979). These functions estimate key parameters of diffusion that can be compared across countries: saturation level (K); the inflection point (t_0 coinciding with the point of maximum growth, i.e. F50%); and the duration of growth (Δt referring to the time length between F10% and F50%).

Drawing on this evidence, the paper uses the TIS framework to investigate the processes at work over time, in order to provide an explanatory account of the fast development of installed capacity in the follower country. First, the formation of the structural components of the wind TIS in Portugal is examined in terms of the evolution of the configuration of actors, networks and institutions over time. Second, the fulfillment of key processes is mapped through the identification of main events and their organization around system functions. Particular emphasis is put on the processes that enabled the identification, acquisition, assimilation and transformation of external technology, i.e. promoted (domestic) absorptive capacity.

For this purpose the paper uses the set of system functions elaborated by Bergek et al. (2008b), which is expanded to comprise international aspects (Binz et al., 2012), and allocates specific activities to each function, using a number of indicators, as suggested by Vasseur et al. (2013). Table 1 presents the functions and respective indicators, distinguishing between processes taking place mostly at national level and those that result from transnational linkages with the global TIS (Gosens et al., 2015). The definition of the national indicators builds on Gosens et al. (2015) "domestic system activities", adapting them to the Portuguese wind energy system. This includes activities that contribute to increase the country's capacity to identify, absorb and transform knowledge or technology obtained through international flows. For instance, development of human capital and local R&D efforts are allocated to resource mobilization and development of formal knowledge, respectively, as part of the country level activities. In order to introduce the international dimension, transnational linkages (e.g. trade in equipment, foreign direct investment, international joint ventures, international research cooperation, and participation in international scientific conferences, see Binz et al., 2012)

[6] Indeed the experience of transfer of wind technology to California in the 1980s (Kamp et al., 2004) has shown that the level of maturity of the technology is not enough to drive a successful energy transition in the local market. We thank an anonymous reviewer for highlighting this point.

Table 1
National and international indicators per TIS functions.

System function	National indicators	International linkage indicators
F1. *Development of formal knowledge*	R&D projects National knowledge exchange (e.g. workshops, conferences, joint projects)	International knowledge exchange (e.g. workshops, conferences, joint projects) Trade in equipment, licenses, patents, technical consulting
F2. *Entrepreneurial experimentation*	Studies, demonstration pilots, field trials	Transferability and imitability of foreign technology Shortcutting typical experimentation times with mature technology
F3. *Materialization*	New factories opened by domestic firms	Foreign direct investment, joint ventures, relocation decisions, merger and acquisitions Strategy of international manufacturers in domestic industry
F4. *Influence on the direction of search*	Perspectives of profits in the future for the new technology vs. conventional New entrants in the market	Selection of foreign technologies that better fits domestic needs Degree of preference for foreign or domestic manufacture
F5. *Market formation*	Unit numbers, installed capacity	Share of domestic and foreign companies in the market
F6. *Resource mobilization*	Financial capital, human capital, complementary assets	Foreign direct investment, venture capital, international banking sector Access to European funds
F7. *Legitimation*	Recognition of societal benefits of the technology Formation of advocacy coalitions and lobbying activities Direction of science and technology policy Regulatory and fiscal instruments (e.g. FIT)	Domestic policy vs. international trade regimes (WTO, EU) International technology growth and legitimation
F8. *Development of positive externalities*	Cost reductions Strength of political networks	Improvements in foreign technology's performance and costs

are transformed into indicators, which are allocated to the relevant system functions (Vasseur et al., 2013; Gosens et al., 2015), as shown in Table 1. For instance: international research collaboration is an indicator for formal knowledge development; the selection of foreign technologies that better fits domestic needs provides direction of search; strategies of international manufacturers for the domestic industry, which lead to foreign direct investment or joint ventures with local companies, are an indicator of materialization; private foreign investment or access to European funds are indicators of resource mobilization.

This framework is applied to the analysis of the process of formation and maturation of the wind energy system in Portugal, drawing on qualitative and quantitative data collected from a variety of documentary sources (e.g., official statistics, policy documents, newspapers and specialized magazines, industry documents). In addition, key actors of the wind and energy sector in Portugal, from industry (e.g. equipment manufacturers, developers, electricity producers), academia and government agencies were interviewed. The information thus obtained permits to trace the evolution of the structure of the innovation system, identifying main events and key actors.

The main sources of data for the time series (e.g. on installed capacity, wind electricity production, investment costs) were official statistics published by organizations such as International Energy Agency (IEA), Danish Energy Agency, Portuguese National Institute of Statistics, Portuguese Directorate-General for Energy and Geology (DGEG), and Global Wind Energy Council (GWEC).

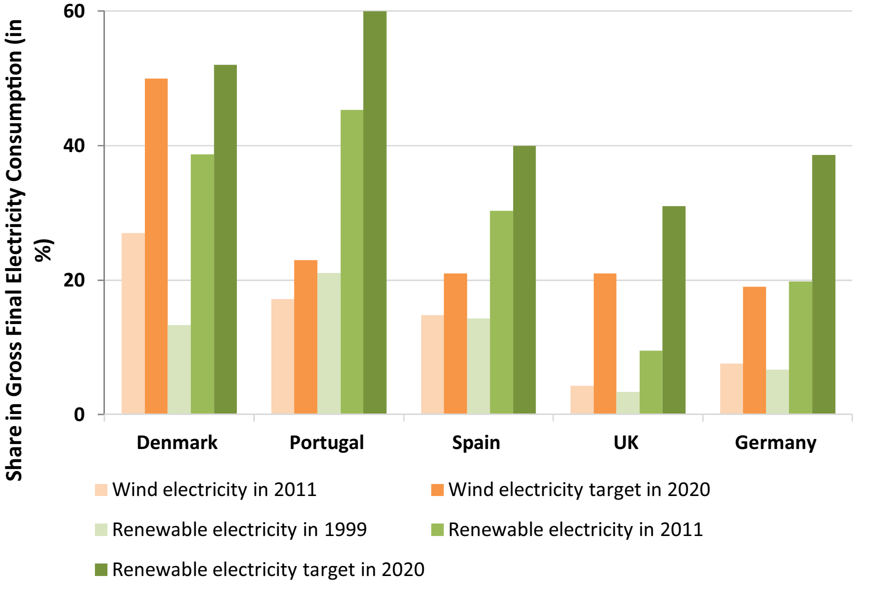

Fig. 1. Shares and targets of renewable electricity and wind power in gross final electricity consumption in top wind countries in the EU.
Sources: DGEG (2013, p.12); National Renewable Energy Action Plans (NREAPs) of the European Member States: Beurskens et al. (2013, Table 3 and 10a/b); Ren21 Map <http://map.ren21.net> (accessed in September 17, 2013); Plano Nacional de Acção para as Energias Renováveis (PNAER in Resolução do Conselho de Ministros no. 20/2013, 10 April).

4. Spatial diffusion of modern wind energy: the case of Portugal

4.1. The diffusion of wind power in a fast follower context

This section examines the growth of wind technologies in a rapid second adopter country: Portugal. The country's involvement in renewable energies was triggered by the signature of the Kyoto Protocol and the subsequent "Renewables Directive" (2001/77/CE, 27 September) which established, for Portugal, the target of 39% for electricity produced from renewable energy sources in gross electricity consumption by 2010. In 2001, the government approves the E4 Program (Energy Efficiency and Endogenous Energies) aiming to double the installed capacity of endogenous energies, in a horizon of 10–15 years. This included the installation of 2500 to 3000 MW of wind capacity by 2010. Wind was chosen since, by the time, it was much more advanced and cheaper than alternative renewable technologies, such as solar photovoltaics (Castro, 2011). To achieve that goal, the government introduced a very attractive remuneration for renewable sources and simplified the administrative procedures for the connection of new capacity.

The diffusion of wind power in Portugal was rapid and impressive, as most of the wind turbines were deployed after 2000. The growth in wind capacity kicks off in 1999, when it was as low as 58 MW, doubling in average every other year. The installed capacity reached 4364 MW (21% of total capacity) in 2011 (DGEG, 2013). As a result, the part of wind in total electricity consumption has been increasing to reach 18% in 2012 (DGEG, 2013). This is the second highest in Europe (only surpassed by Denmark), and was decisive to raise the share of renewable energies in final electricity consumption from 21.1% in 1999 to 45.3% in 2011, which is also one of the highest in Europe (Fig. 1).

The comparison of the patterns of wind power growth in Portugal and in Denmark (representing the "core") is presented in Fig. 2. The raise in total installed capacity takes off in the former when diffusion was well advanced in the latter (i.e. around 40% of saturation). However, the speed of deployment accelerates when the technology enters into the Portuguese market. The adoption lag can be measured

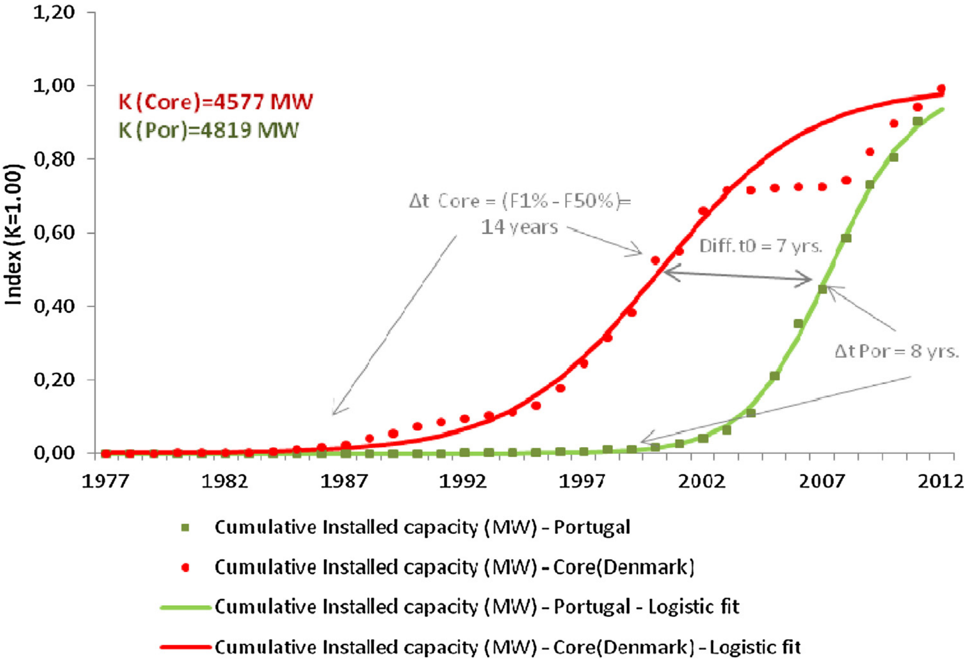

Fig. 2. Historical evolution of total cumulative installed capacity of wind power in Portugal and Denmark (1977–2012), indexed to the estimated saturation (K = 1.00).
Source: DGEG (2013), Spliid (2013).

by the difference in the inflection points (F = 50% coinciding with the year of maximum growth) of the logistic curves fitting actual growth in the two countries. In these terms, the delay of adoption from Denmark (core) to Portugal was only 7 years, which is very fast comparing to the spatial diffusion of other energy technologies in developed countries in the past (Grubler, 2012; Bento and Fontes, 2013a). Furthermore, the diffusion took 8 years in Portugal, whereas it had taken 14 years in Denmark (see differences in Δt). The reasons for a faster growth in the receiving country are analyzed more in detail in the following sections.

More than 500 MW of wind power were installed annually in Portugal in the period between 2004 and 2009. At the same time, wind turbine prices were raising everywhere (Fig. 3), in spite of the declining cost trajectories predicted by the learning curve theory and observed in the previous decades (Grubler, 2012). This reflected a general movement at international level, due to the joint effect of a surge in demand for wind turbines and the raise of production costs motivated by increasing labor and materials prices and profit margins (Bolinger and Wiser, 2012). Still, the increase in the remuneration of electricity generated from wind in Portugal more than compensated the rise in costs, guaranteeing the profitability of wind farms.

4.2. *Comparative analysis of spatial patterns of diffusion*

A new technology typically progresses in the core and spills over when it is competitive enough to start diffusing in other regions. The moment when the technology leaves the core (before or after up-scaling) is investigated below, for the case of wind power. Yet the implementation of units of a larger size in the subsequent markets always requires the availability of local resources (e.g. human, financial, knowledge). The speed of scaling is therefore an indicator of the rhythm of absorption, diffusion and use of the innovation in these new markets, whose emergence can be explained with the TIS literature.

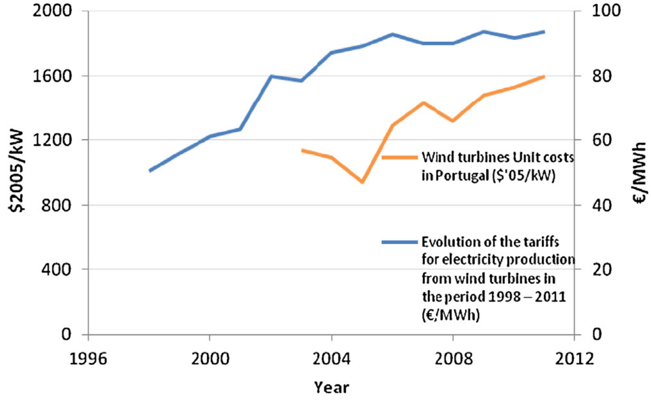

Fig. 3. Evolution of average wind turbines costs and tariffs for wind power in Portugal between 1998 and 2011. *Sources*: IEA (2012, 2009, 2003).

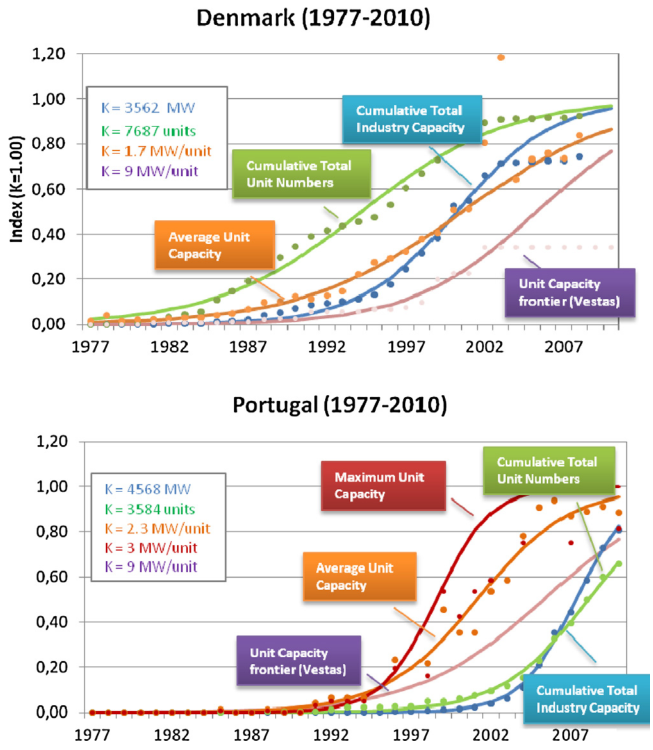

Fig. 4. Unit and industry scaling: known data (dots) and logistic fits (lines) indexed to $K = 1.00$.
Source: DGEG (2013), Spliid (2013).

The dynamics of growth of wind power in Denmark and Portugal are compared in Fig. 4. In this case, the follower country adopts the new technology after its up-scaling in the core. In fact, Danish manufacturers were already commercializing 3 MW wind turbines by the end of the 1990s. The new models had significantly improved their efficiency and performances, registering important reductions in the average downtime rates (to less than 2%) and turbine noise (Neij and Andersen, 2012). At the same time, investment costs in wind turbines were cut by half between 1980 and 2000 (op.cit).

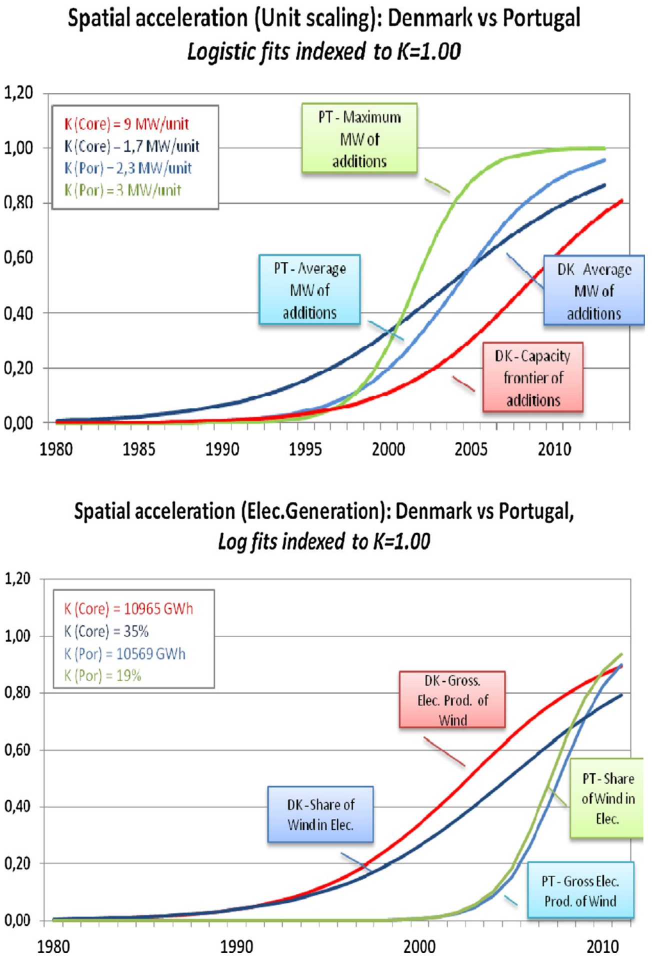

Fig. 5. Comparing unit scaling (top) and the share of wind in the electricity mix (bottom) in Denmark and Portugal, logistic fits only.
Sources: DGEG (2013), Danish Energy Agency (2013).

Moreover, the results confirm that the sequencing of unit and industry scaling is faster in the follower country (PT) than in the core (DK). Comparing the three-stages of growth in the two countries permits to conclude that: the "formative phase" is much longer in the core than in the follower, because of the need of experimenting with more units in the former; the "unit scaling" is much more rapid in the follower, which shows a faster growth in the size of average and maximum unit additions; and, finally, the "growth phase" reaches saturation more rapidly in the follower (steeper slope of the light blue curve) than in the core. In all, the steeper curves in the case of Portugal indicate the acceleration of growth once wind power leaves Denmark, i.e. the core market.

A more detailed analysis of turbine scaling and growth of wind electricity production in the two countries gives further information about the spatial diffusion of wind power (Fig. 5). The top graph compares the evolution of average and maximum (or capacity frontier for DK) unit additions in the core (DK) and in Portugal. The graph reveals that growth was again much more rapid (i.e. steeper curves) in the second than in the first, showing clearer the acceleration of unit scaling in the next market. According to the historical scaling dynamics approach, the diffusion of larger size turbines was quicker in the follower mainly because much of the technical problems had been previously solved in the core and due to the existence of knowledge spillovers – we come back to this in the next point.

The second graph (Fig. 5, bottom) shows how quickly capacity growth translates into higher electricity production. The figure presents the increase in gross electricity production from wind (in GWh), as well as the progress of its share in the overall electricity mix. Both indicators follow a close path, particularly in Portugal. In this case, wind production takes off well within the 2000s – with a great delay when compared with its beginning in the late 1980s in Denmark – a few years later than unit scaling. Its evolution is particularly fast when compared with the trend of average unit additions (i.e. a growth rate or "ΔT" of 13 years vs. 6 years for the increase of the share of wind in electricity production). Nevertheless, the share of wind power in the electricity-mix is larger in Denmark: it is currently 28% and can potentially reach 35%, if the present trend is followed in the coming years. These figures compare to 18% and 19%, respectively, for Portugal. Still, the growth potential falls short of the 2020 target in both countries (i.e. 50% for Denmark and 23% for Portugal).

All in all, the evidence surveyed from wind development in Denmark and Portugal points to an acceleration of diffusion when this technology spills over from the core to reach new markets. The data also reveals that diffusion starts in Portugal when the innovation is sufficiently mature in the core. The growth rate was impressive and has no parallel with the diffusion of other energy supply technologies in this country in the past (Bento and Fontes, 2013a). What is more, the installation of wind farms has often relied on domestic resources (e.g. wind assessment, planning, interconnection) including, at a later stage, the production of equipment (Matos, 2013). The next section discusses these developments with the lens of the TIS framework, highlighting the process of local creation of an innovation system. This is followed by a discussion about the mechanisms operating at the interplay of different spatial levels that contributed to accelerate growth in the subsequent market.

4.3. The process of creation of a new technological innovation system in the receiving country

This section analyzes the processes that contributed to the spatial diffusion of wind power at local level, particularly through the establishment of the structural components, the fulfillment of the functions of the innovation system (e.g. knowledge creation, entrepreneurial experimentation), and the interactions established between them, as the new technological innovation system emerges and grows.[7]

The wind TIS in Portugal has involved a growing number of *actors*. The former national utility EDP was the first developer of modern wind farms and remains the largest producer of wind electricity. The company also plays a key role in the consortium ENEOP, which is the main domestic equipment supplier. ENEOP was established as a joint venture between wind farm promoters (EDP, Endesa, and GDF-Suez) and an industrial partner (Enercon), following the public tender in 2006 for building, installing and operating 1200 MW. It also includes several small and medium local companies. In 2012 the wind industry provided 2700 direct and indirect jobs, with EUR 0.5 billion turnover and more than 60% of exports (EurObserv'ER, 2013; Público, 2011). These figures comprise manufacturing of turbines, installation, operation and maintenance of wind farms. Wind research is well established in Portugal, with some organizations – e.g. LNEG and research groups based at Faculty of Engineering of Porto University (INEGI, INESC) – working in the field since the 1980s and being active in international projects (IEA, 2004). The national energy policy is traditionally managed by the Secretary of State for Energy (under the Ministry of Economic Affairs and later the Ministry of Environment, Spatial Planning and Energy). In what concerns *networks*, the association of renewable energy actors (APREN), formed in the late 1980s, is the main advocacy coalition that lobbies the government and had an important role in the establishment of the incentive schemes for wind energy. Learning networks are composed of research institutes, universities and institutes involved in R&D projects financed through national and European grants. These organizations also collaborate with energy companies and equipment manufacturers in specific pilot projects. Finally, the *institutions* were decisive for the growth of the home

[7] A more detailed analysis of the process of formation and growth of wind power in Portugal can be found in a separate paper: Bento and Fontes (2013b).

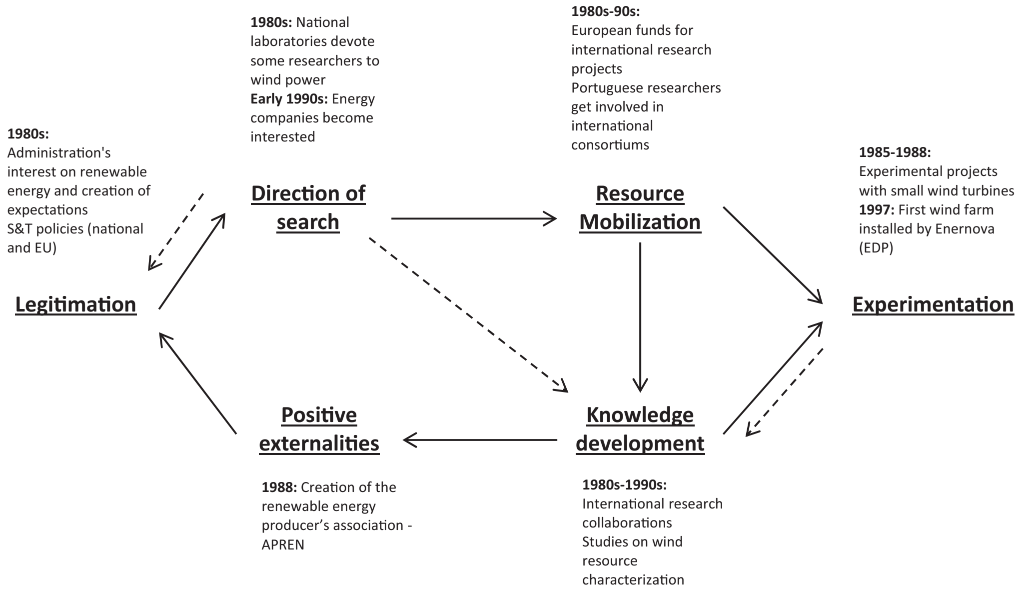

Fig. 6. Exploratory and formative stage of wind energy in Portugal.

market: there was a stable policy and consistent regulatory regimes for wind (IRENA-GWEC, 2012; Peña, 2013). The targets for wind are established in the national plan for renewable energies (PNAER). However, the recent economic crisis led to a revision of the goal for the installed capacity of wind power by 2020, which decreased from 6875 MW in the 2010 version to 5300 MW in the 2013 revision.

It is possible to distinguish two distinct periods in the development of wind power in Portugal: the exploratory and formative stage; and the implementation stage. The former begins with exploratory activities in the 1980s and goes on until the installation of the first wind farm, whereas the latter comprises the up-scaling phase of turbines between 1996 and 2003 and the capacity growth that followed. The processes taking place along each stage are depicted in Figs. 6 and 7, where a full arrow indicates a direct relation; and a dotted arrow indicates indirect flows.

The exploratory stage was triggered by conventional science and technology policies, both at national and European levels (Fig. 6). On the one hand, the government's interest in renewable energies after the oil shocks created "expectations" (Borup et al., 2006) about the development of alternatives that *influenced the direction of search.* On the other hand, the country joins the European Community in 1986, at the moment when EC programs start providing *resources* for R&D and demonstration projects on wind energy, beginning to displace nationally funded projects (Hendry and Harborne, 2011). Portuguese researchers, mainly from national laboratories and universities, get involved in international projects on the physical mapping of wind profiles and resources, already in the 1980s. This contributed to increase the productivity of wind farms, as well as to form local knowledge on wind modeling and wind technologies (Matos, 2013). At the same time, the *experimentation* with several imported small wind turbines generated applied knowledge that was helpful in the installation of the first wind farm in 1997 (Castro, 2011).[8] In fact, although this (and subsequent) wind farms used imported turbine technology, their efficient implementation relied on the competences already developed by the local actors. The good results from the first trials reinforced the credibility of wind as an alternative to incumbent technologies. Meanwhile, a community of actors was formed that contributed to further *legitimatize*

[8] In the first half of the 1990s, Nordtank (Danish) 100 kW and 150 kW turbines equipped almost all new installations in the country. But by 1996 the first big wind turbine Vestas (Danish) 225 kW starts being installed, followed by the Vestas 600 kW in the next year (INEGI/APREN, 2011).

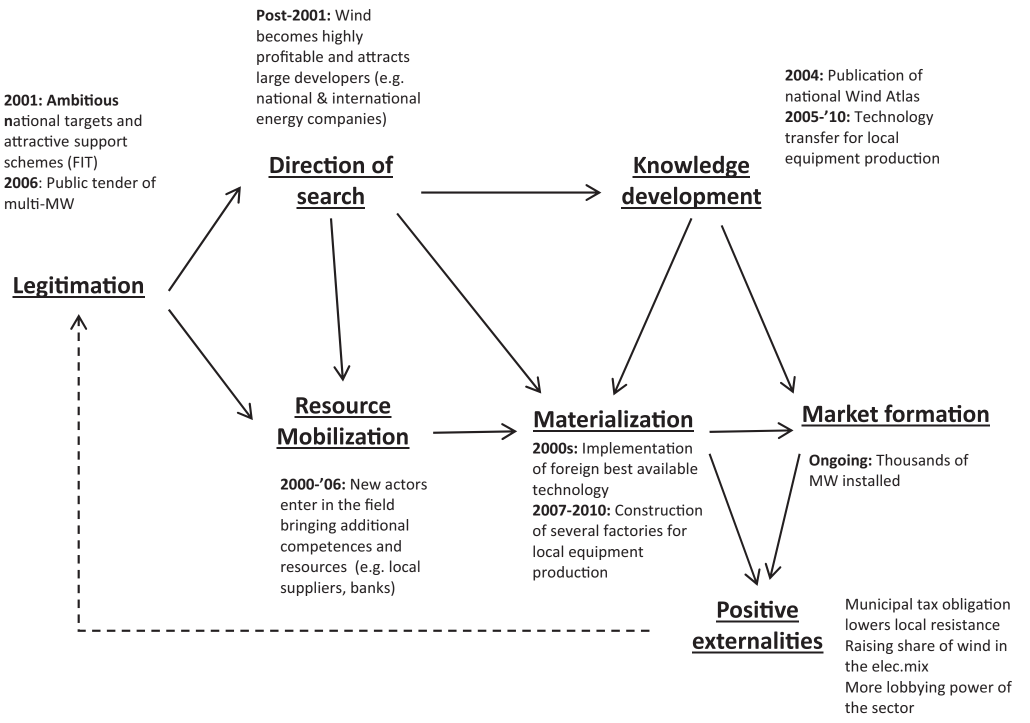

Fig. 7. Implementation stage of wind energy in Portugal.

wind power and disseminate the belief in its growth potential. The creation of the renewable energy producers' association (APREN) in 1988 was the key point in the emergence of an advocacy coalition (IRENA-GWEC, 2012). This had *positive externalities* for the development of the TIS, in particular for the implementation of wind support schemes.

The innovation system enters into a new stage of implementation in late 1990s (Fig. 7). The development of commercially viable multi-MW turbines and their successful market diffusion in Denmark, Spain and Germany, had set a favorable context for wind energy growth (Neij and Andersen, 2012). The obligations imposed by the European Directive on Renewable Energies opened a "window of opportunity" to invest in wind energy. These factors worked together to *legitimatize* wind energy and helped to align institutions to the requirements of the emerging innovation system. The setting-up of a new feed-in tariff, in 2001, *influenced the direction of search* of the main actors, starting with the energy utility. It also attracted new investors (e.g., private financers, financial institutions, engineering and electrical equipment companies), who brought more *resources* to the TIS, in the form of capital or complementary knowledge. The feed-in tariff was important for the development of wind energy in Portugal, as it enabled hard *market formation*. During the next years, total installed capacity jumped from dozens to thousands MW. Good remuneration of production and high land costs contributed to the adoption of large, imported multi-MW turbines (IEA, 2003). Later, the attribution of licenses for new installations was organized around public tenders, tied with local production obligations (Martins et al., 2011). This measure brought a series of investments in the emerging "wind cluster", through the establishment of joint-ventures between the energy utility, engineering companies and international equipment manufacturers.[9] These investments *materialized* in several factories of blades, towers and

[9] Even though some weakness can be pointed to the tendering system such as complexity that may hinder the participation of smaller and medium developers or lack of transparency in the formulation of the calls or in the choice of the winner bids. See: Friebe et al. (2014).

turbines to equip the new wind farms. The difficulties faced to finance the implementation of the new wind farms led exports of wind power plants to start earlier than expected (by the forecasted saturation of the internal market).

In contrast with the strategy followed in the previous phase, which mainly opted for the direct acquisition of equipment to international manufacturers, like the established Danish producers, the strategy in the implementation phase was focused on building-up a local industry. This combined the attraction of foreign direct investment by manufacturers of the core technologies (i.e. turbines), with the continued development of competences, among local companies, in the production of additional components, as well as in the activities required to install, operate and maintain the wind power plants.

This reinforced the positive public perceptions concerning wind power (Delicado et al., 2013). In fact, resistance to the installation of turbines is globally low, mainly thanks to an additional requirement that obliges wind energy producers to pay 2.5% of the revenues to local municipalities. As more and more capacity is added and the best sites onshore are exploited, the focus of the research starts to shift toward the development of the offshore potential (IEA, 2012). Though, more recently, the financial crisis raised questions about the *legitimacy* of the rents in the sector, and producers are nowadays actively involved in lobbying to preserve their benefits.

Hence, the development of wind energy in Portugal reveals two virtuous cycles, characterized by a positive dynamic relationship between system functions (also described as “motor of changes”, cf. Hekkert et al. (2007) and Suurs and Hekkert (2009)) that pulled other functions and created momentum in the growth of the innovation system: a knowledge development cycle and an implementation cycle. Interestingly, the two cycles are similar to those identified by other research on the development of renewable technologies, such as wind in Denmark (Kamp, 2008) or solar PV in Japan (Vasseur et al., 2013). The knowledge development cycle refers to a feedback loop cycle that boosted the production of knowledge. Referring to the system functions defined previously in Table 1, this cycle was triggered by Science and Technology Policy (F7) that influenced the direction of search (F4) for wind activities, mobilizing resources (e.g. R&D funds) for the development of local knowledge (F1) and for entrepreneurial experimentation (F2). In a more advanced stage, the implementation cycle starts with the regulatory change that established goals and introduced a market stimulation mechanism (i.e. feed-in-tariff) (F7), attracting new actors (F4) that brought more resources (F6) to the industry, resulting in the growth of the internal market and exports (F5). The growing penetration of wind power boosted the capacity of networks of actors to influence policy making, in order to keep or even improve the favorable remuneration (F8). All these events took place in an open environment, in which the contact with foreign actors from external innovation systems was decisive for the growth of the wind TIS in Portugal, as will be discussed in more detail below.

4.4. Integrating the international dimension in the emergence of the national TIS

The evidence on spatial acceleration of wind diffusion raises an important question about the main processes that contributed to intensify the growth of the Portuguese wind TIS, as the technology got out of the core and reached the new market. The analysis conducted in the previous section provides some evidence that, as suggested by the (catching-up) literature, this phenomenon has not only *internal* but also *external* causes, which are connected with the context where the innovation takes place.

The presence of external *knowledge spillovers* from the diffusion in the core may be a major driver for growth acceleration in the subsequent markets. Technology starts to penetrate into new markets when it becomes more mature and a significant part of the learning investments have already been supported by the pioneer markets (Nemet, 2009). Other regions benefit from knowledge and technology spillovers created during the early innovation stages in the lead countries (Jaffe, 2005; Perkins and Neumayer, 2005). In fact, wind power only takes off in Portugal in the beginning of the years 2000s, when turbines had already scaled up and diffusion is well into the growth phase in the core (See Section 4.2). That said, the effective implementation of the imported technology always requires the recipient country to have some internal technological, as well as institutional, capacity to absorb and assimilate the new technologies (Mowery and Oxley, 1995; Teixeira and Fortuna, 2010; Criscuolo and

Narula, 2008). In the case of the adoption of wind power in Portugal, the creation and reinforcement of the *absorptive capacity* took mainly three forms.

Firstly, the participation in *international R&D projects* contributed for the formation of knowledge in the early years, enabling a more rapid technology transfer and growth of wind power. The participation of national research laboratories in European projects since the 1980s was decisive to form a local knowledge base on wind modeling and evaluation, which proved useful later on, when the market took off. In fact, the implementation of wind parks has unfolded almost without the need to hiring any international consultants (Matos, 2013; Estanqueiro, 2013). The Portuguese case corroborates the theory which suggests that by conducting basic R&D activities, organizations (and ultimately countries) can improve both the rate of technology transfer and the effectiveness in its use (Fabrizio, 2009; Cappelli et al., 2014).

Secondly, the *development of the value chain* was important to support the implementation of the technology. It drew on local engineering and industrial competences in non core technologies (i.e., besides wind turbines) such as tower technologies and electrical components, as in other fast follower countries (Lund, 2009). In fact, the emergence of the wind innovation system benefited from available knowledge on hydroelectric power, and from the conversion into wind of activities from declining sectors (e.g., metalomechanics, construction). This is similar to what had previously happened in Denmark, when local firms sought, in the emerging wind cluster, the opportunity to diversify the activities from their declining business (Karnøe and Garud, 2012). Consequently, national incorporation was relatively high since the beginning. Almost all towers, as well as transformers and other electrical equipment, were built in Portugal, by local firms (Wind Directions, 2004). The sharing of elements with other innovation systems enlarged the knowledge and resources at the disposal of the new innovation system, contributing to raise the social consensus around wind power (Geels, 2005). Yet, in contrast to the more "distributed" experience of Denmark (Karnøe and Garud, 2012), the main energy utility has played a central role in the development of wind energy in Portugal since the beginning, affording increased legitimacy and lobbying power.

Thirdly, the establishment of *strategic alliances with foreign companies* allowed to overcome weaknesses in indigenous technical capacity regarding the core technologies, as well as to foster knowledge transfer (Mowery et al., 1996; Lewis and Wiser, 2007). The joint ventures established between international turbine manufacturers, such as Enercon and REpower, and local promoters led to the installation of manufacturing subsidiaries in the country, enabling the (timely) access to state-of-the-art technology and the creation of a local industrial cluster.[10] These alliances were established to answer to the public tender organized in 2005, which required the bidders to produce locally equipment for wind farms, in exchange for the right to connect new capacity and to receive the regulated tariff (Martins et al., 2011). The tendering process provided enough stability and perspectives of domestic market growth to encourage global actors to delocalize full turbine manufacturing plants (Lewis and Wiser, 2007; Jenner et al., 2012). Therefore this scheme was successful in creating collective resources and ensuring that some benefits (i.e. value-added creation, jobs) reverted to the country.

All in all, the story of the development of wind power in Portugal points to the importance of transnational contacts for technology transfer, as well as to the need of stimulating the local capacity to capture knowledge spillovers in order to rapidly implement the new technology. The interactions established with the global TIS clearly helped to fulfill the system functions and to accelerate the emergence of the local innovation system. Table 2 presents a synthesis of several events, comprising both domestic and transnational activities, which were decisive for the fulfillment of the core activities or functions.

[10] Lewis (2011) examines the case of development of the wind industry in China, India and South Korea, whose strategy for technology transfer arguably took the form of licensing and mergers and acquisitions of companies from the core of innovation. This opened the access to technological know-how that enabled these countries to play an important role when the market became increasingly globalized.

Table 2
Selected domestic and transnational events that contributed to increase absorptive capacity and to capture knowledge spillovers through the fulfillment of functions of the innovation system (FIS).

Event/FIS	F1. Development of formal knowledge	F2. Entrepreneurial experimentation	F3. Materialization	F4. Influence on the direction of search	F5. Market formation	F6. Resource mobilization	F7. Legitimation	F8. Development of positive externalities
Domestic activities (increasing absorptive capacity)								
National R&D	•	•		•			•	
Development of local value chain		•	•	•		•	•	•
Support schemes			•	•	•	•	•	•
Transnational activities (capturing knowledge spillovers)								
International R&D projects	•	•		•				
Strategic alliances with foreign companies		•	•		•	•	•	•

5. Conclusions

The international diffusion of energy technologies and the formation of technological capabilities in the receiving country were studied through the comparison of the growth of wind energy in Denmark (core) and in Portugal (fast follower). The very short delay with which wind technologies were adopted in Portugal relatively to the core and the scope of market penetration make this an interesting case of study, permitting to highlight the factors that can contribute to a rapid spatial diffusion.

The research drew on the empirical historical scaling dynamics to compare patterns of diffusion, and proposed an explanation for the patterns identified with the help of the technological innovation systems approach, in particular recent conceptualizations that attempt to (re)introduce the spatial dimension. Special attention was given to the factors that resulted from the interactions between an emerging country innovation system and the global TIS, which allowed the fulfillment of the key innovative processes.

A couple of lessons can be drawn from this case, which may contribute for technology policy design elsewhere – even though the efficacy of policies may change, depending on the country and the timing. The central one is that the development of wind power took advantage of the assimilation of knowledge spillovers from abroad, through an improved local absorptive capacity. On the one hand, the diffusion of wind power benefited from the available competences in engineering and industrial activities. The formation of local knowledge was also possible thanks to the initial science and technology policy that permitted to build a knowledge base in the field and contributed, at the same time, to raise confidence in the new technology and establish its legitimacy. On the other hand, the local absorptive capacity was reinforced through policy incentives that explicitly required the promoters to produce their equipments locally. This led to the establishment of strategic alliances with international turbine manufacturers for the installation of production factories in Portugal, which enabled local companies to have access to the best available technology and were essential in the process of formation of an industrial cluster.

The use of theories and concepts from the TIS literature to explain patterns of international technology diffusion has proven pertinent and has an enormous potential in future analyses. However, this research revealed that some improvements can still be made in order to enhance the explanatory power of the theoretical framework in relation to spatial diffusion. We see at least two possible refinements. Firstly, by highlighting the contribution of the external resources for the follower country, including the activities developed locally to take advantage from them, in each stage of development of the innovation system. In the case under analysis, the contacts with the global TIS during the formative period allowed the fulfillment of functions that strengthened the absorptive capacity (e.g., knowledge creation, experimentation). This enhanced the exploitation of technology spillovers and the concretization of other functions of innovation systems (e.g., resource mobilization, legitimation, market formation) during the more advanced stage of implementation. Secondly, by better integrating, in the (functional) analysis, some capacity-building activities (e.g. education and general R&D expenditures) that are likely to improve the absorptive capacity of new technological systems. This point may namely lead to reconsider the links with the literature on national innovation systems and sectoral innovation systems, in terms of assets creation at a more regional and local levels.

Acknowledgments

We gratefully acknowledge the funding of this research by the FCT (Fundação para a Ciência e a Tecnologia) through the research grant Refª SFRH/BPD/91183/2012 and the research project Refª PTDC/CS-ECS/113568/2009. The authors would like to thank Ana Estanqueiro, José Carlos Matos, Alexandre Kisslinger, Rui Castro, Vítor Marques, Sergio Faias, Arnulf Grubler and Charlie Wilson as well as the participants of the 4th International Conference on Sustainability Transitions, in Zurich, and two anonymous referees. The usual disclaimer applies.

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