THE SPANISH WIND ENERGY RISE

Cristian Matti

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Pathways of Knowledge Creation within a Multilevel Environmental Governance System

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"La mayoría de la gente ignora que ser innovador es buscarse la vida"

~ Ferran Adrià [1]

[1]In English "*Most people ignores that being innovative is make a living".* Excerpt from interview published in Levante (Galindo, 2014), newspaper of Comunitat Valenciana

Abstract

The wind energy sector globally has had an outstanding growth during the last decade. The Spanish wind energy sector has emerged in a context of political change characterised by the entry of Spain into the European Union, a decentralization process which led to transference of competences and responsibilities to regions and, the gradual liberalization of energy markets. A policy mix combining energy, industry and innovation areas was delivered aimed to support market deployment and technology development, however, differences appear in the way each region face the challenge in term of the variety of regional setting and the creation of linkages among policy, industrial and technological areas within the multilevel environmental governance system.

This research aims to contribute to the analysis of pathway creations for the development of new technological sectors within and across a multilevel environmental governance system by looking at two particular processes: the use, combination and transfer of knowledge from existing to new sectors and in the other hand, regional renewal, transformation and specialization based on locally available assets. Literature on innovation studies and regional issues has recently emphasised the relevance of structure of technological sectors to provide a proper innovative context and conditions favourable to technological change, however less is known on the linkages between technological maturity and environmental change in order to exploit specific sector and market characteristics by applying different types of policy actions and instruments at different times.

The first part of this thesis is focused in the characteristics of environmental governance systems and the multi-level and multi-actor interactions. We propose a chronological investigation of the policy instruments implemented at different levels in a variety of policy domains affecting the renewable energy and wind sectors (more specifically) in Spain. The emphasis is put in the search of complementarities across multiple level of governance and the dynamic pattern of implementation of policy instruments over time. The results indicates a coordinated multi-level policy to promote the emergence of new sectors through linkages with the innovation process aimed at developing technologies, and market deployment based on R&D support. However, even when the provision of long term targets and the removal of barriers to the electricity market have encouraged the industry in the process of market deployment, technology maturity and its evolution over time have been rather overlooked.

The second part examines the wind energy sector through market forces associated with commercial opportunities and technological forces driven by scientific advances. The investigation explains the rate (and speed) and direction of wind energy technology development within the adaptation process of industry capacity and technological background, by looking at the process of transfer knowledge and capacity from existing sectors to new ones. The results confirms that the modular combination of technological components has facilitated industry progress which has been driven by the search for increased size and maximum power capacity. The industry has evolved through diversification and fragmentation motivated by the search for greater efficiency in capturing emerging markets. In practice this process has involved a mixed strategy based on the process of knowledge transfer from existing to new sectors and integration process through mergers and acquisitions. More specifically, the Spanish case reveals as critical factor the long term cooperation agreements between the developers and wind turbine manufacturers.

Finally, the third part moves on the analysis of pathways creation regarding the development of the wind energy sector in Spanish regions. The study compare the variety of key technological, economic and institutional factors across regions in order to improve the understanding on the way that different regional setting and competences may facilitate industrial specialization. We found that the role of regional policy has been critical for the process of implementation of renewable energy policy set by the introduction of government tendering (i.e. regional wind plans) introduced to provide a temporal horizon to the deployment of new markets. However, these actions are defined by different pathways towards regional specialization in term of natural resources endowments, differences in regional industrial settings and infrastructure as well as dynamics in the regional process of creation and application of knowledge. Specifically, results reveals that a pathway of specialization may not be fully articulated, however, same results suggest that there is no single route or pathway. At last, the pathway is defined by using and transforming existing capacities to develop a new technological sector.

This thesis confirms that while international commitments act as a guiding force in establishing long-term environmental perspectives, national governments provide the right market signals and financial support while regional institutions act as a powerful selection mechanism to differentiate actors and their capacities which leads to distinctive patterns of implementation across regions. The maturity of the technology has revealed as a key element for value creation and a critical condition for policy implementation where the trade-off between flexibility and stability is a key element for long term planning. In that sense, the process of pathway creation to develop a new technological sector may be stimulated by a trade-off between provision of suitable conditions for innovation and flexibility in the policy instrument designed to foster competitive market. Finally, this research has showed that the regional setting and industrial histories can generate variety of specialization strategies. Thus, it would not be logic to expect a convergence to a particular pathway of smart specialization in term of sequence of action or specific combination of locally available assets. Conversely, it is expected to find different smart ways to achieve regional specialization.

Resumen

El sector de la energía eólica a nivel mundial ha tenido un notable crecimiento en la última década. En tal sentido, el sector eólico español ha surgido en un contexto de cambios normativos caracterizados por, la entrada de España en la Unión Europea, un proceso de descentralización que dio lugar a la transferencia de competencias y responsabilidades a las comunidades autónomas y, por la progresiva liberalización de los mercados energéticos. Una combinación de políticas de energía, áreas de la industria e innovación fueron desarrolladas con el objeto apoyar el despliegue del mercado y el desarrollo de tecnologías, sin embargo, las diferencias aparecen en la forma en que cada región se enfrentan al reto en términos de la variedad de las configuraciones regionales y la creación de vínculos entre política, industria y áreas tecnológicas en el sistema de gobernanza ambiental a varios niveles.

Esta investigación tiene como objetivo contribuir al análisis de las creaciones de sendas para el desarrollo de nuevos sectores tecnológicos dentro, y a través, de un sistema de gobernanza ambiental multinivel, observando dos procesos particulares: el uso, la combinación y la transferencia de conocimiento existente hacia nuevos sectores y, por otro lado, la renovación, transformación y especialización regional basada en los activos disponibles a nivel local. La literatura sobre los estudios de innovación y cuestiones regionales ha enfatizado la relevancia de la estructura de los sectores tecnológicos para ofrecer un contexto y unas condiciones favorables para el cambio tecnológico innovador adecuado, sin embargo existe menos conocimiento sobre los vínculos entre la madurez tecnológica y los cambios medioambientales con el fin de explotar específicamente algunos sectores y características del mercado mediante la aplicación de diferentes tipos de acciones e instrumentos politicos en diferentes momentos.

La primera parte de esta tesis se centra en las características de los sistemas de gobernanza ambiental y las interacciones de múltiples niveles y múltiples actores. Proponemos una investigación cronológica de los instrumentos de políticas implementadas en los diferentes niveles en una variedad de ámbitos que afectan a los sectores de la energía renovable y eólica, y más específicamente en España. El énfasis se pone en la búsqueda de complementariedades en múltiples niveles de gobernanza y en el patrón dinámico de implementación de los instrumentos de política a través del tiempo. Los resultados indican una política multinivel coordinada para promover el surgimiento de nuevos sectores a través de los vínculos con el proceso de innovación orientado a desarrollo de tecnologías y del mercado basado en el apoyo de la I+D. Sin embargo,

aun cuando la instalación de objetivos a largo plazo y la eliminación de barreras para el mercado de la electricidad han impulsado a la industria en el proceso de implantación en el mercado, la madurez tecnológica y su evolución a través del tiempo no han sido tenidas en cuenta.

La segunda parte examina el sector de la energía eólica a través de las fuerzas del mercado asociadas con las oportunidades comerciales y las fuerzas tecnológicas impulsadas por los avances científicos. La investigación explica la tasa de cambio (y la velocidad) y la dirección de desarrollo de la tecnología de la energía eólica dentro del proceso de adaptación de la capacidad de la industria y el contexto tecnológico, observando el proceso de transferencia de conocimientos y capacidades desde los sectores existentes a los nuevos. Los resultados confirman que la combinación modular de componentes tecnológicos ha facilitado el progreso de la industria, la cual ha sido impulsada por la búsqueda de mayor tamaño y capacidad de potencia máxima. La industria ha evolucionado a través de procesos de diversificación y fragmentación motivados por la búsqueda de una mayor eficiencia en la captura de los mercados emergentes. En la práctica, este proceso ha implicado una estrategia mixta basada en el proceso de transferencia de conocimiento entre sectores y el proceso de integración a través de fusiones y adquisiciones. Más concretamente, el caso español revela como factor crítico los acuerdos de cooperación a largo plazo entre los desarrolladores y fabricantes de aerogeneradores.

Por último, la tercera parte gira en torno al análisis de la creación de sendas relativas al desarrollo del sector de la energía eólica en las regiones españolas. El estudio compara la variedad de factores tecnológicos, económicos e institucionales clave en todas las regiones con el fin de mejorar la comprensión sobre la forma en que diversos esquemas y competencias regionales pueden facilitar la especialización industrial. Hemos encontrado que el papel de la política regional ha sido fundamental para el proceso de implementación de la política de energías renovables dado por la introducción de mecanismos de licitación por parte del gobierno (es decir, los planes eólicos regionales) introducidos para proporcionar un horizonte temporal para el despliegue de nuevos mercados. Sin embargo, estas acciones se definen por diferentes sendas hacia la especialización regional dadas por la dotación de recursos naturales, las diferencias en esquemas industriales regionales y en infraestructuras, así como también por las dinámicas en el proceso regional de la creación y aplicación del conocimiento. En concreto, los resultados revelan que las sendas hacia la especialización pueden no estar totalmente articuladas, sin embargo, los mismos resultados sugieren que no hay una sola ruta o senda. En definitiva, la senda está definida por el uso y la transformación de las capacidades existentes para desarrollar un nuevo sector tecnológico.

En esta tesis se confirma que si bien los compromisos internacionales actúan como una guía en el establecimiento de perspectivas ambientales a largo plazo, los gobiernos nacionales proporcionan señales adecuadas para el mercado y apoyo financiero mientras que las instituciones regionales actúan como un poderoso mecanismo de selección para diferenciar los actores y sus capacidades, que conduce a patrones distintivos de implementación a través de las regiones. La madurez de la tecnología se ha revelado como un elemento clave para la creación de valor y una condición fundamental para la aplicación de las políticas donde la compensación entre flexibilidad y estabilidad son elementos claves de la planificación de largo plazo. En tal sentido, el proceso de creación de sendas para el desarrollo de nuevos sectores puede ser estimulado por un equilibrio entre la provisión de condiciones adecuadas para la innovación y la flexibilidad en los instrumentos de política destinados a fomentar el mercado competitivo. Por último, esta investigación ha demostrado que la configuración regional y las trayectorias industriales pueden generar gran variedad de estrategias de especialización. En consecuencia, no sería lógico esperar una convergencia a una senda particular de especialización en términos de secuencia de acciones o combinación específica de los recursos disponibles localmente. Por el contrario, se espera encontrar diferentes "smart ways" para lograr la especialización regional.

Resum

El sector de l'energia eòlica a nivell mundial ha tingut notable creiximent a l'última dècada. En aquest sentit, el sector eòlic espanyol ha sorgit en un context de canvis normatius produïts per l'entrada d'Espanya en l'Unió Europea, un procés de descentralització que va donar lloc a la transferència de competències i responsabilitatas a les comunitats autónomes i, la progressiva liberalització dels mercats energètics. Una combinació de polítiques d'energia, àrees de la industria i innovació varen ser desenvolupades amb l'objectiu de recolzar el desplegament de mercat i el desenvolupament de tecnologies, no obstant açò, les diferències apareixen en la manera en què cadascuna de les regions s'enfronta al repte en termes de la varietat de les configuracións regionals i la creación de vincles entre política, indústria i àrees tecnològiques al sistema de governança ambiental a diversos nivells.

Aquesta recerca té com a objectiu contribuir a l'anàlisi de les creacions de sendes per al desenvolupament de nous sectors tecnològics dins i a través d'un sistema de governança ambiental multinivell observant dos processos particulars: l'ús, la combinació i la transferència de coneixement existent cap a nous sectors i d'altra banda, la renovació, transformació i especialització regional basada en els actius disponibles a nivell local. La literatura sobre els estudis d'innovació i qüestions regionals ha emfatitzat la rellevància de l'estructura dels sectors tecnològics per a oferir un context i unes condicions favorables per al canvi tecnològic innovador adequat, no obstant açò existeix menys coneixement sobre els vincles entre la maduresa tecnològica i els canvis mediambientals amb la finalitat d'explotar específicament alguns sectors i característiques del mercat mitjançant l'aplicació de diferents tipus d'accions i instruments polítics en diferents moments.

La primera part d'aquesta tesi es centra en les característiques dels sistemes de governança ambiental i les interaccions de múltiples nivells i múltiples actors. Proposem una recerca cronològica dels instruments de política implementats en els diferents nivells en una varietat d'àmbits polítics que afecten als sectors de l'energia renovable i eòlica més específicament a Espanya. L'èmfasi es posa en la cerca de complementarietats en múltiples nivells de governança i en el patró dinàmic d'implementació dels instruments de política a través del temps. Els resultats indiquen una política multinivell coordinada per a promoure el sorgiment de nous sectors a través dels vincles amb el procés d'innovació orientat a desenvolupament de tecnologies i del mercat basat en el suport de la R+D. No obstant açò, tot i que la instal·lació

d'objectius a llarg termini i l'eliminació de barreres per al mercat de l'electricitat han impulsat a la indústria en el procés d'implantació en el mercat, la maduresa tecnològica i la seua evolució a través del temps han sigut tenides en compte.

La segona part examina el sector de l'energia eòlica a través de les forces del mercat associats amb les oportunitats comercials i les forces tecnològiques impulsades pels avanços científics. La recerca explica la taxa de canvi (i la velocitat) i la direcció de desenvolupament de la tecnologia de l'energia eòlica dins del procés d'adaptació de la capacitat de la indústria i el context tecnològic, observant el procés de transferència de coneixements i capacitats des dels sectors existents als nous. Els resultats confirmen que la combinació modular de components tecnològics ha facilitat el progrés de la indústria, la que ha sigut impulsada per la cerca de major grandària i capacitat de potència màxima. La indústria ha evolucionat a través de processos de diversificació i fragmentació motivats per la cerca d'una major eficiència en la captura dels mercats emergents. En la pràctica, aquest procés ha implicat una estratègia mixta basada en el procés de transferència de coneixement entre sectors i el procés d'integració a través de fusions i adquisicions. Més concretament, el cas espanyol revela com a factor crític els acords de cooperació a llarg termini entre els desenvolupadors i els fabricants d'aerogeneradors.

Finalment, la tercera part gira entorn de l'anàlisi de la creació de senderes relatives al desenvolupament del sector de l'energia eòlica en les regions espanyoles. L'estudi compara la varietat de factors tecnològics, econòmics i institucionals clau en totes les regions amb la finalitat de millorar la comprensió sobre la forma en què diversos esquemes i competències regionals poden facilitar l'especialització industrial. Hem trobat que el paper de la política regional ha sigut fonamental per al procés d'implementació de la política d'energies renovables donat per la introducció de mecanismes de licitació per part del govern (és a dir, els plans eòlics regionals) introduïts per a proporcionar un horitzó temporal per al desplegament de nous mercats. No obstant açò, aquestes accions es defineixen per diferents sendes cap a la especialització regional donades per la dotació de recursos naturals, les diferències en esquemes industrials regionals i en infraestructures així com també per les dinàmiques en el procés regional de la creació i aplicació del coneixement. En concret, els resultats revelen que les sendes cap a l'especialització poden no estar totalment articulades, no obstant açò, els mateixos resultats sugereixen que no hi ha una sola ruta o senda. En definitiva, la senda està definida per l'ús i la transformació de les capacitats existents per a desenvolupar un nou sector tecnològic.

En aquesta tesi es confirma que si ben els compromisos internacionals actuen com una guia en l'establiment de perspectives ambientals a llarg termini, els governs nacionals proporcionen senyals adequats per al mercat i suport financer, mentre que les institucions regionals actuen com un poderós mecanisme de selecció per a diferenciar els actors i les seues capacitats, que condueix a patrons distintius d'implementació a través de les regions. La maduresa de la tecnologia s'ha revelat com un element clau per a la creació de valor i una condició fonamental per a l'aplicació de les polítiques on la compensació entre flexibilitat i estabilitat són elements claus de la planificació de llarg termini. En aquest sentit, el procés de creació de sendes per al desenvolupament de nous sectors pot ser estimulat per un equilibri entre la provisió de condicions adequades per a la innovació i la flexibilitat en els instruments de política destinats a fomentar el mercat competitiu. Finalment, aquesta recerca ha demostrat que la configuració regional i les trajectòries industrials poden generar gran varietat d'estratègies d'especialització. En conseqüència, no seria lògic esperar una convergència a una senda particular d'especialització en termes de seqüència d'accions o combinació específica dels recursos disponibles localment. Per contra, s'espera trobar diferents "smart ways" per a aconseguir l'especialització regional.

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Chapter 1
Introduction

1.1 Introduction

This research analyses the long term process of pathway creation within and across a multilevel environmental governance system. Pathway creation is understood as a process of delivering strategies and specific actions to develop a new sector by using, combining and transferring knowledge from existing to new sectors. At the regional level, these processes involve capacity building for renewal and transformation based on locally available assets. Emphasis will be put on the strategies for pursuing security of energy supply and supporting the renewables industry in Spain, by considering areas of technology development and environmental policy. The research seeks to contribute to a better understating of key technological, economic and institutional factors with a view to identifying whether and how different regional contexts facilitate or not an emerging sector. Chapter 1 describes the background to and objectives of the research and formulates the research questions. It introduces the case of Spain within the context of the EU multilevel environmental governance system and the international wind energy industry.

1.1.1 Background of this study

Energy became an important issue for Spain after the second oil crisis (1979) due mainly to the scarcity of natural resources (mostly carbon and hydroelectric power rather than oil) and the high risk related to the external energy supply (more than two-thirds of Spain’s total energy needs). Spain’s industry sectors are diverse in terms of infrastructure type and age, which mainly define the possibilities for shifting the industrial structure.

The Spanish wind energy sector is a particular case in the context of Europe, and has shown outstanding growth[1] and particular dynamics related to expansion and transformation of the infrastructure. This dynamics have been driven by support and regulation, both of which differ significantly from region to region (González, 2008; Morata & Font, 1998)

Two key events triggered a critical change in policy making related to the energy and building sectors. First, Spain's entry to the European Union (EU) linked energy and building policies to climate change commitments and the EU framework and programmes on energy and environmental issues. Second, there was a decentralization process which led to the transfer of competences and responsibilities to regions and local authorities.

According to a 1991 European Commission (EC) report on the enforcement of community legislation, Spain was one of the member states least adapted to the task of implementing EC environmental directives. However, Spain did not attempt to negotiate special provisions in the accession treaty to grant a delay or other derogation on the execution of Community policies. This meant that the effect of European policy was more sudden and more disruptive than in the case of other member states (Morata & Font, 1998). Although the R&D to GDP rate has increased since the mid 1990s, thanks mainly to the European Structural Funds and other nationals programmes, Spain is not one of the leaders in Europe for R&D performance (E. Muñoz, Espinosa de Monteros, & Diaz, 2000), but has shown successful performance in specifically energy programmes (Izquierdo, 2011).

The effect of decentralization means that, while regions and local authorities do not have much input to policy formulation, they are responsible for implementing national[2] and EU regulations. Domestic pressure for adaptation to directives was generated by the interactions among regional councils and various interest groups (business and industry), over the implementation of energy and environmental issues (Borzel, 2000; Bukowski, 2001). This allowed large regions with sufficient competences and resources, to develop their own policies, often in collaboration with other national and international partners (Bache & Jones, 2000; Roller & Sloat, 2002).

[1] Spain is the first country in the world where wind energy is the major source of energy (El País, 2014b) and is the world's fourth largest wind energy market (GWEC, 2014)

[2] 1985 Local Government Act (competences of municipalities) and Law 9/1992 (transferred competences from national to regions).

The incentive system in Spain was established in 1994 (before the EU normative) with a special regime based on a differentiated price (feed in tariff -FIT) for renewable energy. However, interaction/coordination among government levels and different stakeholders, and use and selection of interaction mechanisms was introduced in 2000 via the Plan for the Promotion of Renewable Energy (PFER 2000-2010), which was the first long-term policy to guarantee subsidies and funding, and set priorities for renewable energy technologies to achieve a target of 12% of renewable in total electric energy in Spain. The Plan provides a platform that allows different levels (i.e. central administration and regions) and sectors of public administration to collaborate and coordinate their actions in relation to: 1) coordination and operation of the recently liberalized energy market and, 2) environmental commitments to transposition of the 2001/77/EC Directive on Renewables Energy (RREE) national targets.[3]

In this general context, characterized by multilevel links, a policy mix combining energy, industry development and innovation areas was developed and implemented locally to foster market deployment and technology development. Thus, the case of Spanish regions exemplifies how these process can be embedded in major external changes (i.e. Spain's entry to the EU, decentralization and transfer of competences to autonomous communities) by tackling energy-climate change issues in a country considered a "laggard" in these policy areas.[4] Also, the regional diversity in Spain has allowed the development of regional specialization strategies, which has promoted more efficient use of public investment within well-identified geographical and institutional contexts (Foray, Goddard, Beldarrain, & Landabaso, 2012; OECD, 2013)

1.1.2 Motivation and objectives

The study focuses on mechanisms for knowledge creation as part of government and industry responses to the current multilevel framework on energy and the environment. It identifies the major contributors to the emergent knowledge base - individuals, research organizations,

[3] Directive 2001/77/CE outlines: 1) national goals for achieving 12% coverage of electricity demand by renewable energy by 2010; 2) energy production from renewables should be 22.1% of total EU energy production (29.4% for Spain); and 3) member countries should develop their own strategies within the common framework.

[4] A "laggard" country is understood as a politically less powerful country with less advanced environmental policies compared to the more influential northern European members states such as Germany and the UK (Borzel, 2000).

governmental agencies, firms. It analyses the reasons behind differences in performance among Spanish regions.

This thesis research attempts to identify key environmental policy and technology factors that have contributed to the development of the wind energy sector in Spain. It highlights the patterns of implementation of the policy instruments that have facilitated pathways to develop renewable energy regionally, and the extent to which the recombination of existing knowledge and new forms of organization within and across the value chain have affected emergent technological capacity in a variety of regional settings.

The research seeks to contribute to the theory by investigating the development of an emergent sector in a multilevel governance context, with particular emphasis on interactions and interdependences within and across areas of technical development and environmental policy. It aims at achieving a better understanding of the processes of adaptation and integration of polices from higher hierarchical levels to local context, as a strategic response to new challenges and opportunities.

1.2 The research questions

The objectives of this research are to improve understanding of the way a policy mix implemented within in a multilevel environmental governance system has facilitated processes of pathway creation to develop the Spanish wind energy sector, and the extent to which the recombination of existing knowledge and new forms of organization within and across the value chain have affected emergent technological capacity. These objectives are achieved by addressing three research questions:

1. How have the energy and industry instruments to support renewable energy been combined with science, technology and innovation instruments within a policy mix that supports the development of the Spanish wind energy sector?
2. To what extent have specific characteristic of traditional sectors such as metallurgy, electronics and power generation influenced the rate (and speed) and direction of technological developments in wind energy?
3. How do the different regional industrial settings influence the pathways of specialization observed in the wind energy sector?

The first question explores the different characteristics of the policy instruments by considering the whole environmental governance system and the geographic setting in relation to the multi-level and multi-actor interaction processes. The pattern of development and diffusion of green technologies cannot be separated from the broader technological, economic and political contexts related to the geographical setting, and factors related to the implementation of policies cannot be confined to a local governance arena or reduced to struggles between the central and local state (Bulkeley & Betsill, 2005). Thus, in the wind energy sector, environmental technological maturity and market structure are critical for the implementation of flexible regulatory frameworks over time. Overlaps among energy market liberalization, harmonization of European energy markets and the sets of actions implemented to foster renewable energy, are part of the multi-level linkages in the regulatory framework, industrial developments and R&D programmes. At the same time, the evolution of policy instruments implement along time in relation to their flexibility and adaptation as a strategic response at different stages in the technology life cycle, implies a multi-level learning process (Flanagan, Uyarra, & Laranja, 2011a).

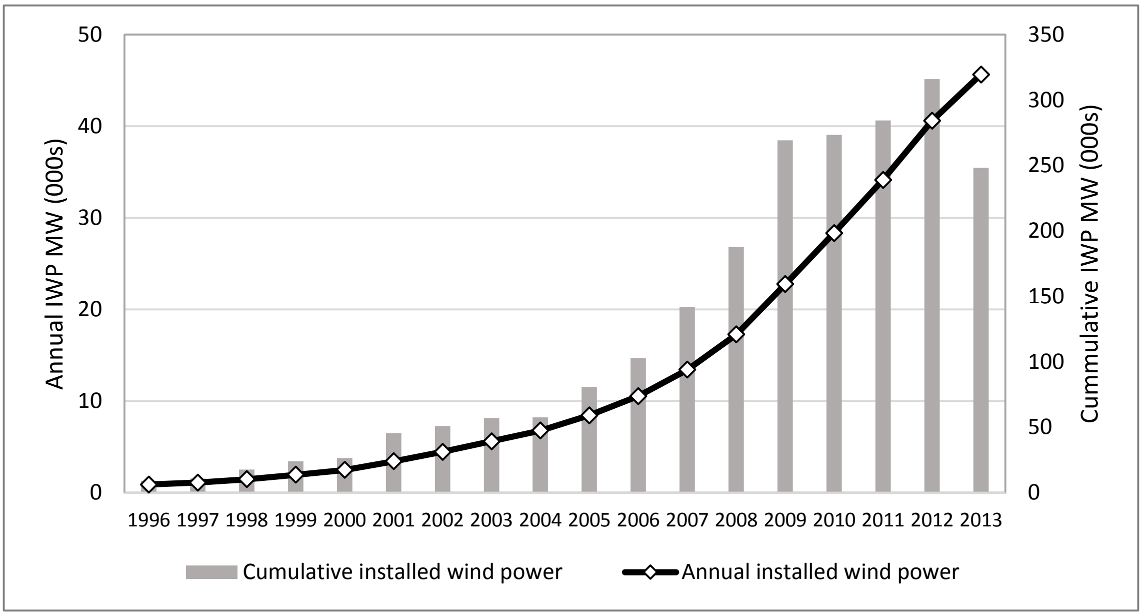
Implementation of the policy mix seeks to influence the use, exploitation and adaption of locally available assets such as natural endowments, industry capacity and variety of knowledge resources. Thus, the second research question is aimed at improving understanding of the rise of the wind energy sector in Spain by investigating the alignment among different large industry actors (utilities, infrastructure), regional governments and leading R&D organizations in terms of adaption of the existing knowledge base, industry capacity and technological background, in order to exploit market opportunities in response to new regulatory and financial stimuli. This should help to clarify the influence of market structure in the regional development of renewable energy technologies through different organizational forms in relation to the wind energy value chain.

The third research question is related to demonstrating the differences among regions in the development of specialization strategies, by highlighting the pivotal role of regional actors such as utilities, technology manufacturers, research centres and local government in facilitating the creation and the mobilization of a variety of knowledge bases (Asheim & Coenen, 2005a). This is relevant and introduces a regional dimension by including factors affecting the performance of Spanish regions in terms of the direction of sector development towards strategic specialization in home market deployment and technology development, which are grounded in the particular characteristics of local resource endowment.

1.3 The emergence of the Spanish wind energy sector

Accumulated capacity in world wind energy production increased fourfold during the first decade of 2000 while world wind power capacity increased more than tenfold (Fig. 1).

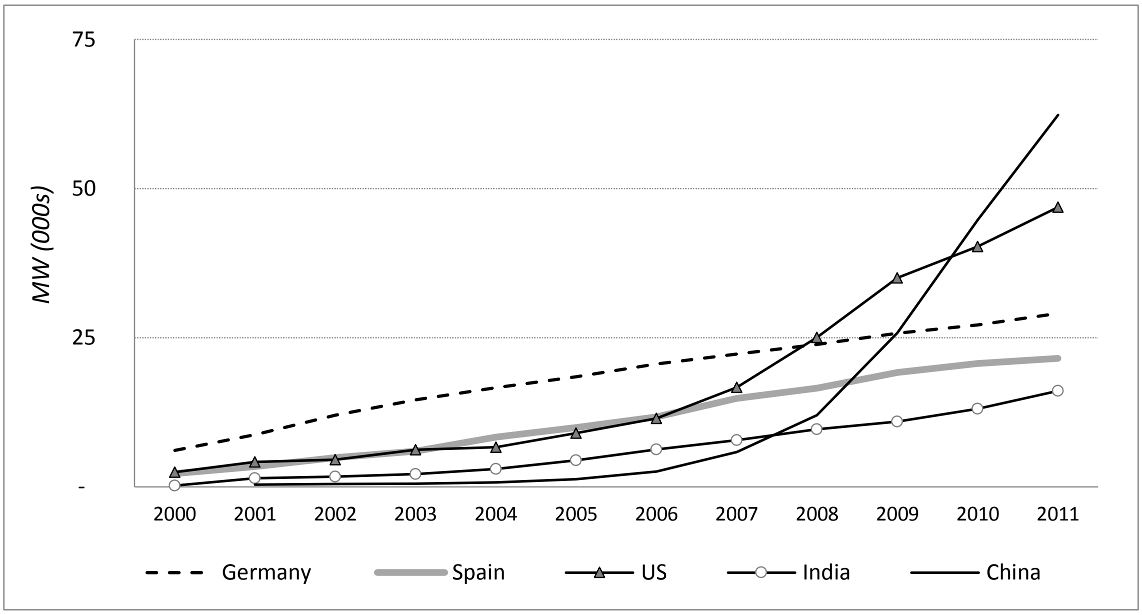
Figure 1 Global wind power installed capacity. Annual and cumulative



Source: own elaboration base in GWEC (2003)

From a global perspective, Spain has kept pace with Germany and India and is ranked fourth among the world's wind energy producers (Fig. 2). Against a changing industry and regulatory landscape, Spain has become a world leader in the wind energy market and the global energy industry. Spain has exploited market opportunities against a background of international commitments and search for security of supply.

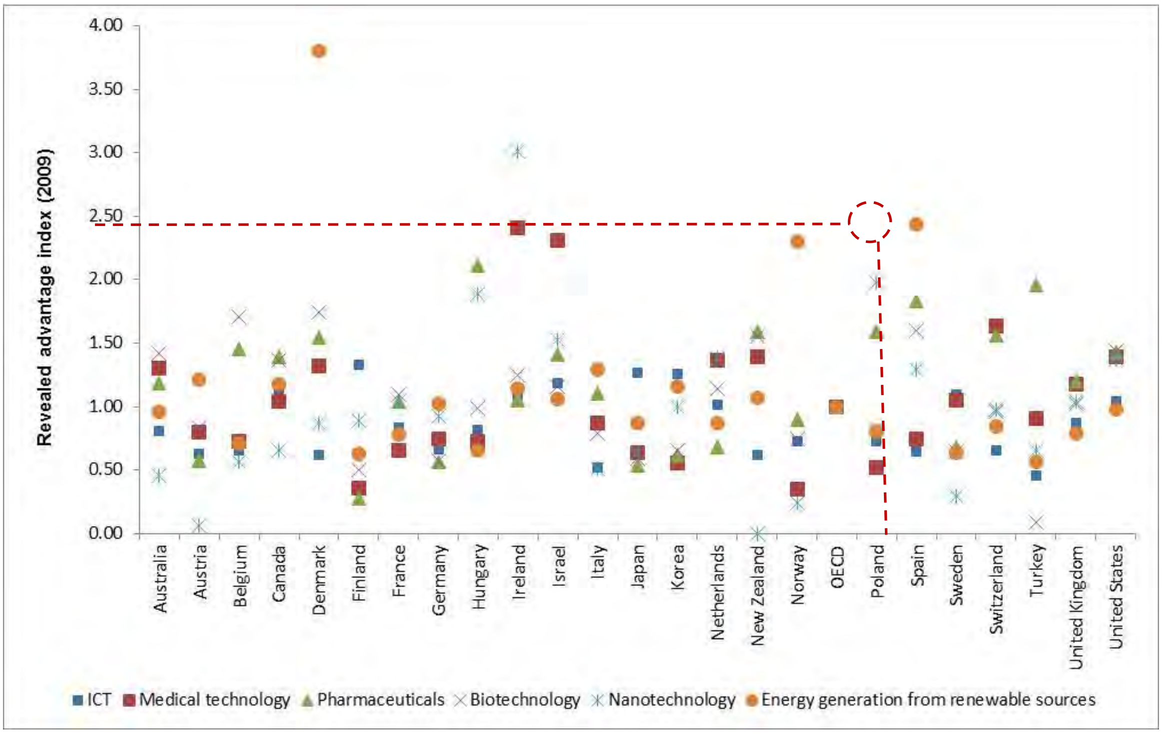
Figure 2 Wind power cumulative installed capacity (Selected countries)



Source: own elaboration based on OECD (2013), DE (2013) and EWEA (2013)

This significant increase in the power capacity can be explained by the policy mix implemented in Spain and the development of technological advantages in the manufacture of renewable energy technology. The policy mix involves a combination of financial stimuli which have provided better economic conditions and increased market volume, while the R&D strategy has facilitated adaptation of knowledge resources to provide local solutions to satisfy increasing market demand. Performance in the two main sectors – electricity production from wind sources and manufacture of wind energy technologies – has made the Spanish manufacturing sector one of the leaders in national and international wind energy measured by number of patents and a trajectory towards sectoral specialization (see Fig 3).

Figure 3 Revealed technological advantage (RTA)[5] in inventive activity by sectors: OECD countries 2009



Source: (Getz, Leck, & Hefetz, 2013)

Despite the progress made in relation to wind capacity and development of technological knowledge, the routes to specialization strategy implementation are still evolving. This is in part because recent performance by the Spanish wind energy sector has been affected by two factors. First, the world financial crisis which began in 2008 has affected global economic activity significantly and has had direct consequence for demand for electricity and related technology and infrastructure. Second, and related to the first factor, the increasing tariff deficit based in the special regime for renewable energy has forced radical change to the regulatory framework (García Breva, 2013). Both these factors have added to the debate on the role of public intervention and the design of measures to foster market deployment and technology development.

[5] The RTA index is based on patent counts filed under the Patent Cooperation Treaty (PCT) and provides an indication of the relative specialization of a given country in selected technological domains. It is defined as share of national patents in a particular technology field divided by national share in all patent fields. RTA is zero if the country has no patents in a given sector, is 1 if the national share in the sector is half of its share in all fields (no specialization), and above 1 if positive specialization is observed (OECD, 2011c).

The Renewables Energy (RREE) has experienced a shock through sudden exposure to more competitive market conditions (i.e. reduction in of financial stimuli) which have forced the mid and longterm reorganization of activities and objectives. The literature on the impact of policy instruments in promoting renewable energy distinguishes clearly between direct and indirect instruments to support market deployment and technology development in a context of increasing competition (Barradale, 2010a; Enzensberger, Wietschel, & Rentz, 2002a; H. Lund & Münster, 2006). Some studies emphasize aspects of the industry life cycle and technology maturity (Del Río González, 2009; Finon & Perez, 2007; Foxon & Pearson, 2007). The conflict that emerges is related to the design of policy to foster technology development which eventually becomes competitive without any kind of public intervention.

Recent work on the Spanish case (del Río & Bleda, 2012; Del Río & Bleda, 2013; González, 2008), point to the need for deeper considerations of the specific characteristics and structure of sectors to influence the rate (and speed) and direction of technological change in order to foster a proper national and regional innovative institutional context and conditions favourable to technological change (i.e. normative, financial resources, governance agreements). Policy instruments should rely more on the linkages between technological maturity and environmental change in order to exploit specific sector and market characteristics by applying different types of regulation at different times. This thesis seeks to contribute to a better understanding of the dynamic relation across time and levels, between environmental policy instruments and technological change, in the context of a policy mix that includes regulation on environmental issues, security of supply and innovation to promote the creation of new technologies and industries.

1.4 The structure of the thesis

The thesis includes six chapters. Chapter 2 provides a systematic review of the conceptual and analytical interpretive approaches to studying the phenomenon of the emergence and development of the wind energy sector in Spain. It includes two parts - Theoretical frameworks, and Methodology - which are presented as part of an integrated approach. The first part focuses on the integration of different conceptual approaches to energy policy, knowledge creation, innovation, multilevel governance, regional development and wind energy. All these concepts are investigated in order to avoid a narrow focus that might miss critical aspects of the phenomena under study. The second part describes the methodological approach, research design, data collection process and the mixed-method approach used to analyse the empirical case. The analytical approach seeks to provide validity for the research findings on complex and multifaceted phenomena. It emphasizes the identification of the linkages between three policy domains, exploration of modular and complementary knowledge through the concept of technical platforms as an analytical tool, and analysis of different regional setting based on diversity and variety.

The empirical part is presented in Chapters 3 to 5. Chapter 3 provides the institutional background to the empirical study and includes sets of instruments from the energy, industry and science, technology and innovation domains. The analysis is based on a chronological investigation of the policy instruments implemented at different levels in a variety of policy domains in terms of rationales, goals and commonalities in the process of supporting new market creation and technology development. It includes a review of the performance indicators for specific areas such as renewable energy and wind in Spain.

Chapter 4 analyses wind energy sector developments based on two drivers: market forces associated with commercial opportunities, and technological forces driven by scientific advances. The empirical study of wind energy technology investigates specific characteristics of traditional sectors such as metallurgy, electronics and power generation, in terms of adapting the existing knowledge base, industry capacity, and technological background in order to exploit market opportunities. Aspects of innovation platforms, such as adaptation, integration and complementarities between knowledge bases, are used as conceptual pillars supporting the description of technological and industrial developments in the wind energy sector. This chapter also examines the wind energy value chain as a general concept to analyse the Spanish case in terms of diversity of activities, market structure and paths to knowledge creation.

Chapter 5 presents analytical evidence on pathway creation regarding the emergence of the wind energy sector in Spanish regions. The variety of regional settings is analysed by identifying and comparing key technological, economic and institutional factors across regions. It explores the way different regional setting and competences can facilitate the pathway creation towards industrial specialization though the recombination of local resources with the existing knowledge base. It includes comparison of regional competences, focusing on the history of the industry and the regional knowledge resources that are the basic inputs to the application of a regional typology based on the concept of related variety.

Chapter 6 summarizes the research findings within a conceptual mixed method approach. Reflections on the policy mix related to wind energy within a multilevel environmental governance system are provided by identifying key linkages among different policy domains and levels. Technological trajectories in wind energy technologies highlight the process of use and combination of technological knowledge and the concept of related variety and summarize the key findings at the regional level in relation to patterns of specialization. It discusses some limitations of the research, managerial and policy implications and suggestions for future research.

Chapter 2: The theoretical framework and methodology

2.1 Introduction

This chapter provides a systematic review of conceptual and analytical interpretive approaches to studying the phenomenon of the emergence and development of the wind energy sector in Spain. The methodology involves keeping track of simultaneous processes such as policy design and implementation, knowledge creation and the deployment of tangible and intangible resources at regional level. The empirical study focuses on research questions concerning different domains, each of which is approached by combining methods to cover the different aspects involved.

Theoretically, the main challenge is the integration of different conceptual approaches to energy policy, knowledge creation, innovation, multilevel governance, regional development and wind energy. The review involves the integration of all these concepts in order to avoid a narrow focus that may miss critical aspect of the phenomena under study. Accordingly, this work has been developed along three main conceptual dimensions the: 1) technological trajectories, as explanatory background for an emergent sector; 2) the policy mix where multilevel and governance elements support sector evolution; and 3) regional setting, which allow the exploration of different specialization paths. Knowledge creation is the common element and main driver of these dimensions because it involves interactions among multiple elements of environmental governance over time.

In practice, analysis of the wind energy case benefits from inputs from a broad spectrum of research areas, evidence-based studies, prior knowledge from regional development studies (Narodowski & Matti, 2007) and consultancy on environmental projects (Ravella, Matti, Giacobbe, Aon, & Frediani, 2011). This chapter describes the theoretical background and research design for the empirical study. Section 2 presents the key theoretical concepts along the three dimension referred to above. Section 3 describes the methodological approach, research design, data collection process and the mixed-method approach used to analyse the empirical case.

2.2 Theoretical elements for a multidimensional empirical study

The emergence and development of the Spanish wind energy sector is approached conceptually to encompass various interactions among the technological, policy and regional dimensions. The recent surge of interest in the potential of renewable energy has placed energy generation at the core of modern policy discourse. Energy policy has become a key arena where different actors seek solutions to climate change, while the climate policy agenda has become integral to energy policy. The long term strategic response has involved the implementation of a set of policies on energy, industry and innovation, which, in turn, has entailed a redefinition of roles and resources across multiple levels of decision-making (i.e. European, national, regional). At the same time, the search for solutions to the environmental problem is providing a window of opportunity for home market deployment and technology development. These opportunities are pillars for process of pathways creation based on the use and recombination of existing knowledge towards the development of an emergent technological sector.

Finally, institutional change and technology development rely on a set of capacities embedded in the regional context. Thus, the policy implementation process requires sound knowledge of regional physical and intangible assets, and tight coordination between businesses, public entities and knowledge institutions. Policy design refers to multi-level decision-making in multi-actor contexts (Laranja, Uyarra, & Flanagan, 2008a) and an appropriate mix of investment in infrastructure and programmes for the application of existing knowledge to foster regional smart specialization. Figure 1 depicts the key concepts around the three dimensions of this study: policy mix, regional setting and technological trajectories.

Figure 4 Dimensions on process for knowledge creations

The process of knowledge creation is the main driver of development across these dimensions, however, each dimension can be enabling or be an obstacle depending on the timing and degree of development of the contexts in which process occurs. Thus, there is a connection between the background processes and institutional conditions. In the following sections, the three conceptual dimensions are described taking knowledge creation as the key common element.

Knowledge is defined first as a driver of change by considering learning, where the use and recombination of knowledge is influenced by market forces and technology development. The typologies of knowledge and institutional aspects related to governance, contextual factors and policy instruments for the creation of knowledge are introduced. These concepts are used to explore the theoretical implications of the policy mix and regional setting. The concept of innovation platform as analytical tool is discussed as a mechanism to foster technological knowledge creation.

In relation to the policy mix, the factors related to policy implementation are explored conceptually by focusing on a context of multilevel governance interaction which entails implementation of different instruments in combination at different political and administrative levels and policy domains by configuring a dynamic policy mix. The industry development trajectory through the introduction of new technologies is discussed in the context of innovation policy as part of a complex portfolio of instruments which includes environmental and industrial policy. Four dimension of this trajectory are introduced- policy domains, governance, geography, and time- to add analytical elements to the interaction and conflicts among instruments, actors and policy goals. The nature of the policy instruments related to market deployment and technology development is discussed.

Finally, the regional dimension is framed in a sequence of concepts starting from geographical proximity and industrial agglomeration. Processes to foster innovation and achieve competitive advantages are presented in terms of coordination among economic and knowledge issues from a multilevel perspective. Particular emphasis is put on analytical elements such as regional supporting infrastructure and knowledge bases, and the concept of regional variety is introduced as an operational concept to analyse shared or complementary knowledge bases and competences.

2.2.1 Knowledge as a driver of change

Knowledge is recognised as a main driver of economic growth. Achievement of the social, economic and technological potential opened up by new knowledge involves a multiplicity of development pathways that are not necessarily mutually exclusive. What is key is that the amount of knowledge is no more relevant than its effective use, which depends on exploration of the space of possibilities and deployment of the right resources to achieve the best possible goal (Nelson, 1974). However, the potential for such exploitation is influenced by the relative stage of development of the technological trajectory (Dosi, 1982; Saviotti & Pyka, 2004)

This argument is in line with Kline and Rosenberg (1986) who point that the relevant question is what kind of innovation is desirable, and which way is the most convenient to achieve it. From this perspective, economic development can be understood as the use of knowledge to stimulate change by means of a selection or “creative destruction” process (Schumpeter, 1950). The path to economic growth is characterized by continuous renovation of economic activities emerging from the combination of various knowledge (J. Stan Metcalfe & Georghiou, 1997) and its recombination across the elements of the internal knowledge base (Quatraro, 2010a).

The notion of innovation can be understood as a process of change in relation to the coexistence of two driving forces: market forces associated with the emergence of commercial opportunities, due e.g. to changes in income levels or demographics and technological forces driven by scientific advancements and the goal of achieving economic benefits such as cost reductions (Kline &

Rosenberg, 1986). However, change increases market uncertainty which requires the ability to apply different types of knowledge along the life cycle of products, processes and forms of organization. Market opportunities are conditioned to the ability to manage different kinds of knowledge (e.g. scientific, technological) to achieve competitive advantages where competition shapes the innovation process (James Stanley Metcalfe, 2005).

More specifically, there are two components to the idea of knowledge as a driver of economic development. First, knowledge itself, as an essential input to be combined in a dynamic process with other factors such as competence, talent and skills, with the aim of generate new knowledge. Second, the governance mechanism by which *"new knowledge is generated, recombined, experimented and eventually applied, which cannot be separated from the specific competitive, productive and organizational context into which firms' conducts and strategies are embedded"* (Antonelli & Quéré, 2002).

Both components, knowledge as a dynamic process and the instruments supporting that process in term of governance mechanism, are key to understanding the creation of new technological knowledge. The elements related to understanding the management of different forms of knowledge are explained below and include governance mechanism as instruments to drive the interaction among the different actors involved.

2.2.1.1 Matching process and instruments

The search for linkages between market opportunities and technical improvements is part of a learning process in which the management of different forms of knowledge is combined with cumulative experience, accurate feedback and appropriate follow-up actions (Kline & Rosenberg, 1986). The chain-link model of innovation proposed by Kline and Rosenberg (1986) suggests that learning processes develop within a "linear model of innovation" - research-development-production-marketing- through the introduction of feedback mechanisms that connect research and all the subsequent steps, namely product specification, product development, production processes, marketing, and service.

The innovation process involves interaction among different forms of knowledge and interactions among the different actors, components and interests. The confrontation between "market pull" versus "technology push" is secondary to the innovation cycle as the dynamic sequence of new contexts and market conditions. According to the literature on the economics of knowledge, knowledge transactions and forms of knowledge interactions are part of the business governance system (Antonelli, 2006) which includes coordinated interaction and long term agreements within economic agglomerations such as technological districts. The technological knowledge stemming from these interactions is intrinsically heterogeneous and can take a variety of forms depending on the opportunities for interacting and transacting in different contexts.

The distinction between science and technology highlights the tacitness of knowledge. Tacit knowledge is an output of a learning process; codified knowledge is related to the processes of systematization and articulation. From a bottom up perspective, technological knowledge becomes scientific knowledge following the process of systematization, which allows its generalization and diffusion. However, technological knowledge may be embedded in routines and procedures that do not allow its diffusion or absorption, in different circumstances and contexts. Codified knowledge is important for introducing feedback mechanisms that connect research with all the subsequent steps (Kline & Rosenberg, 1986).

Thus, knowledge transactions among different actors and the steps towards innovation are the main mechanisms enabling the selection and combination of different pieces of knowledge to be used in a variety of ways and applications, and often referred to as modular divisibility (Antonelli, 2006). So, a preliminary question relates to how the characteristic of technological knowledge can influence the dynamics and direction of new technology developments. This is particularly important in relation to the heterogeneity of technological knowledge in terms of different activities and process and the need to develop mechanisms to manage the complexity of the interactions and coordination among actors related not only to the generation but also to the distribution and transformation of technological knowledge within the innovation system.

According to Metcalfe et al. (1997), the heterogeneity of knowledge is the main challenge for policy related to promoting more intensive exploitation of knowledge resources. Innovation policy could foster innovation capacity in terms of accessing external knowledge, recombining resources and supporting new types of innovations. However, the policy intervention mechanism depends on the a broad set of priorities on the demand and supply sides and how these priorities are interpreted (Nelson, 1974). Flanagan et al. (2011) state that innovation policies go beyond traditional science and technology policies by considering a policy mix in which innovation instruments are directly and indirectly induced by 'demand-side' as well as 'supply-side' instruments pursuing other policy goals such as energy, education or public services.

The literature on evolutionary approaches points out that the rationale for policy intervention should consider the diversity of regional settings, the variety of competences and the main regional technological areas (Laranja, Uyarra, & Flanagan, 2008b). The emergence of a new sector will be conditioned by the way policy intervention can create linkages between the variety of knowledge and the regional industrial setting (Boschma, 2009) where governance mechanisms entail the generation and distribution of technological knowledge across economic activities (Antonelli & Quéré, 2002)

More specifically, the geographical space is considered a critical element for the effective use of technological knowledge by operating as a governance mechanism to facilitate interaction, knowledge transfer and communication as well as management of a large amount of technological knowledge content which can be applied to a variety of products and processes (Antonelli & Quéré, 2002). Additionally, the regional governance mechanism also provide vertical and horizontal division of processes and activities which can be understood as an advantage to be exploited by a variety of complementary actors who are able to access the production of collective knowledge where it takes place (Antonelli & Quéré, 2002).

The division between the processes and activities among actors implies critical decisions with regard to selecting modes of governance that best suit the need for knowledge generation and exploitation. One example of these governance mechanisms is innovation platforms which represent intermediate forms of vertical integration by retaining the autonomy of the units while providing effective coordination and complementarities among innovative activities. Innovation platforms as a governance mechanism are an operational element of this study and are explained as follow. In what follows, conceptual elements related to the rationale of policy interventions are explored by considering multiple sets of actors and levels. Finally, the focus is on the regional dimension of knowledge where policy setting, regional variety and industrial history set the context for the development of new technological knowledge.

2.2.1.2 Innovation platforms

The path of technology development in wind energy involves the use, adaptation and combination of different types of knowledge belonging to a variety of economic sectors such as electricity production, manufacture of power generation and electronic technologies and infrastructure and logistics. The interaction of different actors in the process of knowledge creation and adaption and, therefore, the development of products, technologies and services, is part of the processes and practices embedded in the search for complementarities. The innovation process benefits from the industries that made the first steps and, thus, the final result cannot be associated to a single framework of an industrial classification (Kline & Rosenberg, 1986). Those processes and practices are aimed at fostering innovation within the broader, complex economic and technological system in which they are embedded. The structure that allows the coordination of a variety of actors within the industrial domain, by combining individual goals and capacities with shared purposes, norms and expectations, refers to innovation platforms (Consoli & Patrucco, 2011) .

Platforms can be understood as the explicit engagement of different actors to foster and reinforce acquired advantages in different knowledge areas in the search for complementarities (Gawer, 2010). This engagement is based on the ability to maximize the variety of knowledge (i.e. to innovate) by maintaining clear direction within coordinated actions (Consoli & Patrucco, 2011). Innovating firms are those that are able to manage different interactions across network by taking into account the selection of resources and the coordination of activities aimed at contributing to a learning process. This coordination is important for increasing scale since the interaction between different elements of the system increases complexity and allows the business strategy to switch from integrated to modular in order to better connect and articulate the knowledge bases and technologies.

The system defined by the platform may include a number of components and activities depending on the scale of the integration. Gawer (2010) proposed a typology of four platforms according to how the resources and activities are managed within different business contexts such as the firm (i.e. internal platform), supply chain and industry. The operation of platforms at all these levels follows the principle of systematic use of modular components to explore complementarities among knowledge areas while maintaining system stability. However, differences between firm (internal) and supply chain platforms relies on the internal/external operation of modules while industry platforms differ in supply chain relations among firms that are not necessarily connected by buyers/seller relations or patterns of ownership in industry platforms. Finally, the internal and supply chain platform focuses on the firm as the integrator/assembler/designer while the industry platform emphasizes a component that is not part of a previously determined product or service.

With respect to the role of the firm in the platform, Consoli and Patrucco (2011) state that innovation platforms are flexible within both modular and integrated systems. Firms play the role of "system integrators" to redirect, combine and manage the different knowledge flows involved in complex innovations. However, the operations of firms as system integrators may depend on the dynamic properties of the platform in terms of the ability to solve problems through effective governance mechanisms, and the search for a balance between increasing variety and heterogeneity of knowledge and pattern of individual specialization. Finally, the platform can incorporate a proper degree of openness to establish a proper direction and convergence toward platform objectives.

2.2.2 Policy mix within a multilevel environmental governance system

Since the mid 1990s, an international energy system has emerged among the main regions in both industrialized and developing countries, which strongly interacts with regional and local natural resources and technological capacities. The interaction between innovations developed at the international level and different local energy system trajectories might explain how a variety technologies and approaches to sustainability have emerged in different locations. Thus, understanding the pattern of development and diffusion of renewable energy cannot be separated from the broader technological, economic, political context or the natural resources confined to the regional and national settings. On the other hand, factors related to the implementation of policies cannot be confined to a regional governance arena or reduced to struggles between central and local government (Bulkeley, 2005; Cash et al., 2006; Morgan, 2004)

Regional implementation processes involve a rethinking of the interaction/relationship between the public and private sector in the subsystem, and with those actors beyond the regional sphere. This entails a focus on multilevel governance interaction (Bulkeley, 2005; Fernandez-Ribas, 2009; Laranja et al., 2008b). The roles and relationships among different players in policymaking have changed in modern Europe, which has become less hierarchical, and have given more power to the regional level through changes in the mechanisms of public management and the process of policy implementation (Schofield and Sausman, 2004). These new roles and relationships are based more on implementing combinations of instruments at different political and administrative levels and in different policy domains by configuring a dynamic policy mix (Flanagan, Uyarra, & Laranja, 2011b; Laranja et al., 2008b).

Regarding environmental governance, the process of Europeanization of national and regional policy-making through the shaping of informal structures such as business-government relations and public discourse (Risse, Cowles, & Caporaso, 2001) has focused on achieving two objectives simultaneously: energy-environmental responsibilities and local economic development (Cooke, 2010; Gibbs, 1993; Jordan & Lenschow, 2000; Jordan, Wurzel, & Zito, 2000). Hajer (1995) emphasizes that the political discourse recognizes the structural character of the environmental problem, but nonetheless assumes that existing political, economic, and social institutions can internalize care for the environment. The decoupling of a general recognition of the problem and the assumption that existing institutions have the capacity to solve it, has promoted discussion of particular regional needs and problems, which require identifying what further actions need to be undertaken in each region, and what other actions each could offer.

The implications for regional economies in this perspective in terms of compatibilities with EU and other global organizations, are substantial. EU legislation and programmes supporting R&D are the effective starting points and bases for local proactive strategies (Flynn 2000) to explore opportunities to foster new regional capacities (MacKinnon, 2012; Ron Martin, 2009; Tödtling & Trippl, 2005). The response to this new context, is a general reorganizing and restructuring of the familiar institutional arrangements and processes of the welfare state that are characterized by terms such as: decentralization, deregulation, privatization, rehabilitation of the market, etc. These processes involve actions and arrangements that require multi-level multi actors and interactions among multiple policy domains such as innovation, industry and environmental policy (Böhringer & Rosendahl, 2010; Lehmann, 2008; Oikonomou & Jepma, 2008; Sorrell & Sijm, 2003; Stewart-Rattray, 2009).

More specifically, recent evidence on regional wind energy developments (Dawley, 2013a; Fornahl, Hassink, Klaerding, Mossig, & Schröder, 2012; Smith, 2007) shows that the evolution of regional strategies to foster home market deployment and technology development is characterized by a variety of institutional changes and shifts in the local implementation of policies on environmental issues. In the following sections, we discuss the policy mix by considering the different levels, geographies and domains involved as well as the existence of reformulations and adaptation through feedback loops across time.

2.2.2.1 Policy domains and multilevel interaction. Unravelling linkages and complementarities between innovation and energy policy

Innovation policy is part of a complex portfolio of instruments used by policy makers to address multiple and interrelated objectives. The literature on innovation studies argues for the need to explore cross relations with other areas (Morlacchi & Martin, 2009) and policy mixes operating in multi-actor and multi-level contexts that require a better understanding of the processes by which policies emerge, interact and affect each other (Laranja et al., 2008b; Flanagan et al., 2011b; Magro & Wilson, 2013). More specifically, in the case of the energy sector, a cluster of recent studies points to the linkages between the instruments designed to ensure security of supply and environmental commitments and the simultaneous innovation process aimed at developing technologies for this purpose (del Río & Bleda, 2012; Horbach, Rammer, & Rennings, 2012; Veugelers, 2012)

Several studies in the RES-E emphasize various elements to understand the trajectory of industry developments through the introduction of new technologies. For example, Lund (2009) distinguishes two different, but compatible paths to industry expansion based on R&D support: improving the position of domestic industry and upgrading competitive capacity to induce technology exports. On the other hand, R&D policies are useful so long as they are part of a wider set of market policies which might include removal of the barriers to new entrants, and forging agreements among advocacy coalitions that might enhance a network environment (Jacobsson & Lauber, 2006).

Along these lines, del Rio (2009) argues for the need to improve explanations of the determinants of environmental technological change by deepening the empirical analysis of the institutional innovation context at both national and regional level, to identify conditions favourable to technological change. The understanding of innovation system is a critical requirements on making effective policy to face the diversity of technologies and recognizing which barriers should be addresses though the different stages of innovation process (Foxon & Pearson, 2007). Thus, stability and flexibility in the implementation of policy instruments can be critical to timing in relation to the maturity of the sector and the diversity of technology complexity. The expected trajectory of a successful technology would be characterized by a clear advance at different stages until achieving conditions for operate in fully competitive conditions (Foxon & Pearson, 2007). In relation to connection between flexibility of instruments and technological maturity, del Rio (2009), emphasizes the need to analyse the connection between environmental policy instruments and government funding for R&D related to new technologies.

These general aspects which we describe as levels, policy domains and time issues, are considered also by Flanagan et al.(2011) who argues that policy instruments are not necessarily stable in terms of their rationales, goals, use and impacts across time, space or policy domains. They strengthen the importance of interactions and trade-offs among policy instruments for a better understanding of their operation and change over time. This argument is based on the work of Bressers and O´Toole (2005) on the interactions among different instruments and action taken at different levels of multilevel governance. However, Flanagan et al. (2011) emphasize the significance of interactions and actions that might not be "predesigned", but might exploit time and context as a source of tension and conflict rather than linear elements of the policy process. They define four dimensions to analyse the interactions among different elements regarding the policy mix.

The policy space is the first dimension and is defined as the context in which different policy domains operate, for example, simultaneous implementation of environmental policy and innovation programmes to foster renewable energy technologies. He second dimension is the governance space which configures the set of interactions across multiple levels (e.g. European, national and regional) of governance (Laranja et al., 2008b). The third dimension incorporates territorial features into the analysis through the geographical space where the implementation of different policy takes place. Finally, they emphasize the dynamic pattern of policy instruments through the time dimension.

The four dimensions are considered in the literature in both general and specific contexts. From a general point of view, the concept of multilevel governance is introduced as part of the process of Europeanization of national and local policy making by focusing on how informal structures such as business-government relations and public discourse (Risse et al., 2001) focus simultaneously on achievement of two objectives: energy-environmental responsibilities and local economic development (Gibbs, 1993; Jordan & Lenschow, 2000). EU legislation and programmes supporting R&D effectively create the starting point and basis for local proactive strategies (Flynn, 2000) and problems should be expected only if there is a significant misfit between EU policy and other national, regional and local policies (Borzel, 2000).

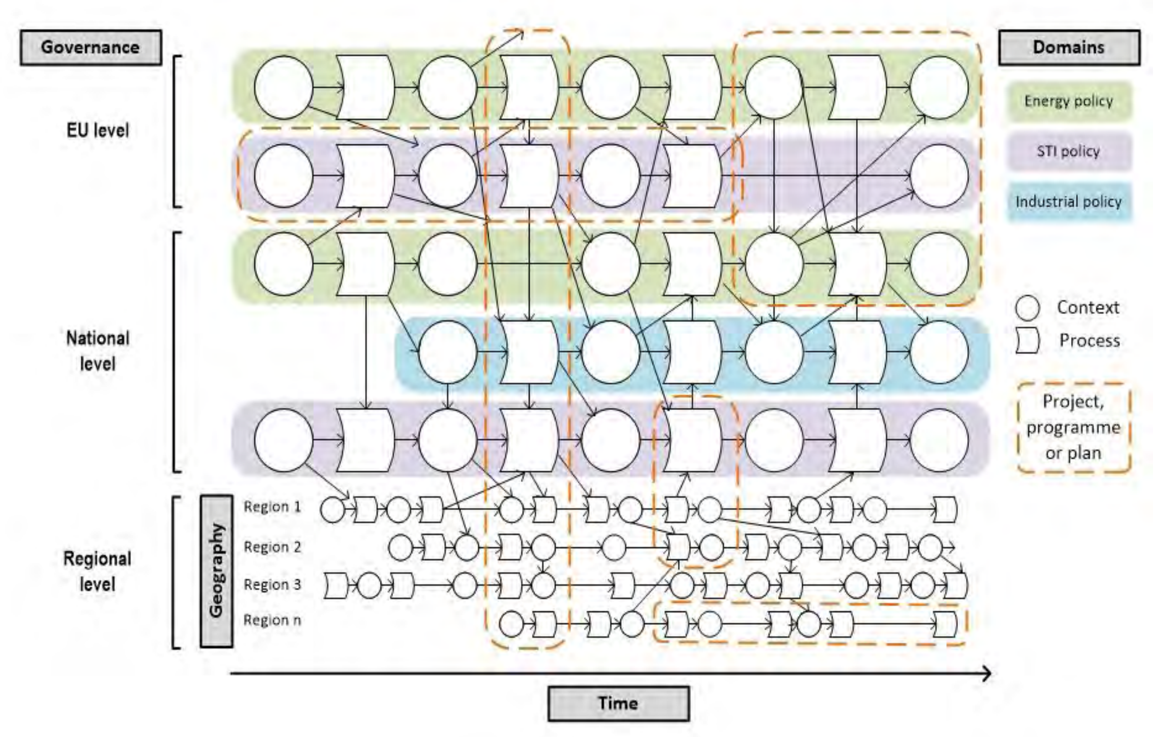
More specifically, the environmental governance system involves new configurations of state and non-state actors playing a variety of roles under overlapping and competing authorities at different levels (Bulkeley, 2005). For example, contextual interaction theory (Boer & Bressers, 2011) specifies domains that define the system regarding the process of policy implementation. These domains include the “scales” at which the relevant actors operate at more than one level, the “sectors” or “domains” that configure the specific topics and aspects of the processes and consideration of “time” regarding the permanent evolution of the process and the interactions among actors.

The interactions among several different sets of levels/actors and sectors/aspects across time provide a systemic view of the governance system that includes integration between sectors (horizontal) or across levels (vertical), or both. This type of dynamics of cross-scale and cross-level interactions has been studied from the perspective of different institutions operating and managing the relations and processes of knowledge co-production, mediation, translation and negotiation across time (Cash et al., 2006). Emphasis is put on aspects related to the management process at different scales and towards assessing problems and finding solutions by applying sustainability criteria

To sum up, the four dimensions described in different approaches (i.e. policy domains, governance – levels-, geography and time) provide a framework to explore and analyse the interaction and conflicts between instruments, actors and policy goals. Conflicting rationales, goals and approaches to implementation are key to understanding the performance of instruments working in combination as part of a policy mix implemented at different levels. A deeper explanation of the characteristics of policy instruments in different domains is required to identify the potential source of conflict analysed in the empirical studies.

Figure 5 depicts the relations between the different elements described above. The governance levels are depicted as a sequence of contexts (problem–solving) and processes that interact across domains and time, with particular emphasis on the variety of simultaneous regional processes. This interaction among different elements (e.g. policies, programme, instruments, and actors) are also analysed empirically. The identification of causalities and logics underlying this interaction are expected to contribute to a better understanding of the process of knowledge creation in the development of the Spanish wind energy sector.

Figure 5 Four elements for analysis multilevel governance systems



We next describe the interaction among these different instruments to support innovation and deployment in the energy market.

2.2.2.2 Matching policy instruments supporting renewables energy sector through different policy domains

The conceptualization of different elements of the policy mix allows a better exploration of the interactions and conflicts among the instruments applied to foster the renewable energy sector. Recent studies provide explanations for the linkages between instruments aimed to promote the introduction of environmental technologies, energy, and policies oriented to foster innovation (del Río & Bleda, 2012; Horbach et al., 2012; Veugelers, 2012) by looking at possible ways to combine technology push, market pull and a regulatory push approach. Work on specific energy policy identifies mechanisms to support the renewable energy sector such as demand pull policies (Barradale, 2010b; Enzensberger, Wietschel, & Rentz, 2002b; Jacobsson & Lauber, 2006; Lewis & Wiser, 2007; Meyer, 2007; Nemet, 2009) which are part of a broader set of supply and demand oriented instruments, but act as direct and indirect mechanisms to foster the development of new sectors.

More specifically, instruments designed under the rational of fostering Electricity production from Renewable Energy Resources (RES-E) can include both direct instruments based on innovation support and industry policy oriented to technology development, and indirect instruments to foster market deployment with accompanying regulation and technical standards (Lewis & Wiser, 2007; Nemet, 2009). The interactions and trade-offs among policy instruments shapes the implementation process over time in different directions, between home market deployment and technology development (P. D. Lund, 2009a; Nemet & Kammen, 2007; Veugelers, 2012) on the one side and balancing society's demands (i.e. environmental commitments) through the promotion of innovation in new technologies on the other (OECD, 2011a; Lewis & Wiser, 2007; Del Río, Carrillo-Hermosilla, & Könnölä, 2010; del Río & Bleda, 2012; Horbach et al., 2012; OECD, 2011b).

Instruments designed to foster technology development are mainly supported by science, technology and Innovation policy which can include R&D support for university-industry cooperative projects and funding for specific research infrastructures (Corsatea, Giaccaria, & Arántegui, 2014). Industry policy includes initiatives to support market penetration, R&D assessment, market evaluation, technology transfer and diffusion and commercialization of new technologies (Lewis & Wiser, 2007; P. D. Lund, 2009a). Government interventions address cooperation among firms in different sectors through value chain integration, and specific regulations on local content requirements.

New market creation is fostered by rules and frameworks that create more competitive conditions (i.e. definition of actors and activities, financial stimulus) for the commercialization and operation of new technologies. Enzensberger et al. (2002) highlight the legislative nature of these instruments, which can include command (demand) and control measures as regulations and standards that establish limits on and ways to achieve particular objectives (types of energy, technical specifications, environmental indicators). Technical specifications and "mandatory fuel off take" as a type of regulation are also included in this category (Meyer, 2007; Saidur, Islam, Rahim, & Solangi, 2010)

Market-based instruments may also be part of supply-push and demand pull measures. Supply push measures are oriented towards construction or production incentives that include financial stimuli such as feed in tariff (FIT) schemes and bonus that seek to internalize externalities and set appropriate prices to facilitate a learning curve in new technologies (Barradale, 2010b; González, 2008). Demand pull measures that influence energy demand are those that establish targets for energy production (Renewable Portfolio Standard - RPS quotas) and emissions (Lewis & Wiser, 2007; Ringel, 2006) and introduce government tendering as a form of public procurement (Lewis & Wiser, 2007). Supply push and demand pull measures work in combination and the interactions between these instruments should result in the creation of new markets (Del Río et al., 2010; Saidur et al., 2010).

Quota setting, government tendering, financial stimuli (i.e. FIT) and regulation and standards can be categorized as demand driven innovation policies. Measures of public intervention in this category can be understood as ways to improve the articulation of demand in order to facilitate innovation and allow diffusion in new markets. Edler and Georghiou (2007, p. 952) define them as follows:

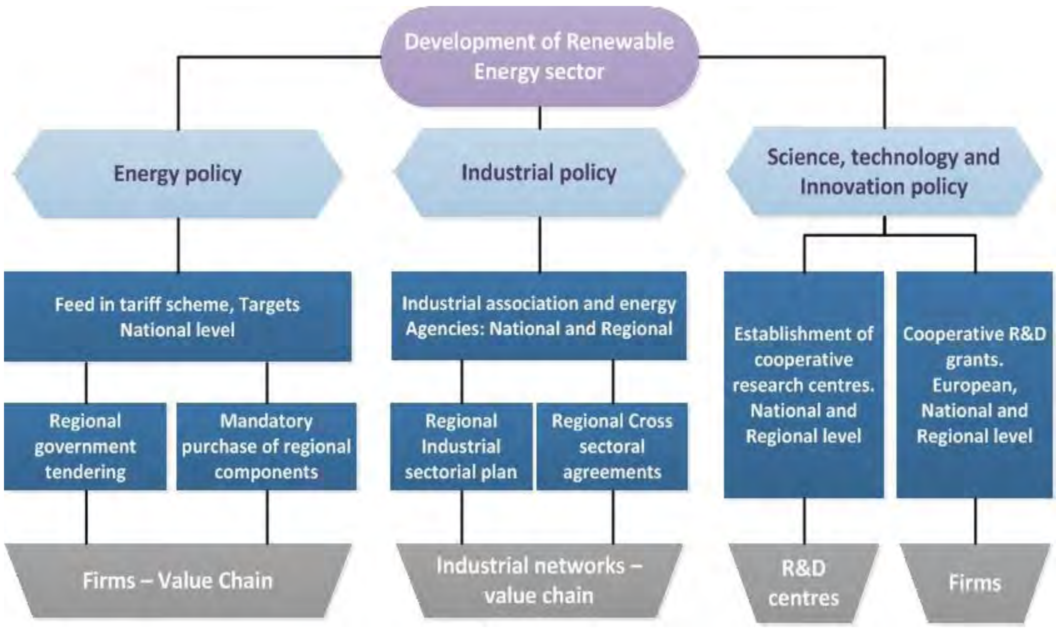
Demand side innovation policies are defined as all public measures to induce innovation and/or speed up the diffusion of innovation through increasing the demand for innovation, defining new functional requirements for products and services or better articulating demand.

Demand side policies can take various forms, but typically are sector specific and address the specific barriers affecting market introduction and diffusion of innovations. OECD (2011a) highlights the relevance of a broad category of instruments such as different forms of public procurement (with or without linkages to R&D activities), regulation and standards, and consumer policies and initiatives associated with lead markets aimed at diffusing innovation from one market to another (see Annex table x). Additional aspects of demand side innovation policy include organizational frameworks and capacity building through training and use of learning pilots to acquire experience and best practice to identify key areas of innovation(Gee & Uyarra, 2013; Georghiou, Edler, Uyarra, & Yeow, 2013). Recent studies highlight the importance of interactive learning to improve cooperation and competition in supply/demand market relations (Edquist & Zabala-Iturriagagoitia, 2012).

In the specific case of the RES-E sector, public procurement can be considered a strategic instrument to influence demand for certain technologies and stimulate their market deployment. However, these instrument can also be part of a specific policy mix in which regulation and standards combine to provide a form of guaranteed tariff and specific power purchase instruments. Support for R&D activities and infrastructures, knowledge transfer and promotion of innovation networks have also been identified as key elements in the development of RES-E technology (del Río & Bleda, 2012; Jacobsson & Lauber, 2006; P. D. Lund, 2009b). All these instruments affect both sides of the market (i.e. supply and demand) by creating better economic and institutional conditions in the sector. The analysis of RES-E policies to promote the wind energy sector should take account of commonalities among all these instruments.

Figure 6 depicted the policy domains and main categories of policy instruments for analysis of the RES-E sector. It follow the approach suggested by Magro and Wilson (2013) regarding the evaluation of policy mixes within a multilevel governance dimension. The science, technology and innovation policy domain is part of the technology push domain, while industry and energy policy are part of the set of market pull (supply/demand) and regulatory push elements which are driven by the common rationale to foster the RES-E sector. The main instruments are presented together with the actors involved in their implementation. Interactions and trade-offs among policy instruments can be identified by considering changes in rationales, goals, use and impacts over time, space and policy domains (Flanagan et al., 2011b).

Figure 6 Policy domains and main instruments fostering the development of wind energy sector



Source: own elaboration based on (Magro & Wilson, 2013).

In the following sections, the four dimensions proposed by Flanagan et al. (20011), i.e. policy space, governance space, geographical space and time – are explored through an empirical study of energy and research policy related to the wind energy sector in Spain. This chapter does not aim to propose an evaluation of policy interventions related to RES-E in Spain, but rather to provide an understanding of the processes and institutional context favourable to sector development and to contribute to explaining how the composition, stability and flexibility of the policy mix affects sector development.

2.2.3 Regional dimension of knowledge creation

The local innovation system becomes important when the components related to technology knowledge work collectively to transfer, combine and use internal and external knowledge resources and the impact of industrial and innovation policy becomes more significant (Antonelli, 2000; Colombelli, Krafft, & Quatraro, 2013). The regional level learning process is important for internal communication mechanisms and network mechanisms to support the search for complementarities and increase regional productivity through investment in innovation activities.

2.2.3.1 Regional setting, industrial history and knowledge bases

According to (Asheim & Coenen, 2005), studies of territorial innovation mostly rely on the concepts of Regional Systems of Innovation (RSI) and clusters. Clusters and industrial districts are based in Neo-Marshallian approaches in which territory is understood as an arena of change and geographical proximity is explained by physical, economic and social elements. Agglomeration externalities facilitate learning processes that foster innovation and enable acquire competitive advantage (Laranja et al., 2008b)

RSI takes account of the linkages among sectors belonging to the regional economy by considering the systemic interaction between knowledge organizations and firms (Asheim & Coenen, 2005). RSI can also be understood in terms of bottom up localized knowledge spillovers affecting geographical concentration of innovation activities or, alternatively, as novel forms of governance that facilitate the process of coordination among economic and knowledge issues from a multilevel perspective - European, national, regional and firm cluster level (Uyarra, 2010). In fact, the region represents and important stage of coordination between the national and local levels through governance structures that may vary from region to region (Asheim & Coenen, 2005).

Regional knowledge resources have been studied by differentiating between codified and tacit knowledge (Uyarra, 2010). More specifically, the geography of innovation emphasizes the process of regional learning by considering diverse forms of existing localized knowledge. Some properties of technological knowledge operate as selected forces and imply that some regions are better suited to combining pieces of information and knowledge than others. This implies regional comparative advantage to foster localized technological change and introduce self-reinforcing mechanisms based on localized increasing returns (Antonelli, 2000). In this respect, Asheim et al. (2005) distinguish between analytical and synthetic knowledge bases. Analytical knowledge is based on scientific knowledge and university-industry relations where scientific principle, methods and processes are applied to create new products and processes; synthetic knowledge refers to industry settings that apply or combine existing knowledge to solve specific problems (Asheim & Coenen, 2005).

Asheim claims also that these industry settings and related divisions of labour are the bases of the national-regional dimensions of knowledge resources through consideration of the role of the political and cultural organizations involved. Uyarra (2010) coincides with this argument and points to the perspective of national systems of innovation (NSI) and RSI in analysing the performance across countries or regions which cannot be focused in the unique study of firm's behaviour. The history of the regional industrial setting and the existence of a variety of knowledge organizations are important factors explaining the relation between territorial agglomeration, learning processes and paths to of sectoral specialization (Colombelli et al., 2013). In fact, the nature of market problems, the way they are addressed, and the state of the industry knowledge varies significantly across regions, as does the innovation output (Kline & Rosenberg, 1986).

These relations traditionally have been linked to the concept of path-dependency (David, 1985), defined as *"the way in which small, historically contingent events can set off self-reinforcing mechanism and processes that 'lock in' particular structures and pathways of development"* (Martin & Sunley, 2006, pp 7). The concept provide elements to explain patterns of industry localization and agglomeration based on regional structural factors, and regional specialization can be studied by examining the agglomeration in the process of overcoming path dependency based on the dominant technological trajectory (Asheim & Coenen, 2005).

Successful regions are those that can overcome “lock ins” and develop endogenous capacity to adapt and transform knowledge resource to innovate in a new sector to create competitive advantage (Asheim & Coenen, 2005). This adaptive performance is explained in evolutionary approaches which identify new pathways based on the ability to transform the cognitive capacity of the agents in the system. These evolutionary approaches suggest that the rationale for policy intervention should be to foster this ability and consider the diversity of regional settings in terms of local path-dependencies (Colombelli et al., 2013), variety of competences, timing and characteristics of main technological areas (Laranja et al., 2008b).

This argument implies that a generic ‘one-size-fits-all’ policy, such as transferring or copying best practice from one case to other, will not be effective (Tödtling & Trippl, 2005). Specific problems have to be addressed with available resources in order to apply a diverse policy mix for differentiated potential development paths (Laranja et al., 2008b). New sectors can be stimulated by considering a selection of instruments according to the region’s history, knowledge and institutional base, such that the policy intervention highlights the relevance of linkages between the variety of knowledge and regional industry settings (Boschma, 2009; Laranja et al., 2008b) that originate in the competitive market process (James Stanley Metcalfe, 2005)

In the following sections, we provide a more detailed explanation of the main regional elements related to path creation by linking the concepts and arguments of RSI and economic geography. Types of instruments and policy mixes to be applied at regional level will be compared in order to clarify the relevance of different knowledge sources and diverse regional settings in the design and implementation of policy instruments.

2.2.3.2 Related variety and pathway of knowledge creation

According to Asheim et al. (2005, pp 1177) RSI can be defined as “The regional supportive infrastructure or knowledge generation subsystem which consists of public and private research laboratories, universities and colleges, technology transfer agencies, vocational training organizations, etc.”. However, in the systemic dimension of RSI in term of linkages among organizations, sector and processes, Asheim and colleagues state that regions play two additional critical roles in the coordination between the higher (European, national) and lower (local) levels.

First, regions provide a governance structure in terms of the economic process that facilitates the stages of policy implementation and also in terms of the richness of the public and private organizations that support and promote innovation through multilevel and multi-sector linkages. Second, empirical studies have highlighted the regional properties related to containing a large part of these activities within the value chain which, while creating interdependencies with regional and national government, means the location of industrial activities is driven by creating connections to regional knowledge infrastructures.

Asheim et al.(2005) base this broader dimension of RSI in Lundvall's (1992) conception of innovation systems and consider the full set of actors affecting the learning processes in which bottom up elements and interactive innovations are included under the category of learning regions. Uyarra (2010) also highlights localized bottom up learning processes by pointing to the evolutionary notion of variety where knowledge sharing networks explore internal and extra regional complementarities in knowledge bases and competences to promote changes in technological trajectories and their associated path-dependent industrial histories.

Following this argument, (Asheim, Boschma, & Cooke, 2011) state that different forms of regional variety, defined as "sectors that are related in terms of shared or complementary knowledge bases and competences", are relevant because of their potential different economic effects. They claim related variety goes beyond concepts such as regional diversity or pure specializations (which implies relations in terms of larges and smaller cognitive proximity) to concentrate more on the linkages between interactive learning and innovation.

Building on this framework, Asheim et al. (2005) provide an example of a typology of RSI. The first type, territorially embedded RSI, where firms are based mostly on the application of synthetic knowledge and engage in innovation activities by interacting with local firms supported by regional knowledge institutions. The second type, regionally networked innovation system, is characterized by firms that engage in innovation activities and interactive learning and develop a stronger connection with regional institutions and knowledge infrastructure. In this sense, this type of RSI is the result of a policy intervention to improve innovation and collaboration capacity.

The third type, the regionalized NSI, includes most of the institutional and industrial elements linked to the national and international innovation system since most collaboration involves extra-regional actors. This type is characterized by collaboration between large firms and leading knowledge institutions concentrated mostly in science parks and technology poles, which implies a lack of local linkages with regional resources and a weak impact on regional learning processes in terms of the variety of the actors involved (e.g. local industry and SMEs). In this respect, lack of local linkages implies that the weakness of regional innovation policy is more important for the implementation than the design and selection of policy instruments (Laranja et al., 2008b; Magro & Wilson, 2013).

Asheim et al. (2005) states that this typology supports the idea of different rationales, elements and understanding to explain the RSIs' reliance on the industrial knowledge base and level of accessibility to knowledge organizations. Dawley (2013) points out that regional industrial structure can facilitate the development of a brand new sector, but it does not show how it is created. Dawley argues for a better understanding of these processes to facilitate a more enabling environment.

The formation of new processes is a main argument in evolutionary economic studies based on the concept of related variety to explore the emergence of new sectors via the recombination of knowledge and technologies from existing sectors (Boschma and Frenken 2009). Dawley (2013) points to four mechanisms identified by this literature that explain the process of transfer of knowledge from existing to new sectors:

- ✓ Diversification of firms (e.g., new products, mergers, acquisitions)
- ✓ Entrepreneurship (e.g., spin-offs and startups)
- ✓ Labour mobility (between firms and sectors)
- ✓ Social networking (e.g., professional associations).

The relevance of these mechanisms relies in the linkages between related variety and technological trajectories and their associated path-dependent industrial history. As already mentioned, the RSI literature suggests that policy interventions should be based on linkages between the variety of knowledge and the regional industrial setting, however, regions are embedded in a wider context shaped by inter-regional relations, national priorities and wider political and economic factors (Coe 2011 cited by Dawley 2013).

According to Dawley (2013), there is a need to better explain the way this mechanism operates and facilitates path creation for developing new sectors within a broad context that includes multi-actor and multi-scalar policy configurations. More specifically, there is a need to focus on better ways to explain how policy intervention can facilitate the process of deepening and broadening existing regional knowledge base to foster path creation for development by considering a broader approach involving multi-level relations (international, national, regional, local) as well as the political, economic and industry specific context.

In the following section, some elements of the context for the development of renewable energy are discussed, taking account of the different types of policy instruments and mechanism applied to comply with international environmental commitments and foster the renewable energy industry at regional level.

2.3 Methodology

This research use the method of triangulation of case study research. Multiple method research based on this approach is seen as providing validity for research findings for complex and multifaceted phenomena (Herman & Egri, 2006). Case study research was selected because it provides sufficient flexibility to investigate a contemporary issue within its natural context, and to emphasize the differences and similarities between the issue and the context (Yin, 2008).

Multiple data gathering and analysis methods were used to better understand the emergence of the Spanish wind energy sector and identify how particular activities and instruments and resources change over time, and under what circumstances. This should provide a richer and deeper understanding of the multi-level and multi-actor governance system. Regarding methodological triangulation, the empirical study develops qualitative data collected in interviews, reviews of policy documents and various other sources. Data analysis includes both content analysis and statistical procedures.

Theoretical triangulation is applied to explore different perspectives on the emergence and evolution of the wind energy sector. We draw on three literatures in order to frame a systemic perspective of the phenomena. First, the innovation and environmental policy literature is applied to define the concept of "policy mix" which facilitates our explanation of the multi-actor and multi-level policy background for the empirical study. We emphasize the linkages between three policy domains: energy, industry, and science, technology and innovation policy. Second, the concept of technical platforms is applied to explore modular and complementary knowledge bases in the formation and evolution of wind energy value chain. Finally, the regional dimension is analysed by considering the variety of regional settings in terms of natural resources, knowledge bases, industrial history and institutional and research structures. The regional aspect is explored by tracking the linkages between interactive learning and innovation through patterns of specialization and related variety.

The empirical analysis is based on a set of elements critical for knowledge creation. These elements have been described in various theoretical approaches and consist of:

1. Time: the empirical study is based in analysis of a sequence of actions and contexts by considering a historical view of the development of the Spanish wind energy sector;
2. Domains: the wind energy sector comprises different and interconnected areas. The main ones are energy issues, industrial and technology trajectories, innovation processes and regional development
3. Governance: the concepts include the variety of actors and process among the different levels of government/policy implementation considered in the empirical studies
4. Geography: the regional dimension is the main element explaining the emergence of the Spanish wind energy sector. In analysing the regional setting and its evolution, we emphasize the path to sectoral specialization.

These four elements, which are linked to the conceptual tools described above, are the bases of the three empirical chapters: policy background, technological development and the regional dimension. The research questions outlined in the introductory chapter are addressed by applying a set of qualitative and quantitative methods selected according to each of these dimensions. The related research design that is briefly explained below.

2.3.1 Research design

The time period of this research was chosen considering the general background of the set of policies formulated since Spain's entry to the EU and the decentralization process. The chronology of policies from the early 1980s to the late 1990s (in particular) are analysed to generate the basic inputs[6] required to frame the deeper empirical study that focuses on the period 2000-2013 and constitutes the most important part of the study. This period (2000-2013)

[6] The period 1979-1991 is considered the early stage when the first Spanish policies were formulated, and Spain joined the EU. The period 1996-1998 saw the co-evolution of policies aimed at supporting the liberalization of energy markets at European and national levels. Long term plans were introduced to induce a sequence of radical of changes in the national energy frameworks towards an incremental harmonization of the energy sector.

was selected by considering the 2001 introduction of the EU Directive on Energy Targets [7] and the following sequence of national's measures representing the Spanish response.[8] This implementation process is the background to the empirical study, which is conducted in three parts according to the knowledge creation dimensions:

1. **Institutional and policy background**. Energy and innovation policies for developing the Spanish wind energy sector are described based on multiple dimensions of the policy mix;
2. **Technology and industrial development**. Includes key elements to understand the technology and industrial development in wind energy sector at general level and by focusing in Spain
3. **Regional dimension**. Emphasis on regional industrial histories and the variety of knowledge bases underlying the wind energy sector.

Each of these dimensions is addressed in an empirical chapter which contributes to the evidence by building up the arguments starting from the general policy background and moving towards a system perspective of technological and industrial aspects. Finally, the focus is on the implementation of policies and use of regional resources to foster home market deployment and technology development. The data sources and methods employed in each empirical chapter described below.

2.3.2 Data gathering and organization of resources

Data collection was conducted in several sequences according to the logic of building a storyline related to the Spanish wind energy sector. The four secondary sources of data are:

1. Compilation of normative, policies and specific energy programmes at national and European levels. Reports of national and regional energy associations and sectoral reports used to develop the general background to the policy implementation

[7] The period is characterized by strong political activity defined by the introduction of the 2001 EU Directive and the Spanish response based on the Special Regime and FIT scheme. At the same time research programmes supporting the development of renewable energy technologies were introduced at multiple levels.

[8] The historical analysis includes 3 stages: A) 1990-2000: Creation of an internal energy market, B) 2000-2010. Creation of renewable energy market and support for opportunities in external markets, and C) 2010 – 2013: Economic crisis and new policy set.

process. Statistical data on economic performance and the evolution of energy balance;

2. Data from National and European programs on basic and applied R&D projects on wind energy sectors
3. Personal and group interviews with experts and researchers in the field, and regional and EU policy officers.

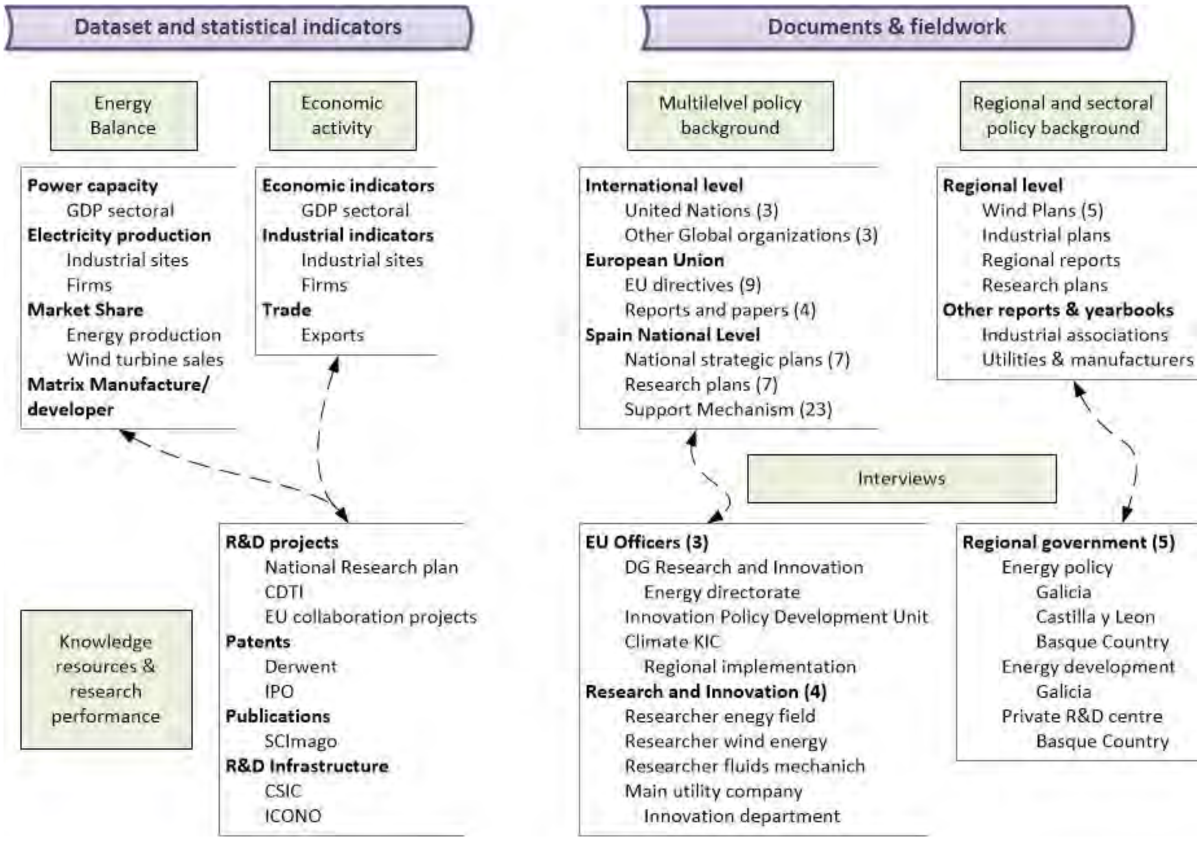
Regarding the compilation of policy documents, most of the documentation was collected in the first stage of the study and included the most recent reports, and other material. The documents can be categorized according to their policy domain as energy policy, industrial policy and research and innovation policy. The last group includes the set of R&D programmes with specific application in the energy sector. These categories were further subdivided based on governance level (i.e. EU/international, national or regional).

Data sets and statistical indicators were collected from different sources and integrated in a common panel categorized by type, domain and geographic scope. Economic and general industry indicators were collected mainly from the Spanish Statistical Institute - INE (INE, 2014); trade data are from the national Trade Office (DATACOMEX, 2013), energy balance data and energy subsidies are from the National Energy Office (DEE, 2013), and data on the wind energy sector are from the Spanish Wind Energy Association (AEE, 2013a). The data were used for describing the economic broader and specific context and were analysed at industry and regional levels as explained in the next section. Specific data on research projects were collected and include applied R&D projects on wind energy from the Centre for Industrial Technological Development (CDTI, 2013), national research projects from the National Research Plan 2004-2012 which were gathered from the official website (MINECO, 2013) and EU R&D cooperation project (CORDIS, 2013). The information on R&D activities were collected for the specific purpose of analysing the evolution of knowledge in traditional and specific fields related to the wind energy sector.

Finally, a series of interviews was carried out at different stages in the empirical study with the purpose of confirming indications emerging from different aspects of the study namely energy policy implementation, technological development and regional strategies. The first set of interviewees included EU innovation, energy and industrial policy officials, who provided the EU perspective related to regulatory frameworks, environmental commitments and innovation and research policy. The second set of interviews included experts in wind energy and related technological areas who provided highlights and specific insights based on their deep understanding of the technological evolution of the knowledge areas related to wind power. The last round of interviews was conducted during the three weeks of fieldwork in a selected group of Spanish regions (i.e. Castilla y Leon, Galicia and Basque Country). They were aimed at reviewing key elements and the results at regional level and collecting additional information on particular actions developed at regional level.

Figure 7 summarizes these four data sources and the categories and key variables considered.

Figure 7 Sources of data used for the empirical study



The data gathering strategy was based on a search for complementarities among sources and feedback loops. For example, economic performance and the evolution of the energy balance at regional level were key to the analysis of specific industrial infrastructures related to wind energy technologies and research infrastructures and performance in wind energy related projects. The semi structured interviews were based on aspects that emerged from an earlier longitudinal study of the portfolio of policies affecting the wind energy sector. The methods used to analyse the data as part of a triangulation approach are explained below.

2.3.3 Mixed methods as an analytical tool for the empirical study

According to the research design for this study, the empirical study comprises a sequence of three stages based on analysis of different dimensions in the process of knowledge creations (technological trajectories, policy mix, regional setting). The empirical study was guided by the research questions related to the process of building evidence on the emergence of a Spanish wind energy sector. It involved a mix of methods applied according to the type of data and phenomena of interested in each of the mentioned dimensions. The description of the applied in each of these three parts of the empirical study is provided below.

2.3.3.1 Part 1: Energy and innovation policies for developing the Spanish wind energy sector. Multiple dimensions of a policy mix

The first research question (RQ1)[9] - introduced in Chapter 1- refers to the analysis of different elements in the mix of energy, industry and science, technology and innovations policy. Chapter 1 reviews the strategies for pursuing security of energy supply and supporting the renewables industry in Spain. Here, we analyse government activity at the point of delivery (Hogwood, Gunn, & Archibald, 1984) by considering the dynamics of emerging needs and policy response underpinning the build-up of a new market.

The main objective is identifying two key dimensions of policy-building. First the set of priorities, strategies, goals, perspectives and activities stemming from them; second, the mechanisms that facilitate interaction across agents (e.g. regulations, availability of resources and economic instruments such as subsidies and technical support). The chapter 3 seeks to make sense of the multi-level policy portfolio (EU, central and regional Spanish government) by considering studies of the impact of EU measures in the Spanish context (de Alegría Mancisidor et al., 2009, Montes et al., 2007), institutional barriers to and drivers of the introduction of new technologies (del Rio and Unruh, 2007) and stability and flexibility of policy instruments (Perez and Ramos-Real, 2009).

[9] Research question 1(RQ1): *How has the policy mix for energy and industry been combined with science, technology and innovation instruments to support the development of the Spanish wind energy sector?*

In so doing this analysis seeks to advance understanding of policy reformulations towards further alignment between public goals, private motivation and the competitive environment.

The analysis adopts a mix of qualitative techniques to build the policy analysis and use of statistical indicators and data to highlight policy performance. The qualitative approach included "textual content analysis" (Saldaña, 2012; Stone, 1997) techniques applied to a variety of official texts and business documents regarding the development of wind energy in Spain.[10]The empirical study is framed by the application of two techniques: semantic analysis and discourse analysis. Semantic analysis is applied to identify relationships between the topics searched in the text. These topics are used input for the discourse analysis on the various arguments representing different positions and perspectives.

More specifically, semantic analysis facilitates identification of common topics around the two key dimensions of policy-building already described. Atlas.ti software is used to systematize and assess content using qualitative techniques. Finally, using the inputs developed in the previews step, discourse analysis is applied to find and represent "patterns of relationships" such as expressions regarding favourable positions to different decisions and actions and linkages across different action points. These relations are critical for developing a framework to analyse the influence of the policies under study (Forester, 1993; Hajer & Wagenaar, 2003)

In the statistical analysis, key performance indicators are applied to describe the evolution of energy sector variables and research performance over time. Key to energy performance are power capacity, evolution of the energy balance, longitudinal analysis of the subsidies granted by national government, price compensation and the cost benefit analysis in terms of the energy produced/subsidies for technology. Key to research performance and innovation activity are R&D expenditure, publications and patents and data on specific projects within European and national programmes. These indicators are evidence of knowledge creation within favourable market and economic conditions related to the renewable energy sector.

[10] The documents include: European policies and initiatives (includes EU directives, and R&D specific programmes), national energy sector plans, official regulatory mechanism documents (laws, royal decrees), business reports and annual reports from business associations, and industry publications.

2.3.3.2 Part 2: Technological trajectories and innovation platforms behind the emergence of wind energy value chain

The second research question (RQ2)[11] seeks to understand the combinations of technological capacities and knowledge leading to the development of a new sector. It is addressed through an exploration of the different elements and components of the wind energy sector and analysis of different systemic relations within the value chain. Emphasis is put on identifying areas of specializations to address home market deployment and technology developments and also the roles of key actors such as system integrators.

The objective is to achieve a better understanding of the evolution of the wind energy sector. We identify the key factors and circumstances related to the emergence of a dominant design (Murmann & Frenken, 2006) within wind energy technology and the main areas of knowledge related to complementarities and new modular combination of existing knowledge (Consoli & Patrucco, 2011). The analysis aims to improving our understanding of the technological trajectories behind the emergence of the wind energy sector. We emphasize particular configurations of the wind energy value chain in the Spanish case and analyse the diversity of activities, market structures and direction of specialization in terms of home market deployment and technology development.

This chapter uses a mix of methods to study technology development from a historical viewpoint of the Spanish wind energy sector. Specialist technical documents on wind energy are used to form a basis for the evolution of wind energy technologies. Emergent technologies and critical knowledge components are identified in interviews with experts in renewable energy, wind energy technologies and mechanical engineering.

Finally, we build a complete study of the general evolution of the Spanish wind energy sector using case study research. Spain is a relevant case; in a relatively short time it has become a world leader in energy and production of specialized technology. The analysis includes aspect such as energy performance, technological performance, the market structure, and knowledge creation through combination and use of statistical indicators, descriptive network analysis and use of

[11] Research question 2 (RQ2): to what extent have specific characteristics of traditional sectors such as metallurgy, electronics and power generation influenced the rate (and speed) and direction of technological development in wind energy?

secondary data to build a storyline related to the main actors in the wind energy sector and the evolution of knowledge and market positions (i.e. fusion and acquisitions operations).

2.3.3.3 Part 3: Regional specialization pathways in the Spanish wind energy sector

The third research question (RQ3)[12] explores the regional dimension of the Spanish wind energy sector by identifying between industrial histories and knowledge resources with respect to specialization paths. The chapter focuses on identifying and explaining regional strategies addressing the recombination of local resources towards the development of new industries through sectoral specialization. The analysis seeks to determine the existence of different ways of being "smart" in the specialization process.

The general objective of this chapter is to provide analytical evidence of paths to industrial specialization that fostered development of the wind energy sector in Spanish regions. We apply qualitative comparison of different configurations based on observation of key technological, economic and institutional factors with a view to identifying whether and how different regional contexts facilitate or not an emerging sector. This exercise illustrates the contingent nature of policy, and the diversity of the routes used to promote smart specialization in relation to what many consider to be a mature technology.

The empirical study of Spanish regions involves first comparison of Spanish regions in terms of regional setting, industry history and knowledge resources and. second analysis of the increasingly varied knowledge base and technological elements. In the first part, statistical indicators of power capacity and electricity production are applied to the energy profiles of each region and economic indicators, such as regional GDP, exports and specialized industrial structure, are used to describe their industry profiles. In addition, the market configuration of the key sectors of wind energy production and wind turbine manufacture are analysed using the Herfindahl-Hirschman (HH) concentration index. Regarding knowledge resources, the geographical distribution of specialized R&D infrastructure for energy is presented and performance on R&D wind energy projects is compared to establish a regional ranking.

[12] Research question 3 (RQ3): How does the regional industrial setting influence specialization paths in the wind energy sector?

With respect to the second part, the variety in regional settings is analysed through the application of specialization and related variety indexes (Boschma & Frenken, 2011; Boschma & Iammarino, 2009). The indexes used are Related Variety, Variety, Balassa specialization and Manhattan distance. The methodology for the estimation of the indexes is explained in Chapter 5

2.3.3.4 The annexes

The empirical study of the Spanish wind energy sector involves multiple sources, approaches and methods described in the empirical Chapters 3, 4 and 5. The main results of the analysis constitute the core of each of these chapters and additional information is provided in a series of annexes that refer to different dimensions of the study such as general economic trends, evolution of energy balance, and information on NSI and RSI. The list of annexes is as follows:

- ✓ Annex 1: Key technological aspects of wind turbines
- ✓ Annex 2: Overview of Spanish Economy and key patterns on regional performance
- ✓ Annex 3: Wind energy in Spanish regions – Key performance indicators
- ✓ Annex 4: Key regional indicators on Science, technology and Innovation
- ✓ Annex 5: Highlights of knowledge networks from R&D projects and patent ownership
- ✓ Annex 6: List of documents and sources for policy and content analysis
- ✓ Annex 7: Tables on EU policy – Chapter 3
- ✓ Annex 8: output cluster analysis

Chapter 3: Energy and innovation policies for developing the Spanish wind energy sector. Multiple dimensions of a policy mix

3.1 Introduction

This chapter provides the institutional background to the empirical study on the pathways created to foster the wind energy sector in Spanish regions. The policy mid includes sets of instruments from the energy, industry and science, technology and innovation domains. Complementarities across multiple level of governance (e.g. European, national and regional) and the dynamic pattern of policy instruments over time are examined by considering the interactions among different policy instruments will be considered within the concept of policy mix (Flanagan et al., 2011b; Laranja et al., 2008b)

The empirical study is based on a chronological investigation of the policy instruments implemented at different levels in a variety of policy domains and a review of the performances indicators for specific areas such as the renewable energy and wind sectors in Spain. It seeks to identify the characteristics of environmental governance systems and geographic settings and the multi-level and multi-actor interactions. Performance on research programmes related to the wind energy sector focuses on knowledge flows within and outside regions. This chapter provides empirical evidence for Research question 1 on the critical elements related to combining energy and industrial instruments to support renewable energy, with science, technology and innovation policy to support the development of the Spanish wind energy sector.

The chapter is organized as follows. The empirical evidence is presented in three main sections in which the linkages between energy policy and innovation policy are explored in terms of rationales, goals and commonalities in the process of supporting new market creation and technology development. A final section provides reflections on the performance of the policy mix. The first section provides a general overview of the policy instruments implemented in Spain to foster the wind energy sector by considering the analytical elements presented in Chapter 2: policy domains, governance levels, geography and time. These elements provide a framework for the analysis of interactions among instruments, actors and policy goals. The second section focuses on the energy policy domain and describes the different stages of development of the wind energy sector through the implementation of a policy mix of energy and industry measures that combine security of supply, market deployment and technology development. The third section reviews the research policy implemented at different levels. The main programmes and strategies are explored by looking at the linkages with the other policy domains involved in creation of new technological capacity in the energy sector. Finally, some reflections on the performance of the policy mix are presented by focusing on the logic behind the implementation process related to common goals, interactions across government levels and the long term perspective of the industry life cycle.

3.2 The unfolding of policies in the development of renewable energy

The implementation of wind energy policy has been widely extended in countries all over the world in the last decade. However, the decision on the design and implementation of the portfolio regarding the most suitable instrument to promote RES-E is still open. Quotas (also call green certificates), auction and government bidding/tendering and Feed- In tariff schemes are the most implied instruments while the last one in the most widespread support scheme. In Europe, combinations of R&D support for technology improvements, national targets and FIT has been applied in Denmark, UK and Germany (Saidur et al., 2010) but while quotas was more effective and cost effective in UK, Germany has deeply implemented FIT to achieve bigger market deployment (Butler & Neuhoff, 2008)

Germany and Denmark as leading markets in Europe have implemented a variety of direct support mechanism aimed to facilitate market penetration (i.e. financial incentives for technical standards, export credit assistance and quality certification) as well indirect mechanism (i.e. FIT scheme) to foster market volume (Lewis & Wiser, 2007). The German case was clearly defined by three stages: technology demonstration, market creation (FIT) and market consolidations (FIT reviewed) with combining elements of indirect and direct support (IRENA-GWEC, 2012). However, against the evidence of outstanding market deployment and technology diffusion, there is no general agreement in the impact of FIT in Germany, the first European market. It has been argued that the FIT has had a weak influence in innovation process and has caused distortion in related policies as the emission trading scheme(Böhringer, Cuntz, Harhoff, & Otoo, 2014).

In US the portfolio in the last decade has been based in instruments oriented to create more competitive market conditions since the beginning. The policy set has been then base in renewable electricity standard (RES or quotas) combined with financial support and R&D instruments. The FIT scheme was applied in 80' and the current approach is leading by US regions based in RES and targets related to CO2 emissions (Saidur et al., 2010). Regarding the financial stimulus, production tax credits in wind energy projects were one of the min instruments by which investors got tax saving for a wind project though specified period of time (e.g 10 years) by being owner or developer of the project (Hopkins, 2012; IRENA-GWEC, 2012).

3.2.1 The policy mix of Spanish wind energy sector

The trajectory of EU policy to support renewable energy (RREE) dates back to the second half of the 1990s when new legislation was introduced to encourage competition while guaranteeing security of energy supply. The promotion of RREE in the early 2000s was based on the establishment of targets for energy production (RPS quotas), criteria for participation, and emission rights regimes. Newer instruments include energy consumption standards, decentralization of energy productions, mechanism for energy trade and the relevance of developments led by regions and SMEs.

Spain has had policy instruments in place to foster the renewable energy sector since the second energy crisis (1979). Early initiatives were aimed at reducing dependence on external supply of fossil fuels through the gradual introduction of alternative technologies for the production of electricity, and achieve energy efficiency. The Spanish energy market has undergone a major transformation to its structure, operations and performance. Most of these changes have been influenced by coupling of higher level energy policy (i.e. EU Directives, international climate change deals) with environmental commitments, and the emergence of European energy markets.

Both aspects – dependence on imported resources and response to international commitments - have made Spain one of among the most active countries for introduction of energy policy instruments. Spain is ranked 7th in Europe and the OECD countries for introduction of renewable energy policy (see Table X IN THE ANNEX). The chronological evolution of policy shows a turning point in 1999 when the number of initiatives increased significantly to promote a trend that lasted nearly ten years. However, the most intense period of policy implementation was 2007-2012, when Spain assumed first position for wind energy sector policy.

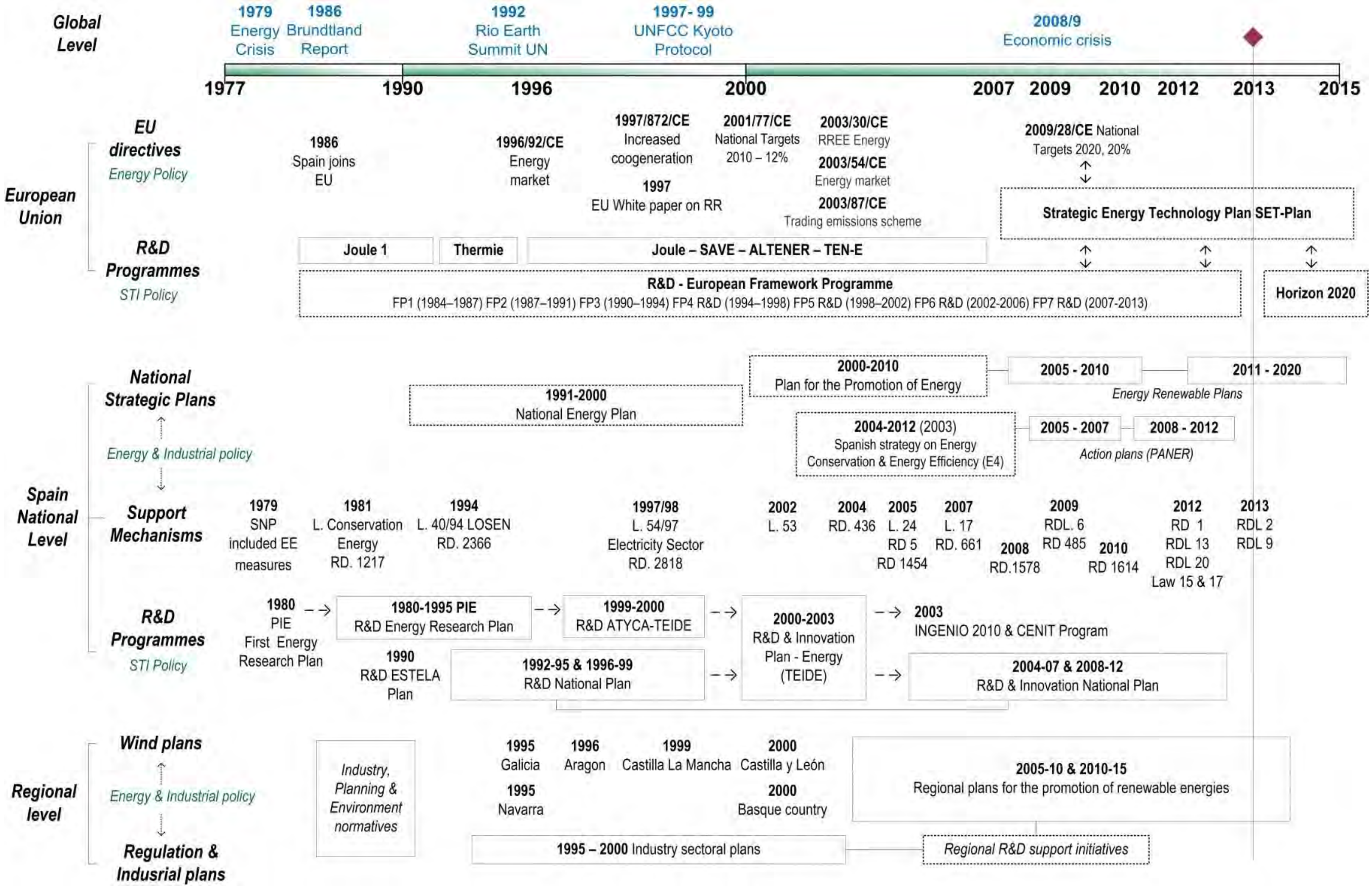
In the energy policy domain, the most important policy instruments for Electricity production from Renewable Energy Sources (RES-E) are the tariff scheme which includes two options - the *Premium tariff (PT)* and the *Feed-in tariff (FIT)*. The PT is a fixed sum (the premium) which is applied to the market price; the FIT is a fixed price for commercialization (González, 2008). The FIT benefits energy generators and increases profits compared with the standard electricity market[13] price. The PT is more beneficial if the market price increases more than forecast. Both schemes are updated annually in combination with a set of national targets (i.e. energy consumption) to increase the share of RES-E in the energy balance

This set of financial instruments is aimed at improving the economic conditions of RES-E by reducing risk and providing stability via long term support. In addition, R&D support programmes for technology developments, and a variety of regional strategies have been introduced to increase technological capabilities related to deployment in the RES-E market. These strategies involve measures affecting the energy sector and renewable energy technologies combined with environmental and planning regulations. Figure 2 provides a chronology of energy policy and the main dimensions of research policy in Spain (i.e. R&D, EU and national programmes).

Figure 8 depicts the regulatory portfolio supporting the creation of the renewable energy sector in Spain, at the European, national and regional/local levels, which allows us to identify cross-level linkages. The key EU energy policy Directives are presented, and Spanish national plans and regulation related to support mechanism are identified. The regional level is includes some important instruments such as: the wind plans, the regional plans for the promotion of renewable energy and the associated industry, environmental and urban planning regulation.

[13] The normal electricity generation regime/market uses traditional energy sources such as hydroelectric, nuclea and fossil based thermal plants (i.e. coal, oil, gas).

Figure 8 A multilevel view of renewable energy policies and programmes

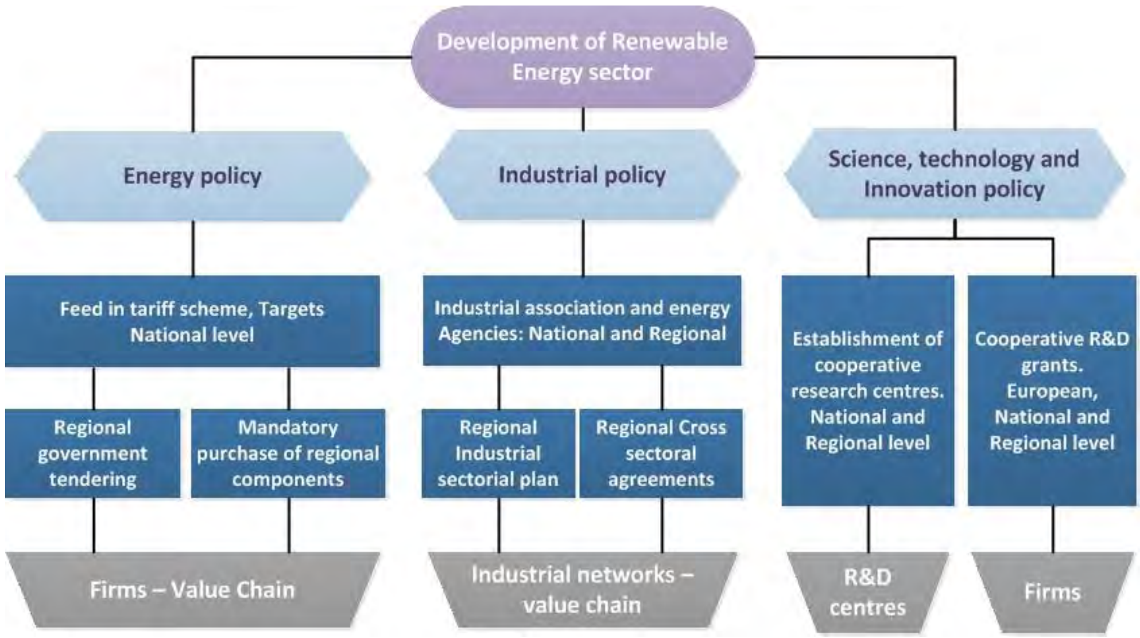


Source: own elaboration

The different instruments implemented are presented according to general aspects, policy domains and time issues considered in (Boer & Bressers, 2011; Cash et al., 2006; Flanagan et al., 2011b), which were already analysed in the theory Chapter 2. Figure 8 enables exploration of rationales, goals, use and impacts of instruments across time, space and policy domains. Interactions and trade-offs between policy instruments to achieve a better understanding of their operation and change overtime, are critical to a better understanding of the stability and flexibility in the implementation of policy instruments, and the connection between environmental policy instruments and government funding of R&D for new technologies (Del Río González, 2009).

Figure 9 presents the policy domains and main categories of policy instruments for tan analysis of the RES-E sector. It is in line with the approach suggested by Magro and Wilson (2013) regarding the evaluation of policy mixes within a multilevel governance dimension. The science, technology and Innovation policy domain is categorized as technology push policy, and industry and energy policy are related to market pull (supply/demand) and regulatory push elements, all of which are driven by the rationale of fostering the RES-E sector.

Figure 9 Policy domains and main instruments fostering the development of wind energy sector



Source: own elaboration based in (Magro & Wilson, 2013)

In the following sections, we explore four elements related to the policy mix (i.e. policy domains, governance levels, geography and time) described in the theory chapter and depicted in Figure

8, through an empirical study of energy and research policy related to the wind energy sector in Spain. The aim is not to evaluate policy intervention in RES-E policies in Spain, but to gain an understanding of the processes and institutional context favourable to sector development to explain how the composition, stability and flexibility of the policy mix affects sector development.

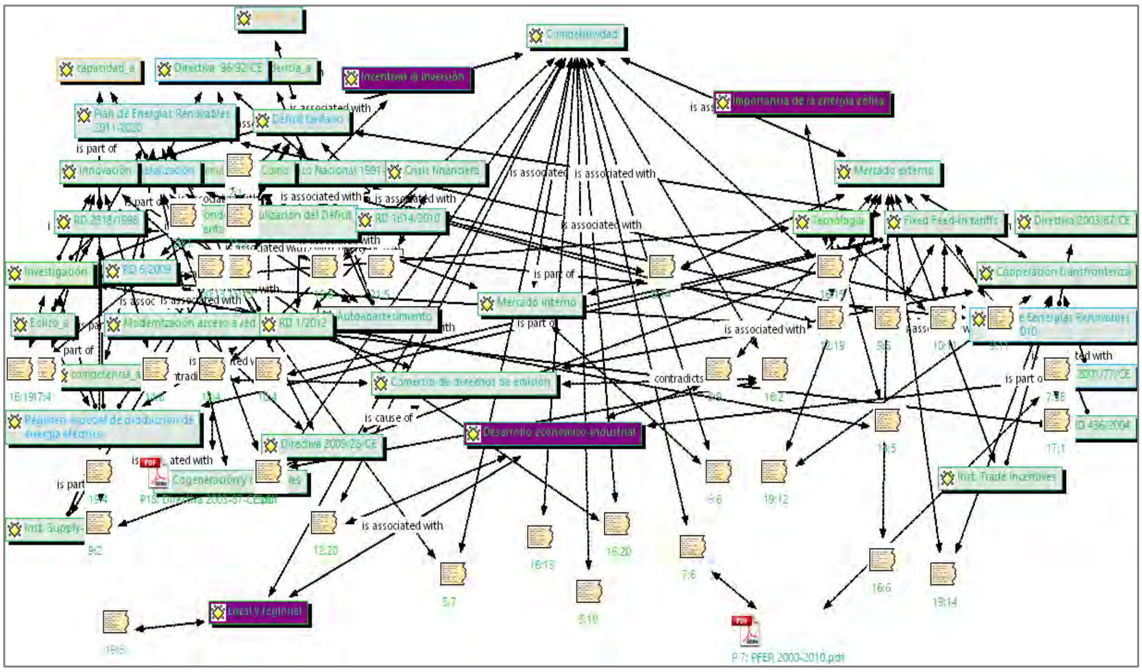
This chapter follows a qualitative approach by applying techniques on textual content analysis (Saldaña, 2012; Stone, 1997). The technique is applied to a variety of official texts and business documents regarding the development of wind energy in Spain[14] .The empirical study is framed by the application of two techniques: semantic analysis and discourse analysis. At first semantic analysis will be applied to identify relationships between the topics searched in the text (e.g. market deployment, technology development, security of supply). Then those topics will be taken as input to follow discourse analysis on the variety of logics and arguments representing differ objectives and positions regarding the design and implementation of the policy mix on wind energy sector at multiple levels.

More specifically, semantic analysis will facilitate the identification of common topics around the two key dimensions of policy-building described before. Atlas.ti software will be applied to systematize and assess content by means of qualitative techniques (Saldaña, 2012). To approach those common topics, the development of a thesaurus[15] will help to cluster and coordinate the variety of terms founded. At last, from the inputs developed in the previews step, patterns of relationships regarding relations between different decisions and actions as well as linkages across different action points will be traced. Those relations will be critical to develop a framework to analyse influence of the policies under study (Hajer & Wagenaar, 2003). The Figure 10 is an example of a network of patterns of connection founds in the different policy documents. Which has been the base for creation the following narratives on process of policy implementation.

[14] The documents include: European policies and initiatives (includes EU directives, and R&D specific programs), National plans on energy sector, Official documents on regulatory mechanisms (laws and royal decrees), Business reports and annual memories of business associations and, Industrial publications

[15] Thesauruses are built up by documental technique in order to reduce the volume of vocabulary. They are post-coordinated languages in which the terms represent the themes contained in the document allows. They include a variety of relation between terms (i.e. equivalency, hierarchical and associative) that represent and frame the ideas contained in the document (Lancaster, 1991; SLYPE, 1982)

Figure 10 Network of patterns of relations between codes and key concepts in policy documents



The content analysis developed in this chapter has been tool to support a deep understanding of linkages between policies and instruments at different levels. The results are briefly presented below.

3.3 The energy policy domain: stages and multi-level interactions

The trajectory of EU policy to support RES-E started in the second half of the 1990s when new legislation was introduced to increase competition while guaranteeing security of supply. The promotion of renewable energy in the early 2000s was based on establishing targets for energy production, criteria for participation and emissions regimes (de Alegría Mancisidor, Díaz de Basurto Uraga, Martínez de Alegría Mancisidor, & Ruiz de Arbulo López, 2009; González, 2008; Montes, Martín, & García, 2007; Río & Burguillo, 2009). Some more recent instruments include energy consumption standards, decentralization of energy production, mechanisms for energy trade, and developments led by regions and small and medium sized enterprises (SMEs).

In Spain, security of supply is a crucial ingredient in the support for emergent RREE sectors. Spain has had a dynamic RES-E environment compared to the rest of Europe, at least up to 2009, by following a continuous process of reorganization of the energy sector (González, 2008). Spain's domestic energy market emerged in the 1990s and developed along the ethos of a renewables market and mechanisms related to trade in energy (2000-2010). Since then, cross-country cooperation has increased with a view to greater energy exchange and achievement of EU-wide objectives.

The significant expansion of the renewable energy sector generally, came to a halt in 2009 with the onset of the economic crisis, resulting in a reduction in tariff deficits associated with the special regime and, after 2012, a reduction in subsidies. In addition, the barriers to entry to the renewable energy market increased.

Wind energy sector development in Spain consists of three stages:

1. Creation of an energy market
2. Creation of a RREE market
3. Financial crisis and tariff deficit.

Figure 8 depicts these stages and the links between policy instruments at different levels, highlighting national policy and also top-down effects across time. In what follows, we discuss European policies as background to the analysis of Spanish national policy. We provide an overview of performance and policy implementation at Spanish regional level. Early policy implications are highlighted in relation to market deployment and technology developments. Specific research programmes and R&D support are investigated in more detail as part of the regional dimension of wind energy development.

3.3.1 European level

EU policy on RREE was introduced in the second half of the 1990s with new legislation to increase competition and guarantee security of supply conforming to environmental criteria. European policy and regulation defined the key actors, such as energy producers, energy transporters and energy distributors, and their roles, and national governments formulated security of supply rules. Each national state supported liberalization through subsides and regulation. The promotion of a renewable energy market started with Directive 2001/77/CE which imposed common norms and targets[16] on member states, and defined the long term strategy for the exploration of external markets opportunities.

[16] Directive 2001/77/CE outlines: 1) national goals for achieving 12% coverage of electricity demand by renewable energy by 2010; 2) energy production from renewables should be 22.1% of total EU energy production (29.4% for Spain); and 3) member countries should develop their own strategies within the common framework.

At this stage, the EU was not considering a harmonized system, but only coordination of schemes to support cooperation among countries. Subsequent directives defined complementary aspects such as specific support for renewable energies for transport and biofuels (2003/30/EC), regulation of internal energy markets and definition of main activities (i.e. generation, transport, distribution), actors and networks (2003/54/CE) and the establishment of a trading rights regime related to greenhouse gas emissions with limits set on the basis of the Kyoto protocol and the new emissions market (2003/87/CE).

Directive 2009/28/CE modified Directive 2001/77/CE by setting general binding objectives for renewable energy production in Europe by 2020.[17] This Directive defines the criteria for achieving gross final energy consumption standards and includes a new calculus mechanism for imported energy and the relevance of development led by regions and SMEs. It provides explicit support for decentralization of energy production and defines independent quotas for renewable energy related to transportation.

During the last years, the European commission consider a critical point the rethinking on policy instruments toward a more deep understanding of industry life cycle where the beneficiaries of financial stimulus such as FIT scheme can take action to move to more competitive conditions without government support (Sequeira, 2012). The sequence of instruments is also critical in term of design and implementation when the EU priorities has turn to encourage long term technological change (even more, foster the new generation of technologies) rather than market volume(Mercier, 2012) which seem to be the major effect of FIT scheme.

3.3.2 National level

The Spanish national renewable energy policy portfolio provides a broad framework to guide implementation by regional governments. It is based on two principles: the transfer of energy competencies and a specific set of regulations related to the management of natural resources, land and environmental impacts governed by industry policy (incentives and regulation), environment (control and monitoring) and urban planning (land use).

[17] Directive 2009/28/CE states that the Spanish target for the share of energy from renewable sources should be 20% of gross final energy consumption by 2020

The evolution of national policy followed the stages of creation of an energy market, creation of a renewable energy market, and crisis which established the conditions for maturity of the sector. Interaction across levels can be found in each stage which has influenced the speed of the implementation process as well as the flexibility and stability of the regulatory framework.

3.3.2.1 1990-2000: Creation of an internal energy market

Energy market liberalization is defined in the National Energy Plan (PEN 1991-2000), but makes no specific reference to renewable energy. However, it emphasizes security of supply. Improving the national energy balance and efficiency and market internationalization are introduced in line with the creation of a common European Energy Market. In 1994, additional regulation (RD 2366/1994 and National law 40/1994) provided better conditions for renewables through the introduction of the special regime (tariff scheme) to support electricity generation from renewables, and use of cogeneration technologies. Subsequently, the energy price was determined by government, and energy supply was defined as a public good.

Law 54/97 started the process of liberalization with the energy price defined by market mechanisms. This is in line with EU Directive 96/92/CE and introduced competition related to energy supply and vertical segmentation in the market, and distinguished between traditional and renewable energy producers through the introduction of the FIT scheme (RD 21818/1998). The special regime includes new technologies and allows RES-E producers to participate in the energy market with the aim of achieving 12% production from renewables by 2010. Under the special regime, RES-E producers received a premium (sum cost), associated with production capacity, in the form of an additional subsidy.

3.3.2.2 2000-2010. Creation of renewable energy market and support for opportunities in external markets

In the first decade of the new century, energy market liberalization progressed according to a set of initiatives that enhanced competition in the different energy sector areas. The main advances included decentralization of activities through the introduction of new actors such as the system operator (Law 53/2002) and energy trading companies (RD 485/2009). Improvements to the productivity and efficiency of the whole system (law 24/2005), and transposition of EU regulation were emphasized, to increase competition and avoid dominance in transport and distribution network operations (Law 17/2007).

Specific renewable energy measures include a sequence of long term plans to guide the promotion of RREE and emphasize specific targets. The Plan for the Promotion of Renewable Energy (PFER 2000-2010) was the first long-term policy to guarantee subsidies and funding, and set priorities for renewable energy technologies to achieve the 12% target. A series of Actions Plans for Renewable Energy (PANER 2005-2010, 2008-2012) was introduced in line with EU regulation (Directives 2001/77/CE and 2003/87/CE) and include procurement mechanisms, R&D programmes and decentralization of energy production and a more significant role for regional developments and SMEs. In 2006, the Spanish wind atlas was presented by national government as a complementary technical tool to support the regional implementation process.[18]

The FIT scheme underwent a series of reforms. A long term perspective was introduced to provide market stability (RD 1432/2002) along with a new regulatory framework and conditions related to different technologies and categories (RD 436/2004). Critical changes to the 2004 regulation include the introduction of improved mechanisms for annual tariff adjustments via the price index, removal of the barriers to RES-E generators participating directly in the electricity market, and explicit support for photovoltaic and hydropower within a 15 to 25 year time horizon.

RD 661/ 2007 updated the 2004 special regime by introducing new prime and tariff schemes based on a cap and floor system.[19] This system was aimed at reducing the costs for consumers putting a limit (cap) on prices and profits, while guaranteeing a certain level of revenues and reducing the risks for investors (floor value, lower limit). It included differing levels of compensation according to the technology and the average electricity price (AET), but decreasing over the lifetime of the installation. The introduction of RD 6/2009 changed conditions: thermosolar and Wind projects had significantly exceeded the goals set by PNER 2005-2010, and this new law decreed closure of the producer register and imposed a new system of annual quotas.

[18] The national agency for Diversification and Energy Saving (IDAE) funded a study to determine the technically available areas in Spain and the distribution of wind quality conditions across the territory.

[19] The cap and floor system affects the FIT by introducing a variable payment adjusted to the wholesale electricity market price and the cap and floor values.

3.3.2.3 2010 – Present: Economic crisis and new policy set

Since 2009 the FIT scheme has undergone repeated reform through the removal of subsidies and attempts to identify a new scheme to provide a more stable regulatory framework. Following an attempt to revert to 2007 conditions (RD 1614/2010), changes were introduced to reduce the tariff deficit. 2012 saw a series of changes: first, the withdrawal of economic incentives for new installations (RD 1/2012), second, cost-benefit deviations were corrected, third, limits imposed on new infrastructure (13/2012). Finally, a new scheme of network tolls, taxes and subsidies was added to both the ordinary and special regimes (RD law 20/2012, law 15/2012 and law 17/2012). These changes removed the special regime economic incentives which had had a major impact in the early days. Although the special regime remained in place, new installations had to compete on the basis of the market rather than a regulated price.

RD law 2/2013 was the most recent change to the special regime for renewable energy. It established two procedures for the energy market: 1) transfer of electricity under a regulated tariff, and 2) sale of electricity for electric power production with no additional premium. RD law 9/2013 is aimed at providing a more sustainable solution to the tariff deficit by imposing a new remuneration regime for renewable energy. Firms receive investment cost plus remuneration based on the particular technology (i.e. less and more risky investment).[20]

The Renewable Energy plan 2011-2020 (PFNER 2011-2020) forecasts a future in which Spain will achieve a 22.7% share of the renewable energy market and a 42.3% share of electricity generation. The surplus can be transferred to other countries under the EU mechanism. However, the changes to energy sector regulation since 2012 have had implications for the costs of production and energy substitution (self-consumption/ auto-producers of energy) and the market price spread. Long term investment in infrastructure is being affected retrospectively through the impact on operating installations (i.e. premium originally assigned) and market foresight since application processes for new energy producer are temporarily suspended.

[20] The new scheme seeks to guarantee a "reasonable" profit based on treasuries interest rate (10 years issue) plus a spread (+300 pts.) which is equivalent to 7.5% profitability. This can be seen as a "latter" I am sure that latter is the wrong word – do you mean a later or a lately adapted construction incentive as a supply side PIRE measure.

3.3.2.4 Key performance indicators for energy policy instruments

The energy balance in Spain has changed significantly since the special regime to foster renewable energy production was launched in 1997. The regime was modified twice, in 2004 and 2007, and in 2007, the energy balance peaked, with energy delivered by the special regime increasing to 239% (see Fig. 11). Since then, total energy production slowed based on the slow down of energy generated by technologies under the ordinary regime. However, electricity production under the special regime has kept increasing until 2012.

Performance under the special regime based on the FIT scheme has been outstanding for energy production[21] as has the corresponding development of power capacity in RES-E (see Fig 12). Capacity under the normal regime has increased 42%, while capacity under the special regime reached 522% and total wind power capacity rose by 3,820% in the period 1997-2008. Overall, in the period 1997-2012, wind energy sector subsidies based on the FIT scheme have increased by 4,336% while the RES-E produced from wind has increased by 3,436% (Fig. 13). Finally, the special regime accounts for 37% of the energy balance and wind energy has been the main contributor to the special regime (46.6%) in 2012. These results confirm that implementation of the FIT scheme and the targets for RES-E have achieved more than the expected 12% target of RES-E for 2010 and even the 2020 target of 20%.

The impact of significant changes in regulation frameworks from 2012 onwards has affected drastically the performance of the renewable energy sector as well as the whole energy system (García Breva, 2013). The first impact was given by the evolution of wind power capacity which was drastically decelerated and affect the structure and the asset ownership in the national market. The analysis of these last results which are not part of these study are considered critical inputs for further research.

[21] *The share of the special regime in the energy balance increased from 9% in 1997 to 37% in 2012 while the share of wind power increased from 1% to 22% in the same period.*

Figure 11 Evolution of Energy balance in Spain: Ordinary and special regime 1997-2012

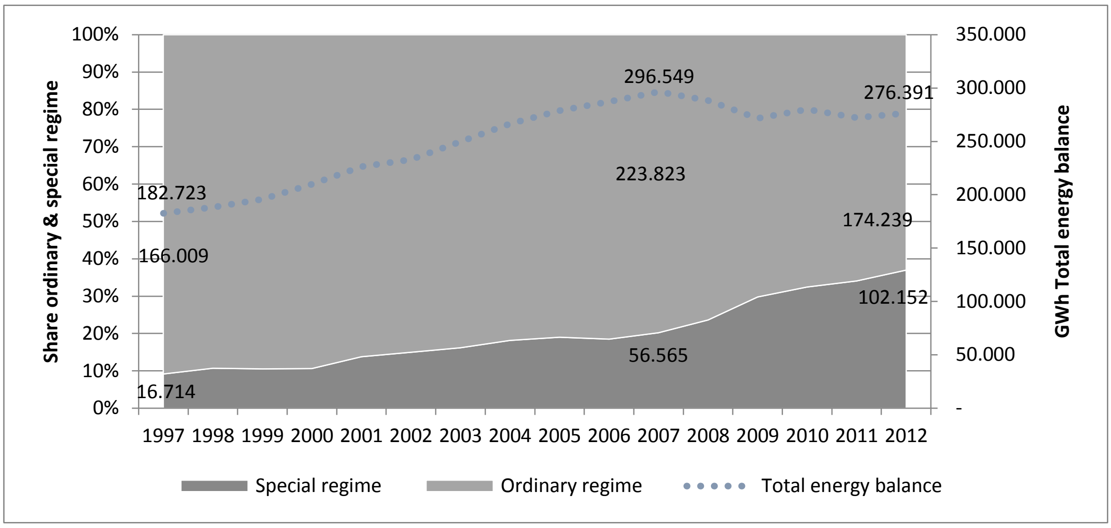
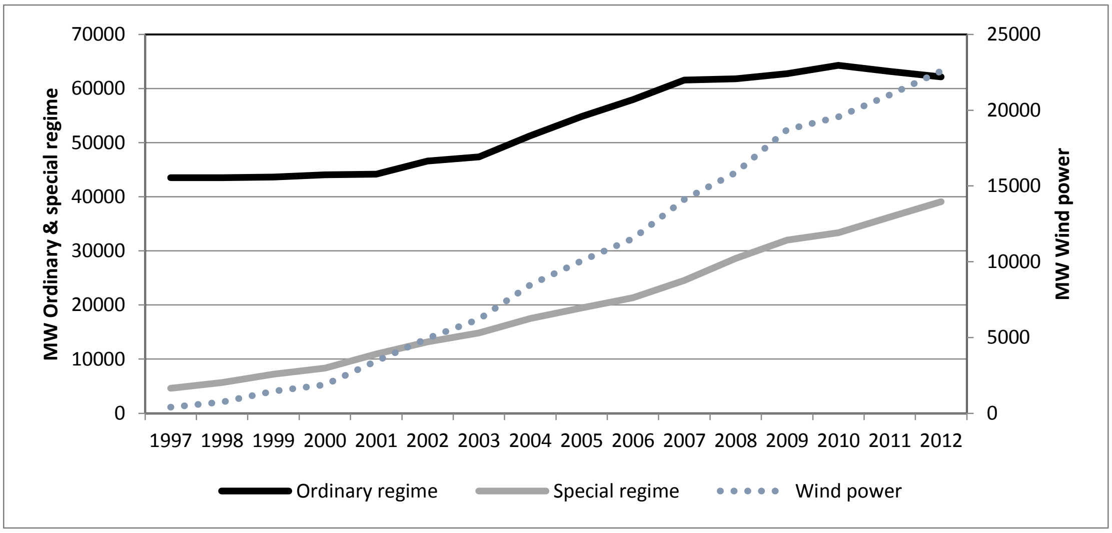
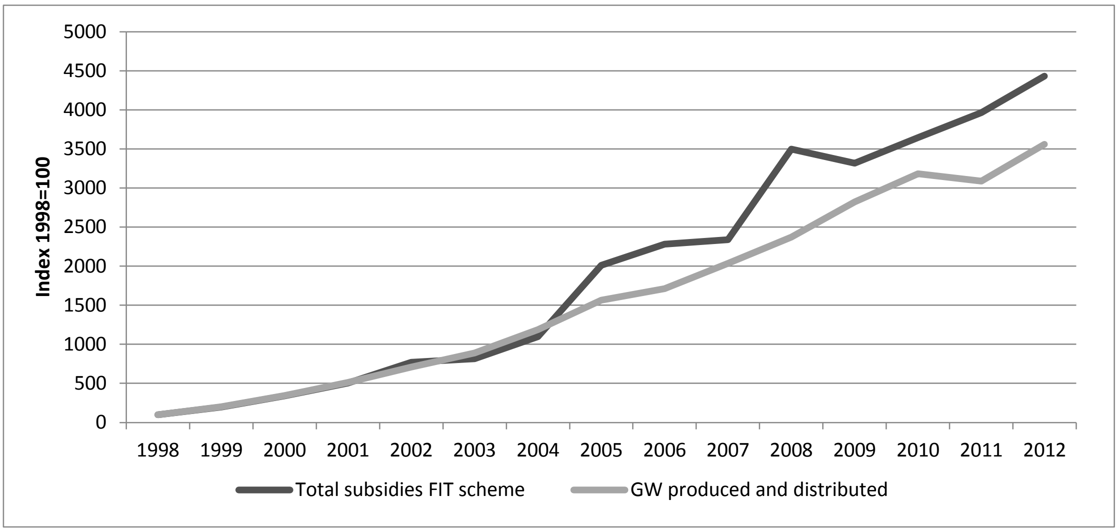


Figure 12 Evolution of power capacity in Spanish electricity system: Wind power, ordinary and special regime 1997-2012



The different contribution of each technology to final national results can be analysed in terms of power capacity trajectory and cost-benefit related to implementation of the FIT scheme. Different and decreasing (since 2007) price compensation has affected the performance (productivity and efficiency) of RES-E technologies. Solar energy has enjoyed significantly larger subsidies than wind energy, but represents a small share of the renewable energy produced.

Figure 13 Evolution of total subsidies granted by FIT scheme and RES-E produced with wind resources 1998-2012. Index 1998=100



Source: own elaboration based on REE (1997-2012) data

The disparity in price compensation (see Fig. 14) and contribution to the energy balance over time, have had a significant impact on the tariff deficit. The price of wind energy has increased from 6.8 cents to 25.1 cents/kw while the price of solar has risen from 7 cents to 32 cents/kW. The average price of solar energy was 59 cents in 2004-2012 with a peak of 128 cents in 2008. In 2004-2012 grants for solar energy increased considerably and relatively much more than the energy produced (see Fig. 15); in the case of wind energy, production increased more than grants.

Figure 14 Evolution of average price compensation 1998-2012

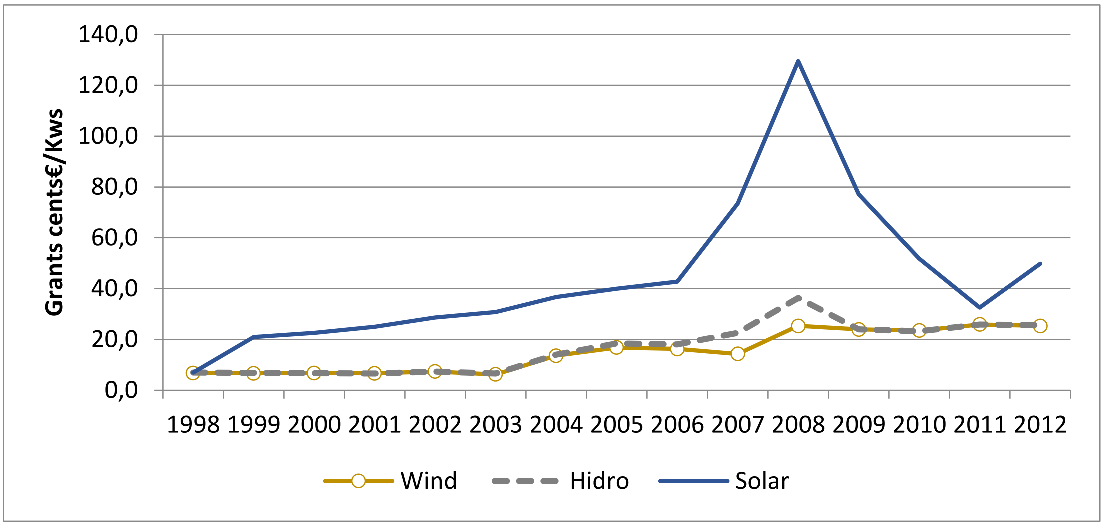
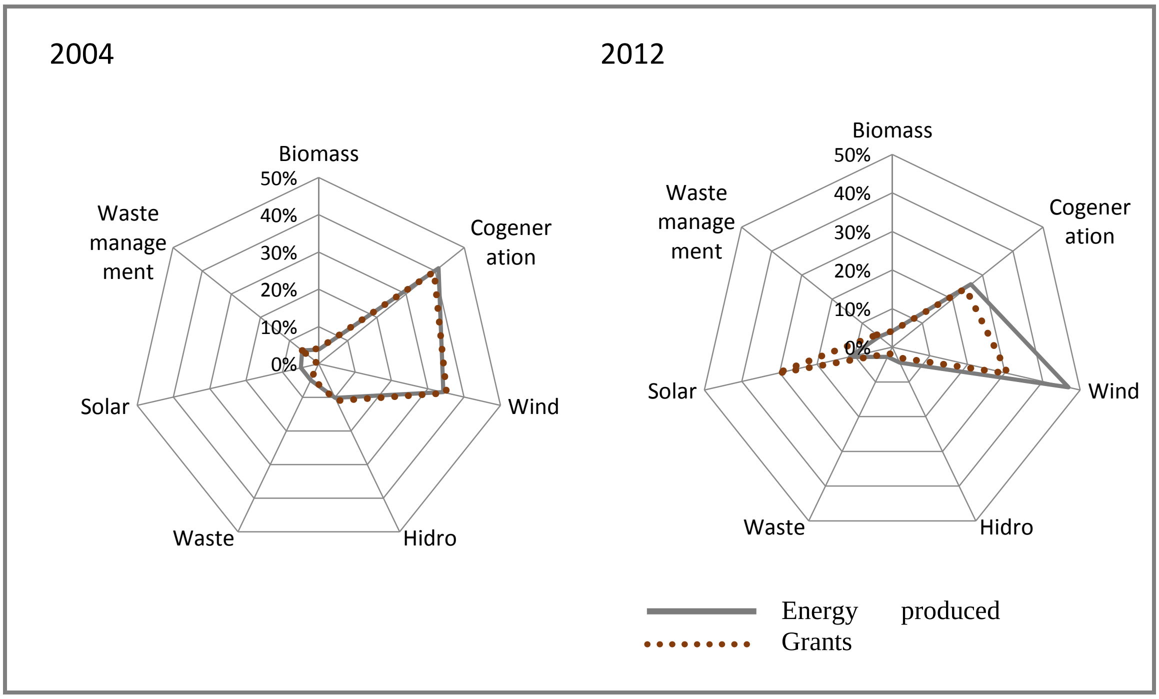


Figure 15 Grants and energy produced as part of the total 2004 & 2012



Source: own elaboration based on CNE (2013) data

To summarize, implementation of the FIT scheme in Spain improved the energy balance mix in favour of RES-E technologies. The series of reforms to FIT improved market conditions and competition among different energy sources under the ordinary and special regimes. In this context, during implementation of the FIT scheme (i.e. 1997-2012), wind energy emerged as the main RES-E and one of the main contributors to the total energy balance. However, implementation of the FIT depends on the conditions related to the development of the energy infrastructure (energy policy) and industry capacity (industry policy) for renewable energy technologies in the regions (geographical space). The main aspects of regional policy are presented below.

3.3.3 Regional level

The FIT scheme is the main national policy instrument supporting renewable energy. It set the base for the development of or RES-E capacity. However, its implementation depends on the development of new infrastructure which is the responsibility mostly of the regions. Two central issues can be identified:

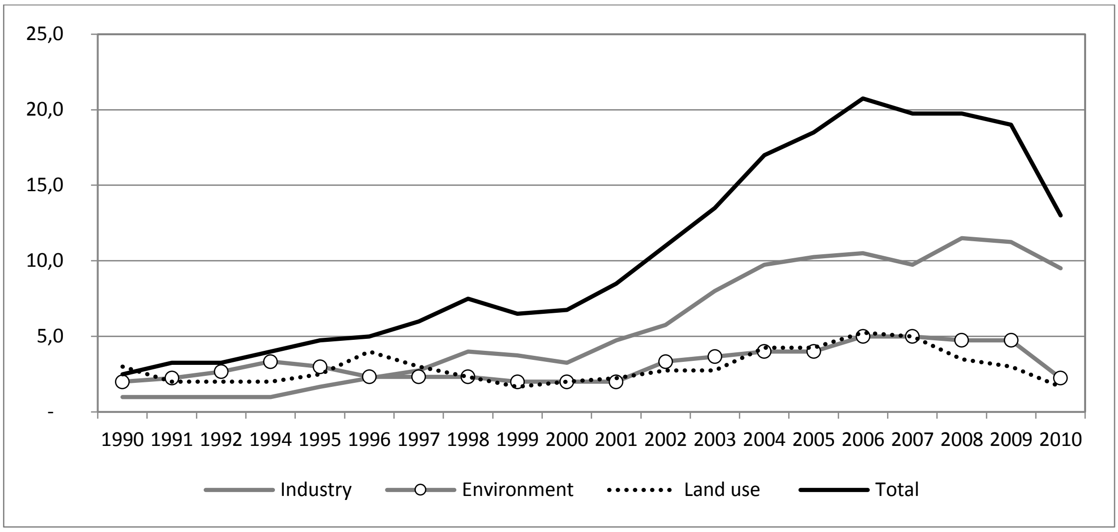
- ✓ Transfer of competences. Following decentralization to CCAAs in the 1980s, regions became responsible for energy consumed within the CCAA in which it was produced, with the result that it did not enter the national electricity network. This required a set of regulations for regional energy production.
- ✓ Management of natural resources, land use and environmental impact related to the design, authorization, implementation and control of the energy infrastructure managed by three types of regional policy: industry policy (incentives and regulation), environmental policy (control and monitoring) and urban planning (land use).

Since the mid 1990s, the regions have had in place frameworks to manage RES-E related policies imposed at a higher level. During the introduction of the FIT scheme, regional regulation on industry, the environment and the urban landscape established better conditions for the development of the energy sector and the manufacture of renewable energy technologies. Figure 16 depicts these developments since the beginning of the 1990s showing high levels of growth in 2000 and 2005 coinciding with the national special regime.

The evolution of regional frameworks has differed across regions, with Galicia, Navarra, Castilla y Leon, Cataluña and Basque Country the policy leaders. These regions have established regional strategies for market deployment and industrial development through a set of mechanism including R&D and demonstration and experimental programmes, mandatory purchase of domestically produced components, and government participation in wind farm ownership. The most import instrument is the territorial wind plan which implies specific actions to identify suitable areas, and includes procedures and conditions for exploiting natural resources.

Figure 16 Evolution of regional normative related to renewables energy in CCAA 1990-2010

(4 year moving average)



Source: own elaboration based on data from PANER 2005-2010 (MIETUR, 2005)

3.3.3.1 The wind plans

The wind plans are linked to a series of actions for the development of wind parks including land expropriation for wind park developments, and agreements with utilities and manufacturers of energy technologies. The features of the regional governance system regarding the level and types of interaction between government and private actors differ depending on whether they are related to home market deployment or industrial development. The wind plans consist of formal long term agreements, including commitments and rights related to the exploitation of wind resources, and set the basis for coordination among regional governments, utilities and manufacturers of renewable energy technologies. Regional governments can adopt a centralized or a decentralized approach to the management of resources and decision making.

For example, the business model for exploitation of regional resources can be designed to favour the participation of the main regional companies (i.e. the utilities) or entrepreneurial initiatives such as IPPs and local public-private management of wind farms. In the first option, a set of industry measures (e.g. long term policies supporting manufacturing related sectors) promotes stronger developer-manufacturer linkages and a broader variety of sizes of industry actors and positions in the supply chain.

In contrast, decentralization of decision making on the implementation of wind plans, to the local (i.e. provincial) level may be aimed at actions related to the environmental impact of the wind infrastructure on other economic activities competing for the same resources (i.e. forestry, tourism) and the options of local actors such as local government and citizens, regarding co-ownership and management of wind parks to satisfy local demand.

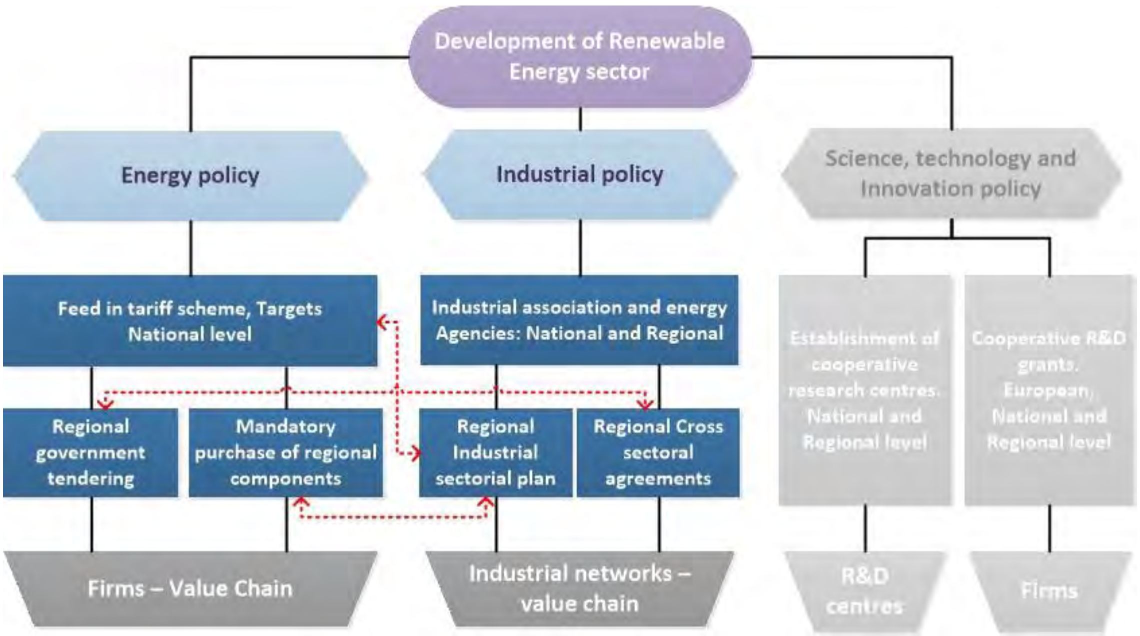
These different objectives can lead to different positions related to the economic and administrative conditions related to land expropriation and local resources management.

3.3.4 Energy and industrial policy linkages

Since the implementation of the special regime by the Spanish government, policy initiatives have been launched to support the two pillars of the renewable energy sector: electricity production and the manufacture of renewable energy technology. While the financial stimulus provided by the FIT scheme and the long term perspective introduced by specific targets indicate a path towards a more sustainable energy balance, regional level industry instruments are designed to provide local technology to the emergent sectors. This first link between policy domains relies on the financial and political power of national policy, supported by the strategic response of regional government based on the transferences of competences in key areas as energy and the environment.

In addition, a key element of market deployment is regional government tendering (i.e. the wind plans) which establish the planning of energy capacity within a long term target. These plans involve regional cross sectoral agreements between the main utilities and the manufacturers of technology, based on sectoral industry plans and specific instruments within the wind plans such as mandatory purchase of regional components. The simultaneous implementation of energy and industry policy at national and regional levels, reveals a circular relation within the main policy rationale for the development of the renewable energy sector (see Fig. 17)

Figure 17 Linkages between main instruments within Energy and industrial policy domains



The development of specific technology within this framework is the result of interaction with other actors and policy instruments in which R&D activities fed the processes of knowledge creation and adaptation of existing knowledge in traditional areas such as mechanical engineering, aeronautics and materials. The main aspects of these processes are presented below.

3.4 The research policy domain: support for knowledge creation and adaption

In this section, the different programmes addressing technology development in the emerging RESE sector are presented. The time dimension guides the series of actions oriented to increasing the knowledge base in the main fields and adapting existing capacity to facilitate the commercialization of new technologies.

Research activities are identified as part of the process to measure the readiness to market of existing technologies. Interaction across programmes will be highlighted, and the linkages between different actors and technologies are described in Chapter 5 on the technology and regional dimensions of the wind energy sector.

3.4.1 European level

The science, technology and innovation policy delivered by the European Commission since the early 1980s has been based on supporting the creation of new energy markets under an integrated and efficient European network of energy systems, and facilitating new pathways for the introduction of new emergent technologies as renewable energy, energy efficient/green buildings and smart grids. Specific programmes focused on technology development have been introduced coupled with more general research framework programmes designed (and aligned) with feedback and loops of interaction with the national research programmes of EU members.

The first initiatives were the programmes JOULE (1989-94) and THERMIE (1990-94). Both were research and technological development programmes aimed at fostering the development of non-nuclear energy technologies including exploitation of solid fossil fuels and new and renewable sources of energy, and promotion of efficient and rational use of energy. These programmes were coupled with the Fourth Framework Programme (1994-1998) within the area of Energy, Environment and Sustainable Development, whose main objectives included increased security of energy supplies, introduction of new technologies and consolidation and improvement to the energy network infrastructure.

A significant impulse was given to renewable energy by the programme ALTENER (1996-2000) and ALTENER II (1998-2002). During their implementation the research budget for RREE increased fourfold. In the same period, the Fifth Framework Programme (1999-2002) was announced and included the Target Action 'Integration of renewable energies and distributed generation into European electricity networks' facilitated the development of 50 projects in key areas such as transforming the conventional electricity transmission and distribution grid into a unified and interactive energy service network.

The Sixth Framework Programme (2002-2006) set the priority of Sustainable Energy Systems by distinguishing among two types of activities: 1) Short to Medium-term Research (DG Energy and Transport) and 2) Medium to longer-term research (DG Research). This scheme was aimed at providing technology developments to support the new normative on competitive energy markets, the efficiency and productivity of energy networks, and introduction of the first RREE targets. The focus on improving the network system was reinforced by the introduction of Trans-European Networks for Energy (TEN-E) Funding Programme (2000-2006).

Finally, Framework Programme 7 (FP7) aimed to consolidate the different energy research objectives by promoting the introduction of new technologies and exploring the challenges of more efficient and scalable technologies to meet EU targets on security of supply and environmental commitments (i.e. CO^2 emissions). The nine activities under the energy theme were in the form of cooperative projects while the Intelligent Energy-Europe programme and the more applied Joint Technology Initiatives (JTI) were introduced to facilitate the “readiness” to market of the set of emergent technologies. FP7 was coupled with EU energy policy through the introduction of the Strategic Energy Technology (SET) Plan aimed at coordinating planning, implementation, resources and international cooperation in the field of energy technology. The SET plan was designed with the aim creation synergies towards the new generations of technologies where research and innovation ecosystem at European level are integrated with national research plans.

In the specific field of wind energy, according to the EU,[22] more than 40 projects have been funded since 1998, 16 under the 6th Framework Programme and 10 under FP7. The main knowledge areas are components and systems for turbines and farms, Integration of wind power into the grid, wind resources forecasting, and knowledge on operations and logistics developed in demonstrations of large scale systems for on- and off-shore wind farms. However, the variety and composition of projects has changed over time. Early Framework Programme projects were small and covered a variety of topics while the 6th Framework Programme included larger and more focused projects (i.e. increased turbine size). Finally FP7 projects had a systems perspective and included significant developments in reliability of wind turbines, wind predictability and grid integration (i.e. off-shore wind platforms).

As already mentioned, EU science and technology policy has a strong interdependence with the national research programmes in terms of priorities, capacities and design of main instruments. According to Mercier (2012), the main challenges are the identification of key segments of value chain in which further develop new technologies and establish a roadmap on innovation and technology development with common agenda an action plan where integration and consolidation of capacities (rather than pick up champions) are the main challenges. In what follows, we describe the main programmes developed by the Spanish government.

[22] http://ec.europa.eu/research/energy/eu/index_en.cfm?pg=research-wind-support

3.4.2 National level

In Spain, early R&D support programmes for renewable energy emerged after the second oil crisis. Since then, a sequence of different programmes has been introduced to explore the available knowledge resources for the exploration of alternatives to fossil fuels and improved energy efficiency. However, despite a similar rationale underlying all these initiatives, they were initially implemented within different policy domains such as industry, science and technology and economic affairs. In 2000, R&D support for this area was transferred to science and technology policy within the Spanish National Research Plan (NRP).

The Energy Research Plan (PIE) was the first important initiative to explore alternative energy technologies through experimental projects and demonstrations of existing technologies. It was launched in 1980 and lasted until 1995 when other initiatives with stronger economic support were introduced. One of these was ESTELA (1990) launched as an R&D plan designed to increase competitive conditions in the energy sector by integrating objectives and commitments defined in the Spanish and EU R&D systems.

Other specific programmes for the energy sector include the Technological and R&D Programme (TEIDE) implemented under the general “Support for technology and safety on Industrial Quality – ATYCA” (1999) programme of the ministry of industry and energy affairs. TEIDE provides support for a total of 121 projects of which 20 were specific to wind energy technologies. TEIDE was eventually coupled with the NRP which introduced a specific funding track for the energy sector in 2000. The NRP was the framework for other specific initiatives launched in the energy sector including the CENIT programme (four projects in the wind energy sector)[23] and other projects sponsored by national government under the energy cluster PLAN-E.

National government has also provided R&D support to CCAA through the management and distribution of funding under the European Regional Development Fund (ERDF) (2007-2013). This funding scheme is based on public-private collaboration for R&D, and facilitates knowledge and technology transfer between firms and knowledge institutions such as universities and technological centre. This funding scheme is managed by the Centre for Industrial Technological

[23] The Cenit Project on wind energy : 1) WINDLIDER (Gamesa), 2) EOLIA (Acciona Energia), 3) OCEAN LIDER (Iberdrola Ingenieria y Construcción) and 4) AZIMUT(GAMESA).

Development (CDTI), the main public body in charge of grants and financing of R&D activities for the private sector which also facilitate the implementation of other R&D and cooperation programmes such as Eureka and Iberoeka.

Finally, regional initiatives to support R&D activities are based in existing (and new) R&D infrastructures and rely on consensus with industry to foster specific sectors. The regional R&D programmes are a combination of national and European funding schemes with opportunities for the exploitation of emergent markets, especially in the renewable energy sector. This regional performance is described in my detail in the analysis of regional dimension for the development of the wind energy sector. The next section presents indicators related to the performance in these programmes from a national level perspective.

3.4.3 Spanish performance in wind energy related research

Based on the science, technology and innovation policy described, research activity in Spain can be described as simultaneous performance in the Spanish National Research Plans (NRP), applied R&D programmes co-funded by national Spanish and European sources and EU projects.

Total expenditure in R&D includes the NRP and participation of national government in co-funding schemes managed by CDTI and the EU projects. Figure 18 shows the evolution of this funding in the period 1995-2011 and shows significant growth in the total budget for R&D activities (232%) and research in the energy sector (382%). This implies that energy research increased its participation in total research from 2.7% to 3.9% at the end of the period.

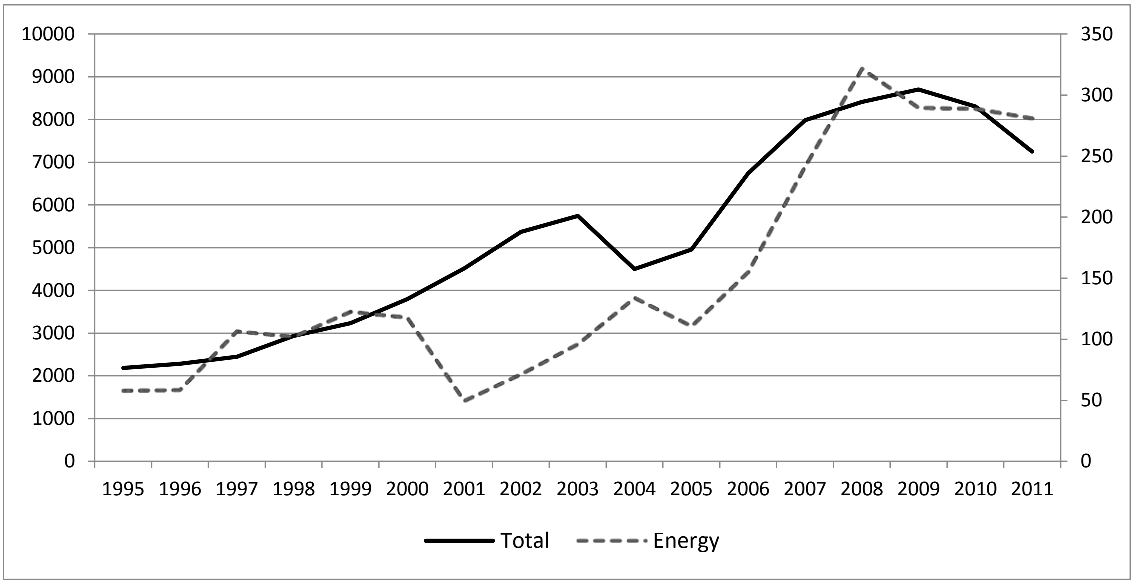
Regarding the performance of individual funding schemes, Figure 19 shows the evolution of number of projects granted in energy related projects.[24] The data show an inter-annual increase in the total number of projects in the period 2004-2010 based on available NRP data and a strong trajectory in relation to other sources of funding. In the whole period the number of projects granted increased 403%.

Regarding the participation of Spanish actors in European collaboration projects related to wind energy, data from EU CORDIS show a cyclical pattern and an increasing number of participations

[24] NRP and EU projects were selected by applying content analysis techniques and keyword codification to titles of projects included in the data set. CDTI projects were provided by the national agency, filtering according UNESCO codes related to the wind energy sector.

[25] (see Figure 20). This unstable trajectory can be explained in terms of two technical aspects: first, the data presented indicate active multiannual projects of varying length, resulting in average duration of projects (3 years) and cycles of calls for projects and, second, cycles related to transition between programmes (i.e. 5th, 6th and 7th research Framework Programmes). The total number of EU funded active projects increased by around 60% in the period 1997-2011, outstanding performance compared with the average at European level. According to Izquierdo (2011), Spain is ranked second (behind Germany) for the best economic results for R&D energy projects.

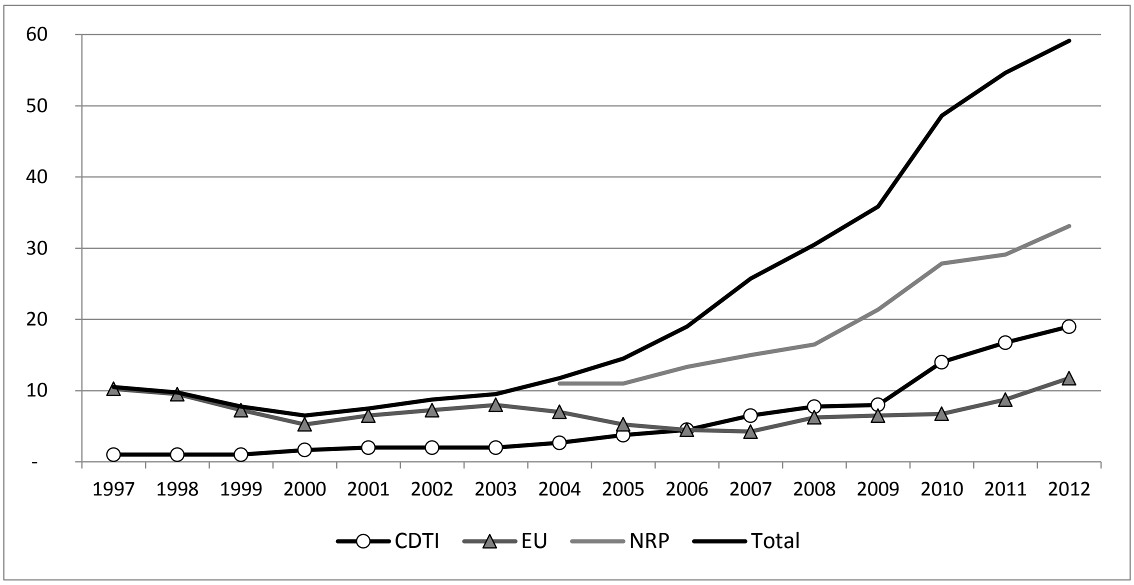
Figure 18 Public R&D expenditure in Spain – Total and Energy sector



Source: own elaboration based in INE datasets (INE, 2014)

[25] The projects in the chart were obtained by applying content analysis to the abstracts and titles. A set of key words related to wind energy technology was used for this purpose.

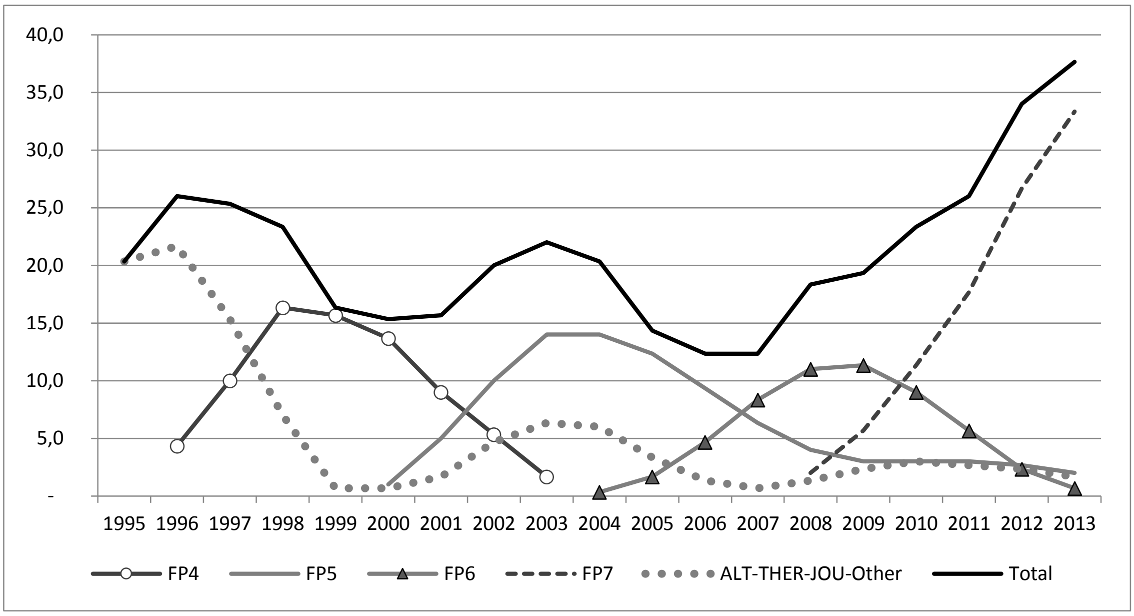
Figure 19 Total number of Wind energy related project granted in Spain per year by source of funding



Source: own elaboration based in several datasets (CDTI, 2013; CORDIS, 2013; MIETUR, 2005)

Figure 20 Total number of active wind energy related project funded by EU programmes

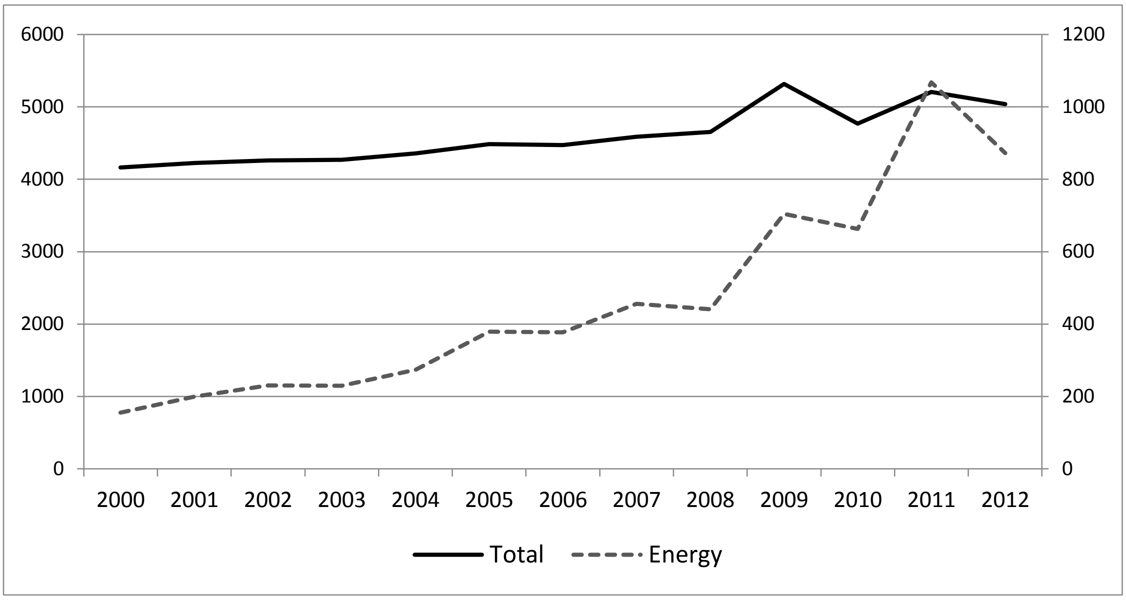
(3 year moving average)



Source: own elaboration based in EU dataset (CORDIS, 2013)

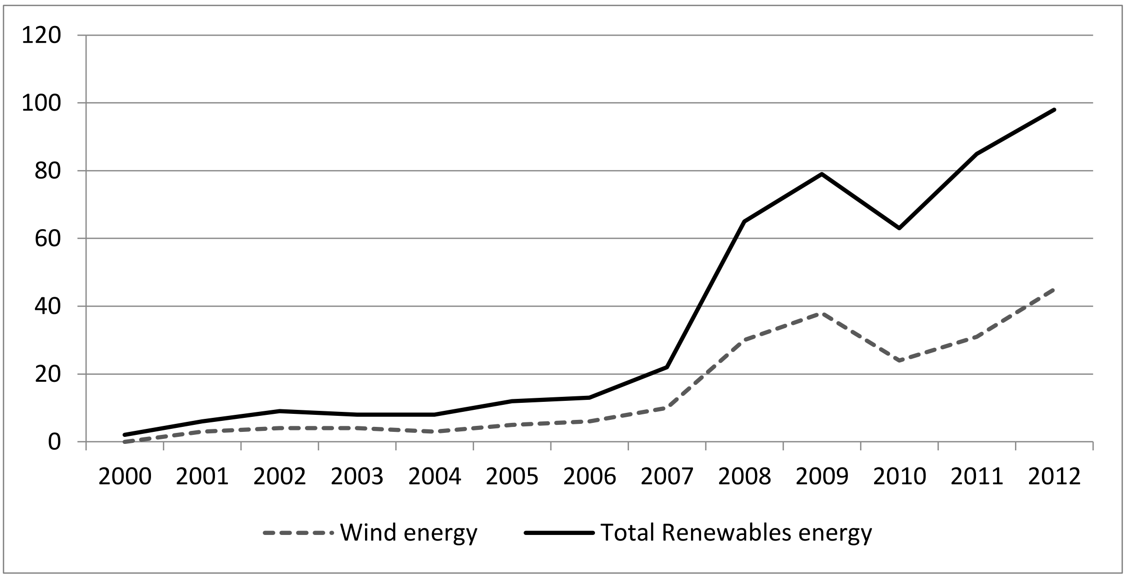
The increasing number of projects granted on renewables energy issues has had a direct impact on research output. First, the rate of growth of publications in the energy field (627%) is almost three times that of the total Spanish scientific system (229%). This means that the share of publications in the energy field has increased from 4% in 2000 to 17% in 2012 (see Fig. 21). Also, data from the Spanish patent office reveals a significant increase in the number of patents. Wind energy was the second sector (43.2%) for number of patents (behind solar energy) in the period 2000-2012 with 203 patents granted and the most significant interannual increase in annual patents granted (see Fig. 22).

Figure 21 Number of scientific publications in Spain. Total and Energy category



Source: own elaboration based in (SCImago, 2014)

Figure 22 Number of patents related to renewables energy sector in Spain. Total and wind energy



Source: own elaboration based in (EPO, 2014)

To sum up, the data show that the implementation of multiple funding schemes has provided significant opportunities to increase research capacity in the energy sector and. in particular in wind energy. Public and private institutions have applied these instruments to increase the variety of knowledge resources and have produced significant outputs in term of publications and patents.

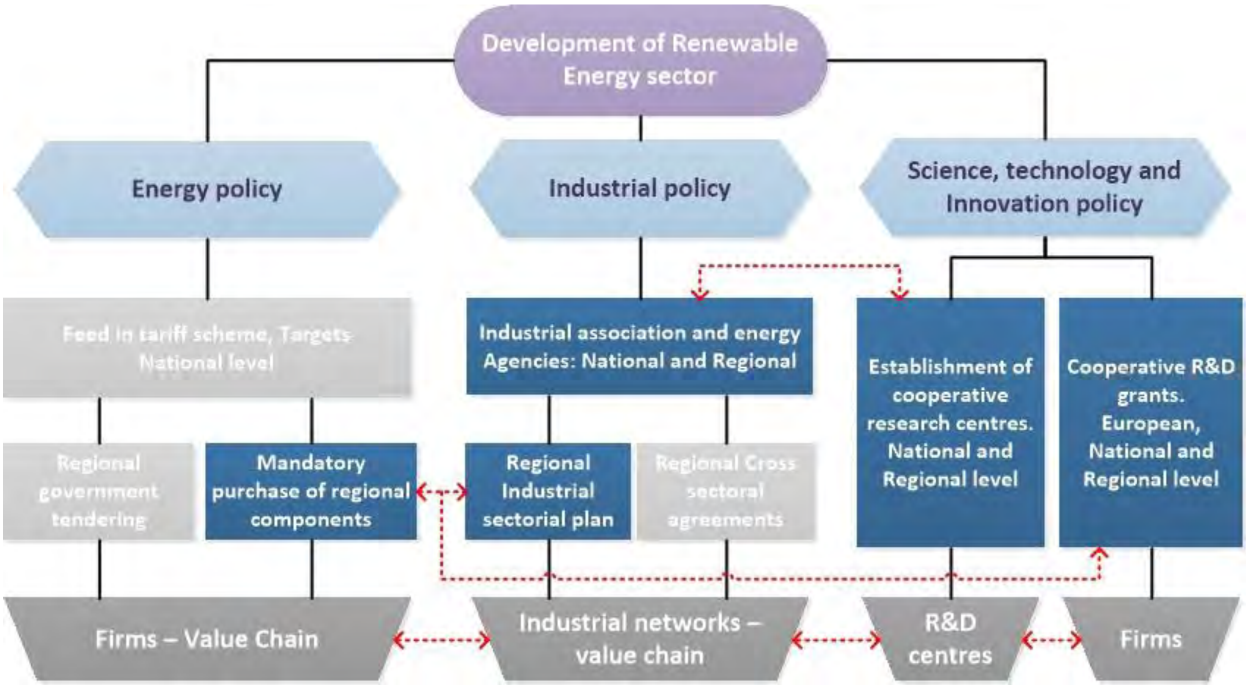
3.4.4 Highlights of research and innovation oriented for industrial development

The wind energy industry as an emergent sector can be described as a combination of a set of components from traditional industries such as electricity production, machinery, electronics and metallurgy and materials. The path within this technological development is described in Chapter 4, however, some simple linkages between the technological requirements of the sector and knowledge creation activities is included here.

First, the challenge of providing local technology (i.e. mandatory purchase of regional components) for deployment in home markets has motivated local manufacturers. Regional governments provide a long perspective and stability through industrial plans which are instruments to develop manufacturing capacity of renewable energy technology.

European, national and regional R&D plans have adapted gradually and their priorities have been coupled to market requirements related to power capacity (e.g. increased turbine size, grid integration and off-shore wind platforms). In this respect, firms along the value chain, and technological centres have been the dominant actors in applied research programmes focusing on key areas in the evolution of the sector (i.e. increasing wind turbine size and grid connectivity). Technological achievements have provided solutions to energy and industry policy issues (see fig 23) such as home market deployments (i.e. mandatory purchase of regional components, long term industrial plans) and exploration of external market opportunities. This last aspect of the sector evolution is explored in the succeeding chapters.

Figure 23 Linkages between main instruments within energy, Industry and STI policy domains



3.5 Summary and conclusions

This chapter was aimed to answer the first research question. How have the energy and industry instruments to support renewable energy been combined with science, technology and innovation instruments within a policy mix that supports the development of the Spanish wind energy sector?

The analysis of evidence has also showed that RES-E policy includes a range of mechanisms linking energy and industry policy to fostering of innovation in emergent sectors. This set of instruments, for application at different levels, may belong to a specific energy policy category or be part of the supply and demand side measures to support industry more generally.

In what follows, we review the policy instruments to foster renewable energy and the sets of measures aimed at promoting innovation. The analysis will seek a better understanding of policy instruments presented in the context of policy mix and explores cross sectoral and cross level connections to highlight the innovative institutional context that creates conditions favourable to (i.e. normative, resources, governance agreements) the emergence of the RES-E sector.

3.5.1 Reflections on the policy mix fostering the wind energy sector

Since the norms for regulation of the energy sector introduced by the EU in 1996, the competences and variety of actors, and system operations have evolved into a complex energy matrix but also a more competitive rather than monopolistic structure more likely to result in an integrated and diversified value chain . Some of the changes introduced have been structural and based on radical liberalization and creation of a market, and have influenced the rate (and speed) and direction of technological development. Other changes, linked to a sequence of different environmental objectives and commitments, have been introduced more gradually.

In Spain, security of supply is a crucial ingredient in support for emergent RES-E sectors. Early policies were implemented to increasing efficiency through vertical segmentation and the introduction of new technologies (i.e. renewables) to improve the energy matrix. Spanish regulation is strongly linked to the EU framework through two interconnected processes: market liberalization and introduction of environmental regulation. Specific sectoral regulation promotes the introduction of new technologies based on technical standards related to efficiency, productivity and CO^2 reductions.

While financial stimuli (FIT), RREE targets and R&D programme are designed at the national level, their implementation and accompanying environmental, energy and industry policies rely on local assets including natural resources, and organizational and regulatory competences. At the local level, policy has created employment and market opportunities on the back of existing R&D and industry capacity. The policy portfolio encompasses direct support, such as mandatory purchase of regionally produced components, financial and tax incentives (manufacturing components), export assistance, R&D, and instruments to facilitate commercialization (i.e. pilots, demonstration, trade missions).

Indirect mechanisms favour market pull to induce demand via FIT and mandatory renewable energy grants (Renewable Portfolio Standard -RPS quotas) explicitly included in long term energy plans and the FIT scheme. The RPS quotas fall within the broad category of public procurement since its implementation requires coordination between the national and regional levels to provide permits and allowances for the development of new energy capacity (e.g. wind, thermal, solar, photovoltaic). This action includes technical requirements related to the scale, type and category of the technology. The regulatory framework has also redefined the activities and roles of actors in energy networks and removed the barriers to electricity market access.

These measures were introduced in the regional wind plans based on competitive government tenders. This common normative framework resulted in a range of responses across Spanish regions with some favouring public procurement oriented instruments (i.e. government tendering and local content requirements) and others keen to improve the competitiveness of their domestic industries (i.e. R&D support and commercialization and internationalization tools). In fact, technological maturity and institutional change seem to evolve together with market characteristics over time

The leading regions adopted the strategy of coupling wind energy plans to sectoral industry plans for the manufacture of renewable energy technologies. This strategy implies a series of regional agreements between the energy producers (i.e. utilities, large and small IPPs) and the manufacturers of the technology. As part of the strategy to increase the variety of business models for RES-E, some regional regulatory frameworks have allowed public-private-partnerships between developers, local manufacturers and local government. Thus, these regional instruments have linked the actors in the local industrial setting to a stable and clear implementation process. This has reduced the risks for investors through the introduction of a long term scenario for market deployment and local technology development.

Table 1 summarizes these policy instruments. The shading indicates the level of policy implementation (i.e. national or regional). Specific features of regional governance regarding both the level and structure of the interaction among local government, the utilities and manufacturers are important determinants of domestic market expansion, deployment and industrial development. The strategic plans for wind energy include instruments aimed at flexible management to adapt decision-making to the local context. For example, the model for natural resources exploitation encourages the participation of regional companies and local entrepreneurial ventures, such as IPPs, and local public-private management of wind farms. In relation to regional companies, the existence of a simultaneous set of industry policies (e.g. long term policies supporting manufacturing related sectors) allows for tighter developer-manufacturer linkages and a greater variety of sizes and positions in the supply chain of industry actors. As a result, the removal of barriers, the mitigation of myopia and short term orientation and the evolving market structure have facilitated the entry of SMEs through innovative models such as IPPs and public private partnership

Decentralized implementation of wind plans at the provincial level responds to the competition for resources, for example, by minimizing the environmental impact of wind energy infrastructures on local activities such as forestry and tourism.

Table 1 Typologies of policy instruments for renewables energy

<table>
<tr><td></td><td colspan="4">Policy instruments fostering wind energy</td></tr>
<tr><td rowspan="2">Demand-driven Innovation polices (OECD)</td><td rowspan="2">Demand & Control (regulatory)</td><td colspan="2">Marked-based(economic)/Market deployment</td><td rowspan="2">Global markets/ Technology push</td></tr>
<tr><td>Supply-push (prices, costs)/financial stimulus</td><td>Demand Pull (amount)</td></tr>
<tr><td rowspan="3">Public Procurement</td><td colspan="2">Government (competitive) tendering for wind projects and resources.
Regional wind plans</td><td></td><td></td></tr>
<tr><td colspan="2">Industrial sectoral plans (manufacturing sector/renewables energy technologies)</td><td></td><td></td></tr>
<tr><td>Participation/ownership of local government in Wind parks.</td><td colspan="2" rowspan="2">←←Existing technology - - - New
R&D and piloting.
Support programmes for demonstrations and experiments</td><td rowspan="5">R&D Programmes
Basic and applied research
University- Industry collaboration projects</td></tr>
<tr><td>R&D & technology policy</td><td></td></tr>
<tr><td rowspan="2">Lead markets</td><td>WE parks & New business models by Independent Power Producers.</td><td></td><td rowspan="2">Commercialization and internationalization support</td></tr>
<tr><td colspan="2">Regional coordination/agreements with Utilities and manufacturers</td></tr>
<tr><td rowspan="3">Innovation-oriented Regulation & Standards</td><td>Mandatory purchase of regional components</td><td></td><td></td></tr>
<tr><td>Mandated fuel off-take RREE</td><td></td><td>Wind map. Information and resource mapping</td><td></td></tr>
<tr><td>CO2 and efficiency environmental standards</td><td></td><td rowspan="2">Renewable portfolio standards (RPS-Quotas) NEP / EU targets: 12% for 2010 & 20% for 2020</td><td></td></tr>
<tr><td rowspan="3">Regulations</td><td>Direct access to electrify market
(barriers removal)</td><td>Retribution scheme based on treasure bones
(substitution of feed-in tariff scheme since 2013)</td><td></td></tr>
<tr><td>National energy plans (NEP)
EU directives on RREE & CO2 emissions</td><td colspan="2">Special Regime - Feed-in Tariff scheme</td><td></td></tr>
<tr><td>Environmental, energy and industrial regional policy</td><td>Land expropriation for wind parks development</td><td></td><td></td></tr>
<tr><td>Standards</td><td>Normative setting wind energy specifications
(type and scale)</td><td></td><td></td><td></td></tr>
<tr><td>Consumer policies</td><td></td><td></td><td>Information and awareness campaign</td><td></td></tr>
</table>

Note: cell colours identify the policy level - National, Regional & Regional & national (R&N).

The portfolio of instruments presented in Table 1 is aimed at security of energy supply and development of the wind energy sector. Support for the creation of a renewable energy market has been expanding in relation to the European market and the technologies (renewable industry and transport). In Spain, the energy market ensures self-sufficiency by emphasizing renewable energy.

The application of regulation in the form of financial stimuli (i.e. FIT scheme) has improved the economic conditions for investment in RES-E power capacity and industry developments related to renewables manufacture. The provision of long term targets encouraging industry sector participation in the process of market deployment has been facilitated by additional regulation aimed at removing the barriers to access to the electricity market. At the same time, the financial stimulus (i.e. FIT) has evolves over time by providing stability in the first period and flexibility in term of differentiated treatment for each technology. This promoted the fast growth of the RES-E sector in the period 2004-2010

The role of regional policy has been critical for the implementation process of RES-E policy set through the introduction of government tendering as a form of public procurement. Public procurement has introduced a temporal horizon to the deployment of new markets and reorganized RES-E value chain operations in relation to the importance of local components and relations between electricity generators and manufacturers. The leading regions have followed different paths to home market deployment and technology development. Learning and technological improvements may occur in regions where public procurement (i.e. government tendering, wind plans and industry plans) are part of the policy mix including R&D support, commercialization and internationalization strategies. In this respect, the commercialization of new technologies should be understood as a process of simultaneous implementation of environmental policy instruments strongly influenced by government R&D on new RES-E technologies

This wider set of policies benefits not only the RES-E generators and the manufacturing sector but also the set of services, operations, maintenance and other activities involve in RES-E.

Chapter 4: Technological development in the wind energy Sector

4.1 Introduction

Chapter 4 introduces the analysis wind energy sector developments based on two drivers: market forces associated with commercial opportunities and technological forces driven by scientific advances. We focus on the range of knowledge areas underlying the development of a modern wind turbine applied along the lifecycle of products (e.g. technological components), processes (e.g. manufacturing of renewable energy technologies, production of electricity) and forms of organizations (e.g. value chain, university-industry relations). We explore linkages between market opportunities and technical improvements as part of a learning process.

The empirical study of wind energy technology development presented in this chapter is aimed at improving our understanding of the above linkages through an investigation of specific characteristics of traditional sectors such as metallurgy, electronics and power generation, in terms of adapting the existing knowledge base, industry capacity and technological background in order to exploit market opportunities. The rate (and speed) and direction of wind energy technology development is explained as part of that adaptation process, by looking at the process of transfer knowledge and capacity from existing sectors to new ones. This chapter provides empirical evidence related to Research Question 2.

The empirical analysis is framed by the theoretical elements presented in Chapter 2 regarding the creation and application of governance mechanism (Antonelli & Quéré, 2002; Antonelli, 2006) such as innovation platforms (Consoli & Patrucco, 2011; Gawer, 2010) to facilitate coordination between the actors and different types of knowledge. Aspects of innovation platforms, such as adaptation, integration and complementarities between knowledge bases, are used as conceptual pillars supporting the description of technological and industrial developments in the wind energy sector. We identify the modular components and search of complementarities among the diverse knowledge bases involved in the wind energy value chain. Some elements of evolutionary economics, such as related variety, are introduced as part of the investigation in Chapter 5 which focuses on regional aspects. These elements also help to explain the emergence of technological trajectories from the recombination of knowledge, and from existing sectors (Boschma & Frenken, 2009) through the application of mechanisms associated with path-dependence industrial history (Dawley, 2013b; Ron Martin & Sunley, 2006).

The chapter is organised in three parts. The first part describes the evolution of wind energy technologies, focusing on the dominant technologies and the main areas of knowledge. The second part provides evidence related to the emergence of the wind energy sector. We study the wind energy value chain as a general concept and then analyse the Spanish case and the diversity of activities, market structure and paths to knowledge creation.

4.2 Evolution of wind energy technologies

The development of wind energy technologies has been described as involving up to four stages. Certain methodologies and conceptual frameworks, such as Accelerated Radical Innovation (ARI), technology life cycle and diffusion of innovation, are considered to be facilitators combined with key events and particular milestones (Dismukes, Miller, & Bers, 2009). The first stage in wind energy technology evolution has been defined as before the first oil crisis (1973). It tracks technology developments from windmills used for mechanical power generation for the agricultural sectors in Asia, Europe and the US, to the first decades of the 20th century. The use of wind for electrical power generation began in 1918 when Poul la Cour had 250 electricity-producing wind turbines built in Denmark - 120 of which were connected to power stations (Jones & Bouamane, 2011). The French designer Darrius in 1931 introduced the Vertical Axis Wind Turbine (VAWT) which became the basis for several still current designs. The wind turbine built by the Danish engineer, Smidth, in 1941-1942 incorporated significant advances in power generation, as did Pulltman's giant wind turbine (53m) built for an American company. After the World War II, Jull in Denmark (1956-1967) and Hütter in Germany (1960s) introduced several improvement related to materials and efficiency (Ackermann & Söder, 2000; Davies & Diaz-Rainey, 2011; Jones & Bouamane, 2011; Kaldellis & Zafirakis, 2011).

The second stage of the evolution dates from the oil crisis. The US government sponsored a large R&D programme on large horizontal wind axes which ran from 1974 to 1981 as part of the US energy programme and was supported by the Department of Energy, NASA (testing) and National Renewable Energy Laboratory. Early developments in the 1980s were to supply energy to farms and rural areas. The most significant developments occurred in California (US) mainly in materials for blades, which were constructed in steel, aluminium, wood epoxy and fibreglass. On the other hand, Us policy based in tax credit was a key financial stimulus that foster the first generation of wind turbines that were exported to Denmark (EWEA 2009). The VAWT was initially a leader, but the need for a technology that would be suitable for mass production directed developments that resulted in the Horizontal Axis Wind Turbine (HAWT). Most wind farms in the 1980s used that technology (Jones & Bouamane, 2011; Kaldellis & Zafirakis, 2011).

The third stage is the acceleration or development stage. Europe led this development in the 1990s, while the US reduced its funding and support for the sector. The pioneer company Vestas, which also played an important role in the US, expanded its set of designs in relation to turbine size and through the introduction of offshore technology which resulted in bankrupting the firm because the design proved not sufficiently productive. However, the company was able to recover based on European demand for traditional wind turbines (European Wind Energy Association, 2009; EWEA, 2009; Islam, Mekhilef, & Saidur, 2013).

At the same time, German companies began to make major advances and became the leaders in this technology. The innovations in power generators allowed these firms to increase the turbine size and achieve significant improvements in other aspects of the supply chain such as control system, gearbox and bearings. New materials for blades were introduced (i.e. aluminum). Finally, at the beginning of the 21st century Europe overtook the US to become the leaders in wind production and technology development. This period is characterized by the entry of big mature technological firms such as General Electric in the US and Siemens in Germany. There is a clear prominence of the HAWT design through massive adoption of the three blade (steel) rotor and achievement of increased size through reduction in weight. New materials for blades and innovative speed control systems (i.e. stall control) pushed the technology and increased efficiency, reduced maintenance costs and operation of wind turbines (Ackermann & Söder, 2000; EWEA, 2009) .

4.2.1 Emergence of a dominant design

The basic design of the technology has changed very little since 1990s. The tubular tower and horizontal three blade design dominates. The technology works through pressure exerted on the blades and the inflow of wind which activates the rotor, which, in turn, spins the shaft and the energy generator inside the nacelle. This relatively simple mechanism poses a number of challenges related to power availability, in particular, unpredictable weather conditions. The wind turbine size is a main aspect of the technological evolution, and relies on three critical principles.

First, the technological principle refers to the concept of torque in the area of mechanical engineering (i.e. mechanics of fluids) where *"The longer the distance from rotation axis, more rotation under the same force (wind)*" (Granell Ruiz, 2013a).[26] The second principle refers to wind capture and relies on physics and micro meteorology. At higher altitudes there is more wind and less turbulence (and more stability), so performance improves exponentially. The third principle refers to economic criteria and is based on the range of the wind turbine which can be measured in relation to capacity for electricity production. This can vary from several kilowatts to megawatts and the critical variable is the diameter of the turbine i.e. the length of the blade which allows the rotor to generate larger amounts of energy. These principles are related to system economics where small turbines are more expensive per KW than larger ones. At the same time, controls, electrical connection to the grid and maintenance represent a much higher proportion of the capital value of the system, and are not proportionally related to the size increase.

[26] The key technological concepts for the understanding of Wind turbines operation were developed through several interviews with Dr. Rafael Granell Ruiz at the Department of Hydraulic and Environment of the Polytechnic University of Valencia

Finally, increase size and megawatts has to do with the long term strategy of exploiting offshore resources. The following table shows the evolution of this variable and the expected results in the next years. All the principle can be also understood in terms of cost-benefit criterion which has driven the design wind turbine in last two decades (see Annex 1 – Part A). Form this, the evolution of wind-energy technology hinges upon the continuing search for material and techniques aimed at improving the capacity and the efficiency of power generation by the capture of air currents.

Comparatively higher efficiency in production combined with greater ease of operation and maintenance favoured the consolidation of a dominant design, namely the Horizontal-Axis Wind Turbine (HAWT) (Islam et al., 2013). The developmental path of wind energy technology is defined by the incremental adjustments that have been made to this relatively stable set of components. Advances in power generation has been driven by the need of simplification but also the potential of manage different speeds as long as the turbine size increase. That potential is also the main factor in the movements from fixed speed to variable speed controls.

Finally, the search of new materials and aerodynamic design for increasing size and reducing weight has been the main mechanism to drive advances in blades, tower (and frame) and nacelle. At the same time, weight has been a critical factor in term of simplifies installation, maintenance and thereby final cost of turbines. All these advances has been driven by core principle of generating a mechanical rotation using the force of kinetic energy as well as the principle on the potential of wind capture from the increasing size of the wind turbine. Table 2 summarize the more significance advance in wind turbine technologies by considering the whole system and the key components.

Table 2 Relevant technological advances on wind turbines

	Level of analysis	70-80	90´	2000-beyond	Dominant design (DD)	Mechanism for DD	Dimension of success	Critical advance
Wind turbine	**System**	VAWT loose significance under properties of HAWT for massive production 30 m Rotor diameter (RD) HAWT	HAWT steel two and three blades. Increasing size 70 m RD HAWT First offshore wind farm	HAWT tubular tower and horizon three blades design Experimental VAWT Rise of offshore wind turbines Offshore wind turbines	Steel tubular tower and horizon three blades (2008)	Increasing size & reducing weight	Capacity	Speed control
Generator	**Subsystem**	DC generators variable speed. Experiments on H&V for electricity generation	AC generators constant speed German leads innovation in power generation	Move to direct-driven generation without the gearbox	NO	Simplification	Voltage control and grid compatibility	Permanent magnet generation
Control System	**Component**	Pitch control Fix Speed	Stall regulation (Key innovation) New power train, variable/fix speed and control system	Modern turbines combine both technologies using “active stall” and Speed variation (better offshore)	Pitch control (early 2000´) Mix control system/wind adaptation	Flexibility by subcomponents (e.g. software, modelling)	Adaptation and efficiency	Mix technology “Active stall”
Blades	**Component**	2 rotor blades & 3 rotor blades Steel	3 rotor blades Introduction of Aluminium	New material and Composites Top: two parts joined GAMESA (2010)	Three blades steel (late 90’)	Increasing size & reducing weight	Increasing size & mechanical stress: Reliability Installation and maintenance: cost reduction	New material and composites
Tower	**Component**	Two types: Guyed pole towers Lattice towers	Tubular cylindrical Steel towers	20-30 metros tubular steel towers. Conical instead of cylindrical New developments on prefabricated mix of concrete and Steel	Tubular conical (2000´)	Increasing wind capture and reducing turbulence by height	Cost benefit (wind capture) Efficiency and reliability (turbulence) Aesthetic (public support)	Material mix to reduce weight and increase strength (offshore)
Nacelle	**Component**	Increase size, design oriented to facilitate maintenance	Increasing the strength and reducing its weight	Yaw mechanism to allow full rotation	NO	Increasing strength & reducing weight	Installation and maintenance: cost reduction	Improvements in mass (materials and design to be lighter).

Source: own elaboration based in (Bilgili, Yasar, & Simsek, 2011; Cortazar, 2010; Dismukes et al., 2009; EWEA, 2009; Granell Ruiz, 2013a; Islam et al., 2013; Şahin, 2004)

4.2.2 Main areas of knowledge and technological trajectories in the development of modern wind turbine technologies

The basic operating principle of wind turbine technology is the capture of kinetic energy generated by the propulsion of air currents and its transformation into mechanical energy that in turn generates electric power. The dominant technological design is a horizontal three-blade turbine that was first conceived in the early 1900s, however, the evolution of technology and adaptation to towards the development of big-scale machines has promoted an update and upgrade based in the couple of technology with the need of better land exploitation and cost benefit principles as scale economies and optimization of maintenance and operation (M&O) requirements (Kaldellis & Zafirakis, 2011). Simultaneously, the evolution of wind turbine has also been driven by an exponential increase in the rotor diameter, which in fact, relies in the core technological principle on mechanical optimization which entails an efficiency trade-off between size (i.e. turbine size diameter -TSD-) and weight in turbine design.

While improving turbine design was the main goal of early inventive efforts, the pursuit of higher efficiency -influenced by competitive energy market conditions - has been in recent times tied to the exploration of new materials and of interoperability across mechanical, electric and electronic systems. In fact, the economically efficient way to generate energy from air currents is the deployment of wind farms (or wind parks), that is, installations of several individual turbines that can extend for up to several hundreds of square miles[27]. Wind farms are energy systems that accrue economies of density due to co-location while at the same time entailing technical and organizational challenges that differ from those related to designing, managing and operating individual turbines. Wind farms entail generation, storage and distribution issues that call upon the integration of complementary technological components. Thereby, in addition to

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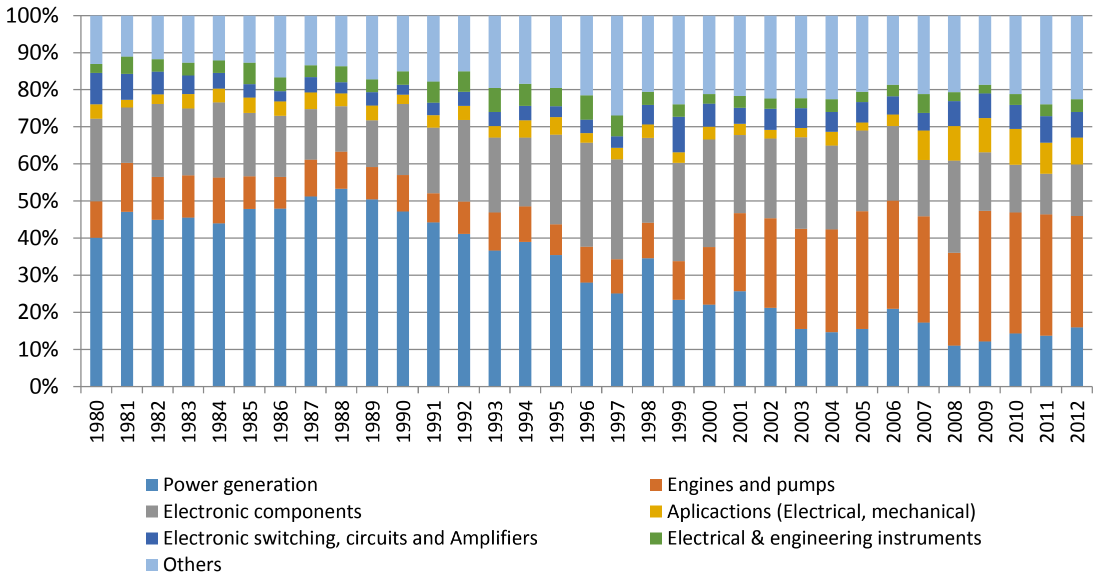
The above description involver a system perspective on the wind energy technology which is characterised by different types of knowledge resources applied to face the several challenges of introducing wind power for the production of electricity. According to Dismukes et al (2009) the variety of knowledge resources can include fundamental aerodynamics of converting wind power to electrical power, power electronics, electrical control systems, development and manufacture of large, cost effective composite wind turbine designs, computing, communication and information technology, and reliable and cost effective linking to the electric utility grid. All these knowledge areas can be understood as complementary modules to be integrated in the technological system around wind energy. In fact, a chronological analysis on the technological categories of wind energy related patents shows that 80% of the patents in the last thirty years can be included in just five categories Power generation, Engines and pumps, Electronic components, Applications (Electrical, mechanical), Electronic switching, circuits and Amplifiers and Electrical & engineering instruments (see Fig 24).The share of them as group is 87% in 1980 and 77% by 2012[28].

[28] Power generation has been the most important category in the whole period even. The second technological category is Engines and pumps which started. Finally, the last main technological category is Electric components which include a wide variety of technologies. The share of this category a long time has not have a stable or clear trajectory, the average in the whole period is 18% and higher rates in the second half of 90'. Key technologies in this group are Inductors, Transformers and transducer applied to change and adapt the electricity frequency and voltage to connect to the network.

Figure 24 Evolution of technology categories among wind energy related patents 1980-2012



Source: own elaboration based in data of Derwent patent dataset

Even when there are specific developments on power generation, electronic and other engineering processes as it was described before; they are not specific or even a novelty in the power generation and mechanical engineering knowledge but they can be easily related with the application in the wind turbine technology. The application involves the use of tacit knowledge for the adaptation and transformation of technological knowledge and then codified knowledge during the systematization process within the wind turbine technology system.

In fact, according to several experts in the field of wind technologies who has confronted the information presented in the Fig 24, the rise of wind energy sector in Spain has been not based in radical innovation but has adapted advances on several traditional knowledge areas which were already available (Granell Ruiz, 2013b; Hurtado Pérez & Pérez-Navarro Gómez, 2013). These arguments are clearly aligned to the concept process of transfer from one industry to other (Dawley, 2013b; Ron Martin & Sunley, 2006) and innovation platform in terms of the ability for maximizing by economies of space and economies of scope the variety of knowledge and therefore, innovate toward a clear and stable direction (Consoli & Patrucco, 2011).

The experts state that the increasing amount of applied R&D funding has been addressed to the exploration of market opportunities provided by governmental subsidies (i.e. Feed in tariff scheme) in order to wake up “asleep technologies” not applied before because the lack of favourable economic, regulatory and market conditions (Cano Santabárbara, 2013; Hurtado Pérez & Pérez-Navarro Gómez, 2013). The table 3 shows the relations of traditional areas of knowledge such as power generation and mechanical engineering with the knowledge application to wind energy technologies. They have been established by confronting patent data, literature review and interviews with experts in the field of wind energy. UNESCO nomenclature has been applied to standardize the knowledge areas and identify knowledge categories to be used in further analysis on firm's activities and R&D project.

Table 3 Knowledge areas related to wind turbines by UNESCO nomenclature

UNESCO nomenclature Code/Name	Knowledge area/application to wind turbines
3201/Aeronautical technology & engineering 3313/Mechanical Engineering and technology	Fluid mechanics: aerodynamics applied for the design of main structural parts as blades, nacelle and tower
3303/Chemical technology & engineering 3312/Materials technology	Chemistry and materials: application of novel materials and composite are critical used to increase the turbine height while reducing weight and increase efficiency
3305/Construction technology 3312/Materials technology 3315/Metallurgical technology	Metallurgy: generic processes are applied for the design and production of main structural components as nacelle, frame and tower
3306/Electrical technology & engineering 3307/Electronic technology 3322/Power technology	Electrical engineering: includes all the elements related to power generator as a basic technology in the energy industry
3305/Construction technology 3310/Industrial technology	Industrial and civil engineering: it includes all the activities concerning and industrial and energy infrastructure as assemble, installation and maintenance
3312/Materials technology 3316/Metal products technology	Solid mechanics: includes all the components that facilitate and control the kinetic movement form blades to the generator.

Source: own elaboration based in (Dismukes et al., 2009; Granell Ruiz, 2013a, 2013b, 2014), (Cano (2013) and Hurtado Pérez & Pérez-Navarro Gómez (2013)

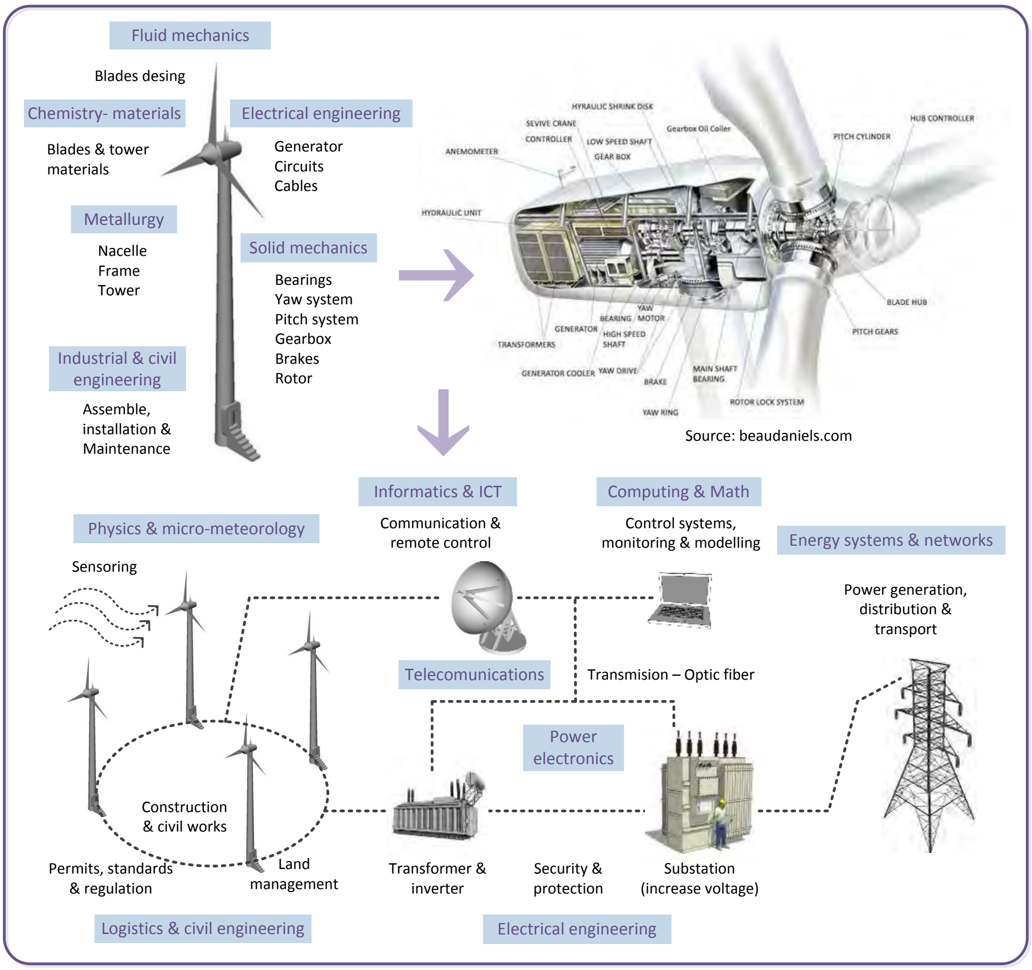
The set of knowledge bases listed above include traditional industries as construction, metallurgy and electronics. The explanations on the application provide some indications on the wind turbines technology form a system point of view. Then, the use and combination of technological knowledge involves the management of modular components and the following optimization and systematization of improvements at system level. In fact, generator, blades and gearbox are technologies already available from other traditional sector as hydroelectricity, naval and aircraft industry (see Annex 1 – Part b)[29]. The existence of these technologies has facilitated a less disrupted advance in the industry.

[29] The main components of a wind turbine are the blades, or rotor, which converts the energy in the wind to rotational shaft energy; the nacelle, that contains a gearbox and a generator; a tower to supports the rotor and drive train; and various other equipment such as including controls, electrical cables, ground support equipment, and interconnection equipment.

The modular combination of traditional technologies with complementary knowledge base was the base of building the systemic view of wind turbines. For example, the wind generator (energy generator), includes a series of traditional electro mechanical components such as train system, gearbox and bearings; all of them contained within the nacelle – the box - (see Fig. 25 below). Thus, the knowledge base for the wind turbine manufacturing comes from the dynamic process of integrations activities and capabilities of relevant agents on traditional basic science in the metal-mechanics industrial sectors.

By scaling up, the set of wind turbines and complementary technologies within wind farms can then considered energy systems where technological and organizational levels are relevant under a platform operation. Wind farms are then not just grids of interconnected technologies, they should be understood as systems of integrated know-how. Wind farms require the other complementary technologies to be connected with the energy networks. As energy generation units, they are part of a bigger system involving generation, distribution and transport, however, variant conditions depending on the availably of continues natural resources (wind) requires additional technological components to stabilize and transform the electricity to be connect to the grid. At the same time, the energy generation should be managed by remote monitoring and control systems which relies on ICT, computing and telecommunications technologies (see figure 25).

Figure 25 Wind Farm technologies and forms of know-how



Source: own elaboration base in EWEA(2009), (Dismukes et al., 2009; Granell Ruiz, 2013a, 2013b, 2014)

The different technologies involved in the managing of wind farm has been applied earlier in the design and implementation of other technological system as general electricity production, transportation or infrastructure. The success in the process developed for the adaptation to wind energy systems relies then in facing the particular challenges such as increasing wind turbine size while reducing weigh and improving efficiency. At a bigger scale, the grid connectivity and the control and operational system were a key advance in terms of the specific features of wind energy production (i.e. predictability, stability, wind quality, turbulence, etc.). These variations around the core technology improves the economies of the system and the utilization of installed capacity (Consoli & Patrucco, 2011) which all together allow a wider and faster diffusion of the technology.

The search of bigger scales determine then a driving factor in the process of technology evolution from with the speed and rate of change can be understood in term of the innovation at component and system level. In particular, the grid connectivity is a critical element for the integration of renewable energy It involves the technical compatibilities relates to the electricity transformation but also the strategic long term coordination of utility companies and technology developers for the exploitation and operation of regional markets. The technical aspects concerning the system integration and compatibilities has been supported by governance mechanism seeking for complementarity in technology development and use (electricity production) which remains a territorial issue (Antonelli & Quéré, 2002)

According to information provided by experts, the experience, knowledge base and background of main energy and technological companies as systems integrators was critical in the process of adaptation of existing knowledge and technologies to the requirement of wind energy generation (Perez Ramirez & Mariscal Melero, 2013; Ugalde Sanchez, 2013). That background and technical expertise - critical inputs in the basic set up for a wind farm – is the main component of tacit knowledge which is characteristics by the system perspective and the logistic of maintenance and operation. The specific knowledge applied for the adaptation and optimization of the different technological components is part of the knowledge systematization and codification process. The Table 4 below describe the different knowledge areas considered.

Table 4 Knowledge areas related to wind farms by UNESCO nomenclature

UNESCO nomenclature Code/Name	Knowledge area/application to wind farms
2501/Atmospheric sciences, 2502/Climatology & 2509/Meteorology 3311/ Instrumentation technology	Physics and micro-meteorology: Aeolian maps are used at large scale and small sensor in the turbines as part of the speed control
3305/Construction technology 3310/Industrial technology	Logistics and civil engineering: it includes several sectors related to develop of infrastructure and its maintenance as construction, land use and related management areas
3325/Telecommunications technology	Informatics, telecommunications and ICT: communication and remote control of wind turbines from operation stations.
1203/Computer Sciences 3304/Computer technology 3311/ Instrumentation technology	Instruments, computing and math: techniques and software using for control, coordinate and plan the energy production under variant conditions
3306/Electrical technology & engineering 3307/Electronic technology	Power electronics and Electrical engendering: includes all the technology and process as transformation (i.e. change voltage) and security needed to connect the wind farm to the grid
3322/Power technology 3310/ Industrial technology & 5311/Organization and management of enterprises	Energy system and networks: adaption of general infrastructure and logistic to transport and distribute the energy generated at the wind farm

Source: own elaboration based in (Dismukes et al., 2009; Granell Ruiz, 2013a, 2013b, 2014)

These categories contain most of the technology and processes critical in each of the energy technologies in both categories fossil fuel based and renewables. However, as it was mentioned before, the search for increasing height, losing weight and improving efficiency has boosted innovation in structure and materials as well as adaptation of power generation and electrical components by point the huge potential of increasing size (i.e. TSD), in particular, towards offshore wind farms.

With that respect, the chief economic concern is the search of better designs towards increasing size and power capacity (cost benefit) and, at the same time simplification regarding technology operation (cost efficiency) . The speed and rate of change are given by these main dimensions of the success of the technology which are based in the mayor capital cost investment (and related financial cost) of infrastructure while the simplification relies in the search of minimizing the mayor variable cost: maintenance and operation. The progress in wind energy technology has then been driven by the search of balance between capital investments in infrastructure and the variable costs involved in the operation and maintenance of turbines (see more on economics of wind turbine in Annex 1 – Part c), these balance is related with the large expertise of companies specialized in construction and infrastructure which mostly relies in tacit knowledge. In the other hand, the cost benefit and efficiency criteria have driven the evolution of the technology in term of a series of challenges and trade-off linked to different aspect of wind turbine design which is part of a deeper process of systematization of knowledge as part of the better understanding of wind turbine as a system . The most important achievements in key components of wind turbines are described below to better understand the search of efficiency and better cost-benefit results as well as the application and combinations of different types and areas of knowledge.

4.2.3 Technological trajectories in the development of modern wind turbine technologies

The evolution of wind-energy technology can be described as a cumulative sequence of problems and solutions around changing relative functionality and interdependence across components (Dismukes et al., 2009; Jones & Bouamane, 2011; Kaldellis & Zafirakis, 2011). The problem-solving mechanism entails and application of tacit knowledge originated in similar previews situation while the adaptation and transformation of technical knowledge relies more is systematic procedures with codify knowledge.

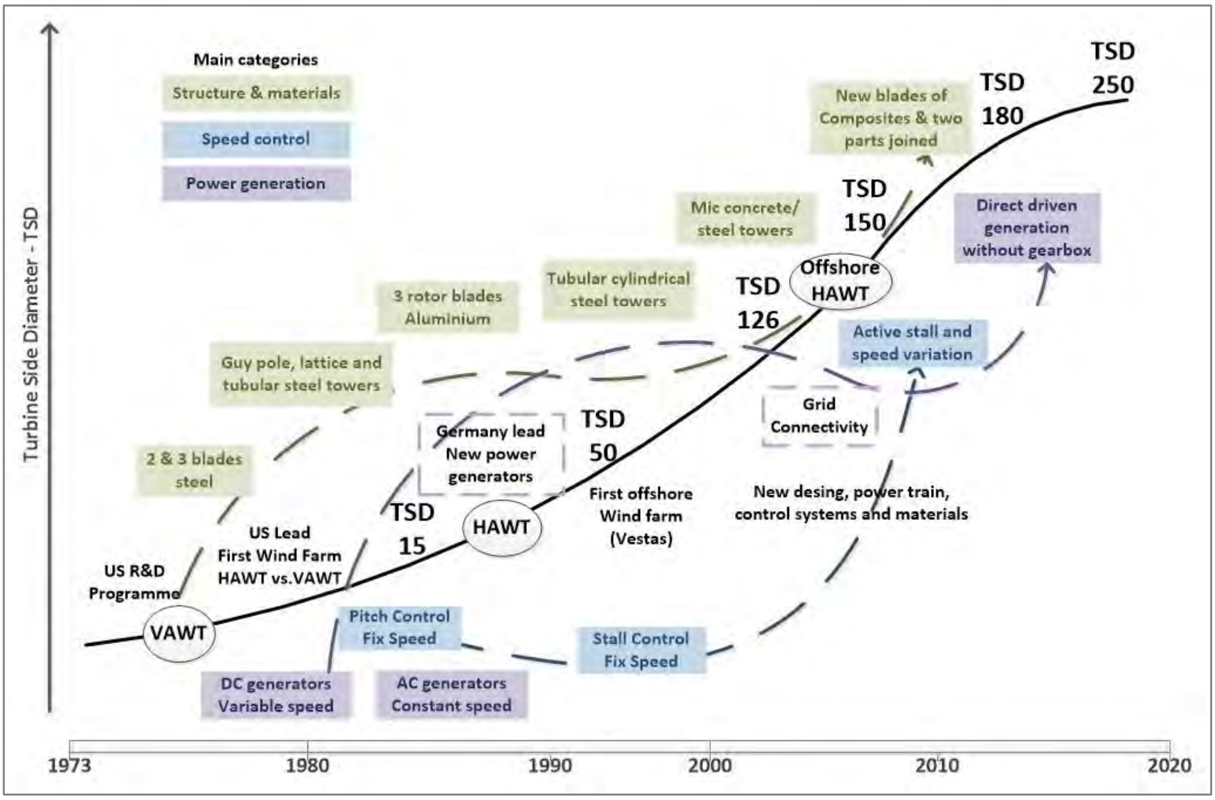
By combining the core principle on generation of kinetic energy and the concept of torque, the variable Turbine Size Diameter (TSD) will be applied as a guide to explore the improvement, combination and integration of the main components that have defined the historical path of development of this technology: the materials, the power generators and the speed control systems. By doing so, any single aspect underpinning the whole transformation of wind turbine design over time will be explained in term of the challenges arising from increasing TSD and, the trade-offs those challenges entailed. The TSD then is the variable that determines the rate and the speed of change in the technological trajectory of wind turbine. Additionally, the TSD is also a technical variable for determining the direction of technological trajectories in term of providing a forecast for further application of technology in better conditions as off-shore wind farms. Around the TSD, three main aspects of wind turbines technologies are described below.

4.2.3.1 Size, weight and materials.

Early design based on 2 and 3 blades in decade of 80´ faced the challenge of being compatible with massive production. Increases in energy capacity can be achieved by enlarging the diameter of the wind capture area with the use of bigger blades up to a certain limit beyond which the increased weight of the helix offsets improved capacity. At the same time, the development of higher towers can increase the wind capture and, thereby, the electricity production (kWh/m2).

A bigger turbine implies an efficiency trade-off between the size and the weight that has traditionally been met by exploring the properties of a broad range of materials that ensure a reliable weight to strength ratio. These elements were critical in the upscale of wind turbine through the movement from 2 to 3 three blades (the rotor is easier to understand) and the early higher tower tubular steel tower in the 80´ of which people think is visually nicer. However, more significant improvements in performance were achieved by the introduction of new materials in blades as aluminium in during the 90´ and a mix of concrete and steel for the tower which allows the fast penetration of cylindrical tower designs as they are lighter and less expensive (see Fig. 26). The technical trade-off between size and weight (maximizing wind capture) combined with the cost benefit regarding economies of scale (bigger size and increasing amount of wind turbines) and economies of scope (increasing variety of related technological components and services) are important inputs in the technological trajectory. Thus, innovations were clearly driven by the search for reliable offshore designs.

Figure 26 Summary of key events and main technological advances in Wind turbine technologies



Source: own elaboration

Finally, the management of big structures implies another trade-off concern the cost on transport, installation and management. Thus, a lighter mix of composites for the blades (e.g. wood epoxy and glass-reinforced plastic) was introduced by 2010 to provide a good combination of weight and strength. On the other hand, innovative joined parts blades designs which simplify the set up logistic and maintenance and thereby, reduce the overall cost of wind turbine.

4.2.3.2 Maximizing wind captures and power generation

Electrical generators, as a mature technology within the energy industry, have evolved in the wind energy by adaptation to the increasing search of power capacity and efficiency. However, the adaption of this already mature technology faces three challenges: the variable frequency of electricity generated by wind turbines, efficiency losses from moving parts and internal mechanism (gearbox, multiplier) and the search for improving productivity in by reducing shut downs for maintenance and reparations.

The three challenges are related and linked to the choice between the two big categories of power generators: induction (asynchronous) and synchronous. While the first one is more reliable in term of network connection and operation but it may have efficient loses, the second one are potentially more efficient[30] but the connection to the grid is more complex.

In spite of these problems, the increasing size of wind turbines (i.e. turbine size diameter -TSD-), the search of more efficient mechanism and the potential of offshore wind farms has pushed synchronous generators during the last years. Thus, The economies of scale of bigger turbine and farms has motivated advances on new technologies related to grid connection and favoured the development of large synchronous generators due to their relative advantage in allowing voltage control (variable electricity frequency) which provide significant gains in efficiency that are especially useful for the development of offshore wind turbines. The technological trajectory is then defined by technological solutions addressed to facilitate the application of more efficient and profitable technologies

4.2.3.3 Increasing wind capacity through speed control

The search for increasing the capacity for wind capture does not only ley on bigger structures and power capacity but also in the management of variable wind speed. In that sense, most of power generation technologies require a fix to operate which represent the main challenge of speed control system. Since that, the evolution and implementation of speed controls system has been conditioned not only by capacity and efficiency issues but also by the need for simplification

[30] Asynchronous generators are the most use by wind turbine manufacturers because allows easier connection to the grid by internal mechanism to stabilize the electricity frequency which avoid additional process and components to achieve grid compatibility. However, it entails an efficiency trade-off in term of exponential loses as the kinetic energy generated at the rotor should rely in several moving parts and a gearbox to final produce electricity. The same issue of complex parts and mechanism also implies frequent services for maintenance and reparation. In the other hand, the synchronous generator relies on a permanent magnet generation which avoid moving parts, gearbox and thereby a more efficient mechanism but there is two trade-off concerns for this technology: first, they are more expensive than induction generators of similar size and second, they have a disadvantage related to connection to the grid as their output is variable not compatible with the fixed grid electricity frequency. This last means they cannot be used as stand-alone systems on a systematic basis.

Early development in the 80´ were based in the pitch control technology by which a set of moving part rotate and adjust the angle of the rotor to adequate the wind flows to a constant rotation. However, the need for simplification and efficiency in term of maintenance and operation push the introduction of stall control systems based in the aerodynamic design of the blade, which became a standard criterion during the 1990s because of simplicity regarding few parts and mechanism, automatic operation (no movement and monitoring or controlling) good performance and easy maintenance. However, the increase in TSD and capacity pushed the pitch control system based in the versatility to operate at variable and large range of higher speeds. Pitch control has similar cost than stall control but provide better output power quality. The system requires the use of multiples techniques and complementary technologies such as wind simulator and modelling software. Thus, the economies of scale of bigger turbines has pushed new advances on control system based in the hybrid systems “stall active control” which are becoming a standard as it gets more efficient performance at high speed.

Wind speed control has then influenced the technological trajectories of wind turbines by searching simplification through the introduction of innovative components (i.e. stall control). Then the challenges of optimising wind capture through increasing TSD has pushed the improvements in the original mechanism (i.e. pitch control) to for managing complexity and get access to a wide range of possibilities. The speed control is an example of modular divisibility (Antonelli, 2006) where a the improvements in a technological component is incorporated to the system as part of a learning process.

4.2.3.4 Turbine Size Diameter as a driver of change

The review of different component of wind turbine provide evidence on the significance of the diameter of wind turbine to determine changes at system level along time. TSD establishes the system economics by the relation wind capture/cost per KW but also in terms of fix cost as controls, electrical connection to the grid and maintenance not proportionally related to the size increase. With that respect, the increase in TSD has facilitated the process of adaptation of different technologies through a learning process but in so doing also leads to complementarities between technologies, introduce standards (e.g. stall and pitch control) and create pathway to possible specialization (i.e. onshore vs offshore wind energy).

At the same time, the increase in TSD comes together with reduction in weight and efficiency by the introduction of new materials as well as more expensive but reliable and efficient wind power capturing technologies as synchronous generators and complex system for speed control. This means response form the combination of modular knowledge to solve specific problems are addressed by maximizing the variety of contributions from a variety of knowledge bases while maintaining and stability and coherence in the technological trajectory (Consoli & Patrucco, 2011).

This section has then provided evidence on the key factors of technological evolution in wind energy sector. However, the variety of knowledge use, applied and combined and the application of expertise as well as lesson learned forma adaptation process involves a different sector of actors operation in different institutional and economic context. The following two sections provide an upscale view to analyse the wind energy industry in term of key actors and market operation but also in term of coordination though different form of governance mechanism. For doing so the value chain perspective is introduced in order to explore the variety of activities involve, the role of coordination and integration of different actors and by doing so, the different pathways of knowledge creation.

4.2.4 Wind energy value chain

The value chain in the sector can be described by considering three different aspect regarding the industrial sector development. The first one has to do with the regulatory frameworks and other issues of the context that conditioned the wind market (already explained in the Chapter 3). The introduction of changes in the energy market regarding process of decentralization, privatization and liberalization has allowed the entrance of a new set of actors at the different stages of market delivery (i.e. production transport and distribution of electricity). At the same time, the increasing variety on energy sources has multiplied the number of man and complementary activities in both sectors electricity production and manufacturing of technologies. This increasing number of actors has pushes the creation of new governance mechanism in term of coordination which may imply vertical and horizontal integrations.

The second dimension is purely the technological, which has been presented in the former section of this chapter and involves the explanation of linkages between main technical components and different forms of know-how. The search of complementarities between the different activities as part of optimization process involves emphasising the system perspective on energy system though a platform operation. This logic follows the logic on innovation platforms where he connections and integration in electricity production and technology development stimulate changes un the network and governance mechanism toward specialization and better use of accumulation of technological knowledge (Consoli & Patrucco, 2011)

Thus, as part of exploring the understanding of the evolution of wind energy sector in relation with innovation platforms the supply chain should be explained based in the different modular technologies characterising the industrial structure. This last can be described by comparing the relation between market and industrial structures with combining analysis of the diversity, complementarities and interdependencies and scope of each of the economic components (actors) that plays a role in the wind energy sector.

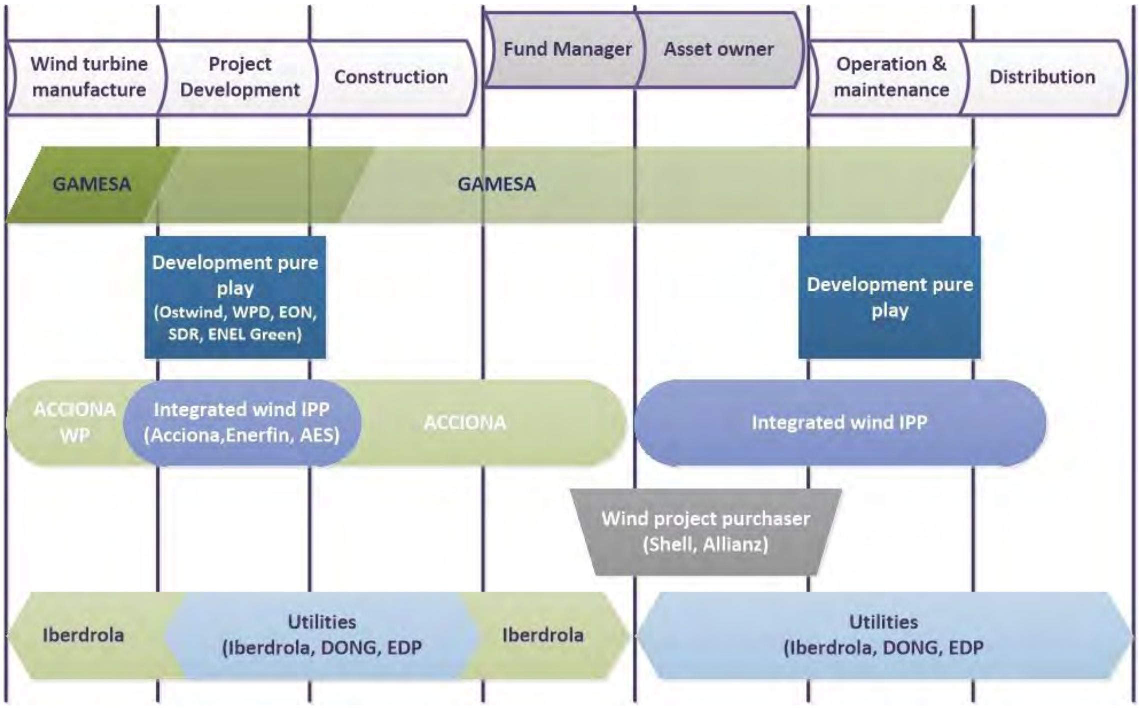
By considering the context of the European energy market, the formation of the wind energy supply chain has been significantly influenced by the wide variation of the demand which depends not only on economic activity, but also on the different national regulatory frameworks and markets conditions. Both aspect have finally shaped the wind turbine market which, in fact, remains regionally segmented. This situation has a big influence in manufactures sales strategies that has evolved through the application of new governance mechanism in tem of specific business lines and procedures to key customers both private and public.

In Europe, manufactures has primarily focus on big wind turbines, around 2 GW or larger, however, most suppliers keep at least one model in each of the categories (500 KW-1MW, 1MW-2MW, above 2MW). On the other hand, some suppliers has developed one generator size with varying power capacity (Vestas, GE, Gamesa, and Enercon). The increasing demand requires significant efforts in the management and coordination of supply chain. The large investments together with the reduction of time to deliver has forced to manufacturers to decide about the optimal balance between full vertical integration of component supply and full component outsourcing. This situation has stimulate the introduction of new governance mechanism to facilitate coordination of competence and knowledge resources among actors. Nevertheless, the final market structure is characterized by different levels of barriers associated with the size of investment and time issues.

That structure can be described by considering different cluster of segments across the supply chain. According to EWEA (2009), the first level - which includes blades, bearings and gearboxes- shows a high concentration of firms and cause what call pinch points in the supply chain. The second cluster of segments including controls, generators, castings and tower seems to have lower concentration of firm and thereby, lower entry barriers. The concentration of firms in the first cluster of firms is a strong incentive for vertical integration in order to reduce risk. Moreover, the conditioned availabilities of the different components means than the number of wind turbine can be constrained by the volumes of parts that can go thought the segments more concentrated in the beginning of the value chain. However, the final positions of main actor among the wind energy value chain will depend not only on the integration of activities but also on the distribution of assets related to other activities related to electricity production.

In fact, according to EWEA (2009), the trends in Europe's wind energy value chain show a redistribution of asset ownership while mature and big markets are targets. This trend has a significant impact in the coordination of networks and activities through governance mechanism. Several and diverse players involved in development and operation has provided a more competitive conditions where local market knowledge, technical expertise and financial capacity has been proved to be very important factors. Among those actors, it is possible to identify three main categories (and their strategies): Utilities, Independent Power producers (IPPs) and Developers. The following figure describes in detail their position in the value chain.

Figure 27 European value chain positioning overview[31]



Source: own elaboration based in (EWEA, 2009) and personal interviews (Cano Santabárbara, 2013; Hurtado Pérez & Pérez-Navarro Gómez, 2013; Perez Ramirez & Mariscal Melero, 2013; Ugalde Sanchez, 2013)

The figure shows the general configuration of European Wind Energy Value Chain according to EWEA(2009) with combining contribution of several Spanish experts (Cano Santabárbara, 2013; Hurtado Pérez & Pérez-Navarro Gómez, 2013; Perez Ramirez & Mariscal Melero, 2013; Ugalde Sanchez, 2013) regarding the role, activities and positions of Spanish actors (indicated in green in the figure). Both EWEA original configuration and the Spanish experts coincide that Utilities as the traditional players of energy sectors, usually engage activities all along the value chain, including the generation, transmission and distribution of electricity in highly regulated markets. Depending on the competitive conditions and the regulatory framework, Utilities can take various organizational forms: investor-owned, publicly-owned, cooperatives or nationalized companies. Owing to increasing market liberalization and to the cost advantages of delocalization, some utility companies have moved away from the established model of vertical integration and adopted mixed forms that entail limited participation in specific segments of the

[31] The original figure from EWEA(2009) was discussed during a set of interviews with Spanish experts in the wind energy sector

value chain. In some cases Utilities operate as brokers that buy and sell, rather than producing, electricity.

In the last decade, the utility companies have boosted their activity by developing big portfolios to achieve national renewables targets under the government support. At the same time they have used the increasing capacity to operate in big and more diverse market for the expansion to emergent international markets. This strategy has been characterized by the use of accumulated experience and the pursuit of risk reduction thought increasing vertical integration.

The other class of important players in the renewable energy market is that of Independent Power Producers (IPPs). These can take the form of small facilities, large corporations or cooperatives. Their business is regulated by long-term price guarantee schemes such as feed-in Tariff or Power Purchase Agreements. IPPs emerged as a result of a wave of deregulation in the early 1980s in the attempt to reduce the market power of incumbent Utilities. The advent of IPPs has changed the logic of competition. These organizations are extremely adaptive and can either compete by developing, owning or operating wind farms. IPPs are often early adopters of new technology and early entrants in niche markets, and promote the mobilization of local competences and the reconversion of existing industrial capacity. This is the case of Spain where IPPs in wind energy have drawn heavily from the installed base of skills in the construction and other large-scale industries. There are two main types of IPP in Europe. Integrated IPPs have competences across the entire value chain and retain high control of all operations within the portfolio. On the other hand, IPPs can also operate as Wind Project Buyers not directly involved in the development of wind plants but rather as coordinators of a platform of independent part producers. This strategic route has brought about variety in the spectrum of relevant knowledge no longer limited to technical expertise on wind turbines but also including managerial expertise and financial literacy.

A third group of actors in the value chain includes Developers, that is, firms that engage activities involving the deployment of a wind farm, namely: purchasing or leasing the land, installing equipment to quantify wind currents, securing transmission, power sales, turbine supply, construction, and financing agreements. Developers have adjusted their strategies in respond to the evolution of value chain and the increasing size of markets and operations. Some large developers occasionally operate entire wind farms, or evolve into proper IPPs, though the vast majority lack the operation capacity and the financing and will limit themselves to develop parts of a project before selling to larger companies. Finally, GAMESA is also included in the figure as wind turbine manufacturers and developer but also as a case of key integrator link along supply and value chain. It is one of the main actors in the Spanish market as it has carried out several additional activities on logistic and services to operate and develop wind farms in local and international wind markets where and integrated view of the system is required.

The resultant configuration of the European value chain determine a pathway of ownership redistribution (i.e., wind farms) according to European and national market. The study developed by EWEA regarding the operation of wind energy value chain has redefined the key players in five categories: 1) Utilities (over 20), 2) top IPPs (over 300MW each working in Spain, Germany, France, the UK and Italy), 3) other Spanish IPPs, 4) German Investors (over 20 GW and 40 % of EU market) and 5) other European investors/IPPS. The study highlights the pathways of evolution of asset ownership during the period 2002-2007 by which the German investors have decreased their participation in favour of Utilities, Top IPPs. The performance of this last in the context of the Spanish market will be deeply explained as part of the description of the Spanish energy sector as follows.

4.3 The Spanish wind energy sector

The emergence of the wind energy sector in Spain has had as a background not only a set of institutional changes in term of national and international energy and climate change policy but also regarding the period of mayor economic growth in last decades. In the period 2000-2008 the Spanish economy has experience a significant growth (78%) characterised by a big service sector (69% of GDP) and three mayor regional economies were Cataluña, Madrid and Andalucía. The industry sector got an increase of 37% supported by main sectors as metallurgy and machinery extensively developed in Cataluña; Madrid and Basque country as well as the other regions in the North of the country (see Annex 2).

In comparative terms, the energy sector is not significant as share of GDP (3% in 2008) but the evolution of structure and level of activity has been significant during the last decades. Since the special regime to foster renewable energy production has been launched in 1997, the energy balance in Spain has changed significantly. The regime was modified twice in 2004 and 2007, and in 2007, the energy balance peaked, with energy delivered by the special regime increasing to 239% (see Fig. 31). After that, total energy production slowed based in the slop down of energy generated by technologies under the ordinary regime. However, the electricity production under the special regime has kept increasing until 2012.

Performance under the special regime based on the FIT scheme has been outstanding for energy production[32] as has corresponding development of power capacity in RES-E (see Fig 32). Capacity under the normal regime increased 42%, while capacity under the special regime reached 522% leading by wind, cogeneration and solar energy (see Fig 33). More specifically, total wind power capacity rose by 3,820% in the period 1997-2008 based in the increase in the number of infrastructures (i.e. wind farms) or the upgrade of installed capacity (i.e. introduction and replacement of wind turbines).

However, the number of active firms operating in the sector Production of electricity from wind (CNAE 3518)seems to have a different trajectory as the increase in the same period is significant (437%) is not proportional to the increase of wind farms (Fig. 34). This last result confirm the argument presented before on the redistribution of asset ownership to Utilities and top IPPs at European level and it will be further analysed in the following section when describing the market structure. At the same time, the increase in the number of firms CNAE 3518 has evolve more stable than the total amount of firms involved in the electricity production (CNAE 35) which has been influenced by the outstanding growth of 3519(Production of electricity from other types). This last includes photovoltaic and thermo solar technologies which has experienced very favourable conditions in term of tariff scheme (see policy chapter).

Regarding the wind energy sector, as it was mentioned before, the remarkable expansion is due to the intersection of various processes. On the one hand, European Union (EU) regulation has provided a solid platform for harmonizing incentives and opening up opportunities. On the other hand, demand for alternative energy has grown significantly and, together with the opening of new peripheral markets, has engendered significant transformations in the structure of supply. In other words, the emergence of the wind energy sector has been based in two pillars: the energy production and the manufacturing of renewable energy technology.

[32] The share of the special regime in the energy balance increased from 9% in 1997 to 37% in 2012 while the share of wind power increased from 1% to 22% in the same period.

Figure 28 Evolution of Spanish regimes on electricity production

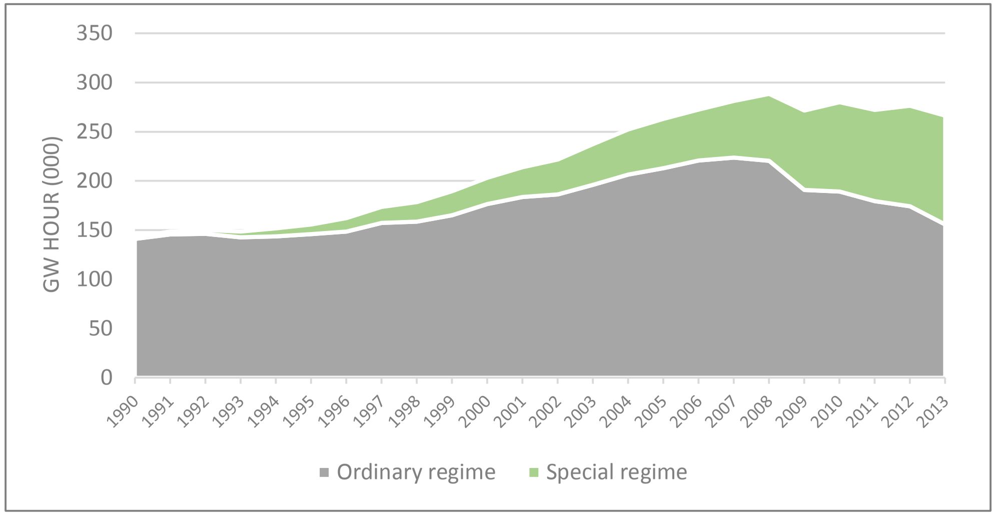


Figure 29 Evolution of total number wind farms and WP installed capacity

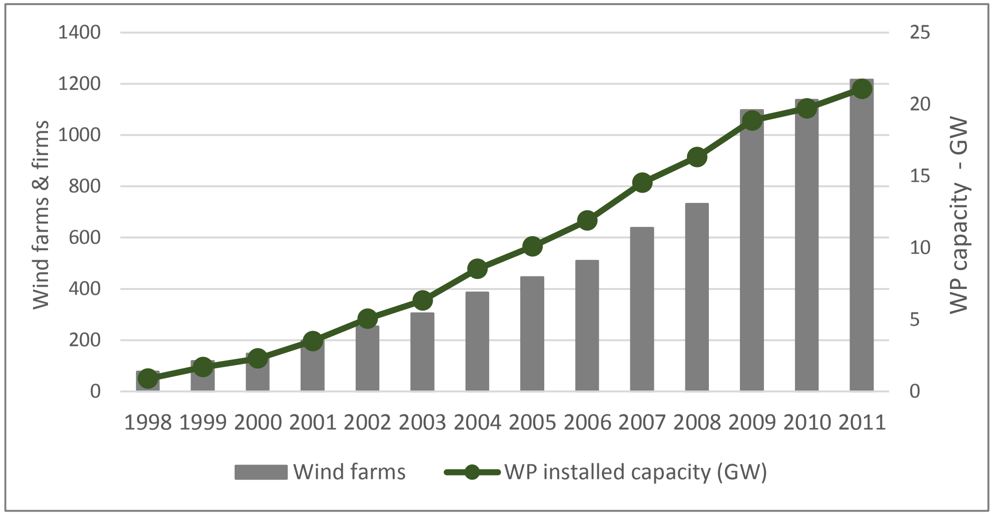


Figure 30 Evolution of Spanish energy Balance 1990-2013

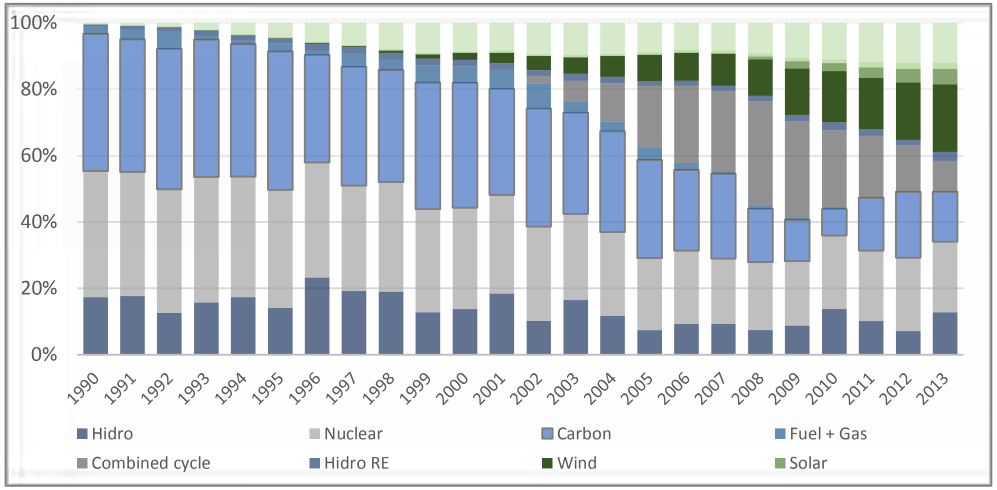
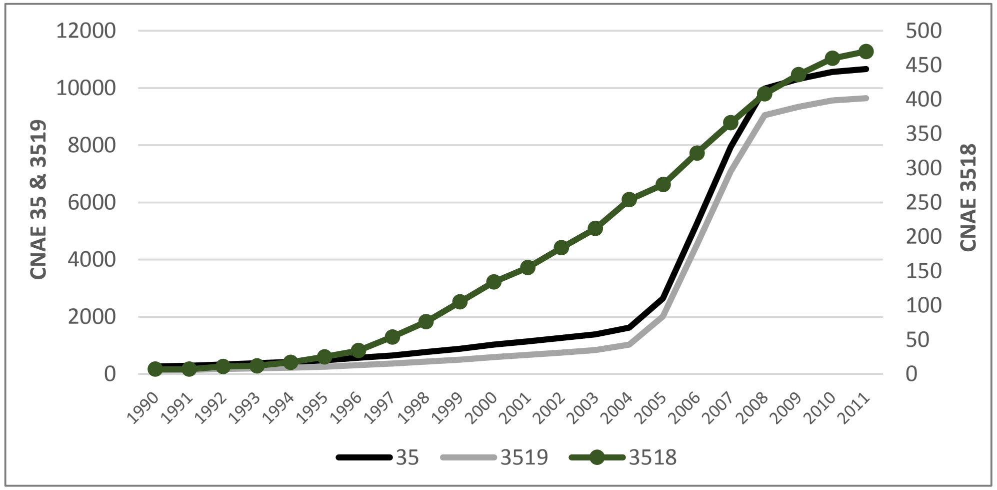


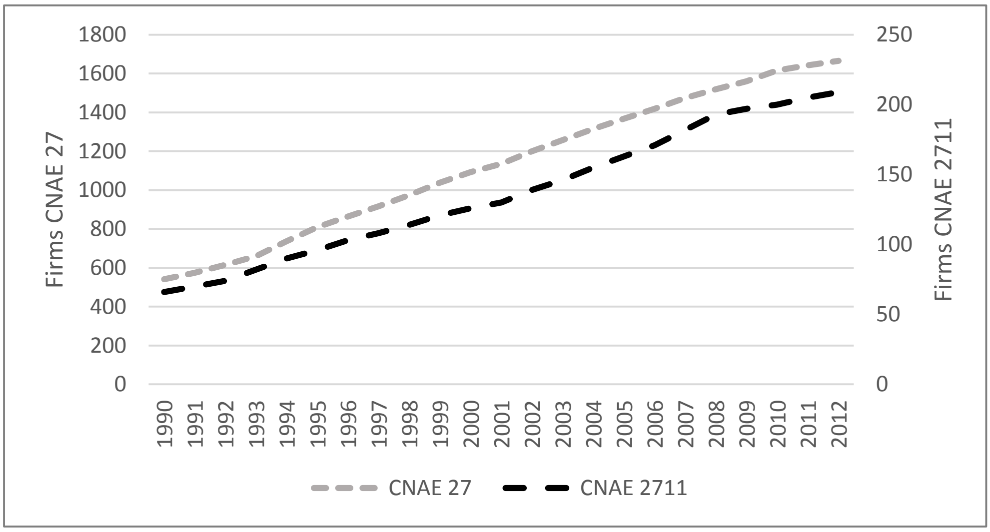
Figure 31 Evolution of total number of firms CNAE 35, 3518 &3519



Source: own elaboration. Fig 28-30 based in REE(2013) and Fig 31(SABI)

That industrial structure supporting the manufacturing on renewables energy technologies is based in the traditional sector as metallurgy, machinery and electronic equipment. More specifically, sectors as Manufacture of electrical equipment (CNAE 27) has had a critical role in the wind energy value chain with a stable growing trajectory since 1990. In fact, the sector CNAE27 has increased significantly and continually the number of firms in the period 2000-2012 with a cumulated growth of 52%. However, by looking at more specific (4-digit) categories such as CNAE 2711 (Manufacture of electric motors, generators and transformers) the increase rise up to 66% (Fig. 32). As we have described before, this category includes one of the critical – even the main one- technological component of the wind turbine, the power generator, that enable the integration in the whole value chain. That significant increase of firms in that sector has also lead to an increase in the turnover and employment (Fig. 33) with expected in impact in other related direct and indirect sectors[33].

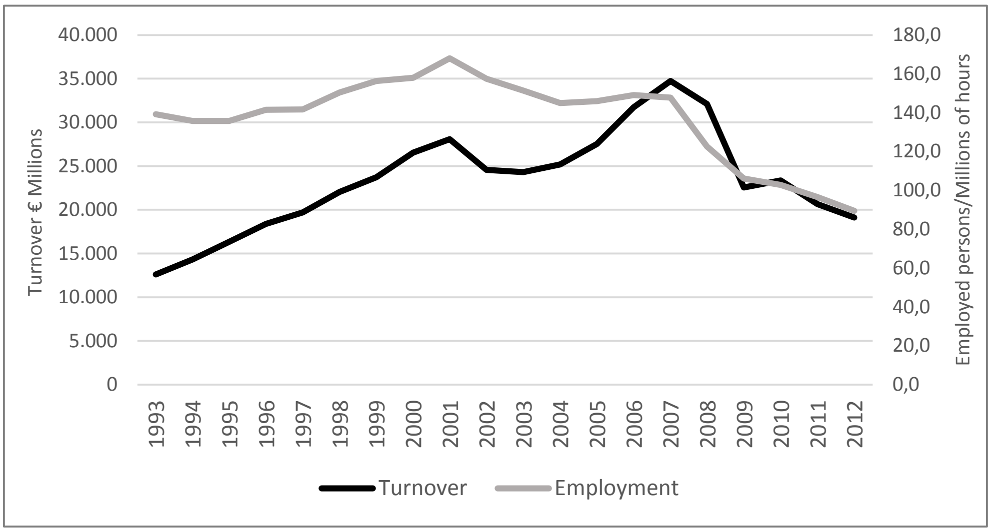
Figure 32 Evolution of total number of firms CNAE27 and 2711



Source: own elaboration based in SABI(2013)

[33] According to Spanish Renewable Energy Development Plan 2000–2010 (IDEA, 2000) the estimated Construction & installation Ratio per Mw is 13 employees

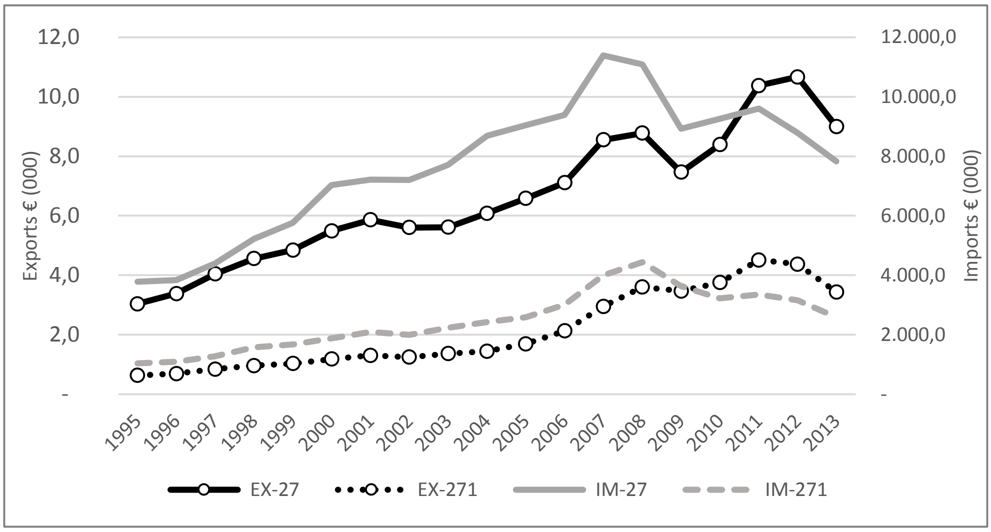
Figure 33 Evolution of turnover and employment in CNAE 26 & 27



Source: own elaboration based in INE(2013)

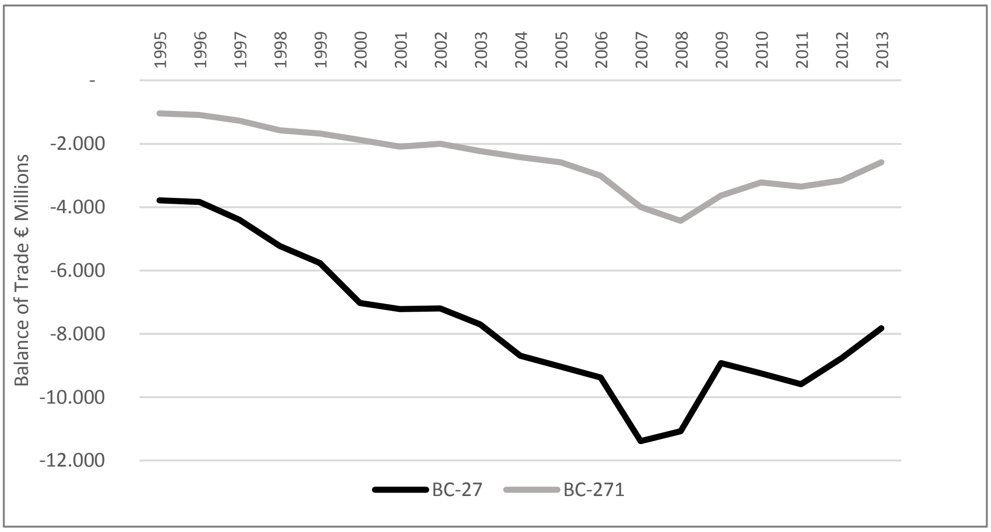
According to the data on external markets, the final destination of electric motors, generators and transformers manufactured locally (CNAE 2711) are not only home market. In fact, the trade balance in these sector is negative but the arte of exports (alongside the imports) has been increasing since 1995 with a significant turning point in 2009 when the imports start to decrease and exports has kept the tendency (Fig 34 and Fig 35.). This change in the tendency can be explained by two factor, the starting of economic crisis and the decrease in growth rate of Spanish wind power capacity as a consequence of the several changes in the regulatory framework.

Figure 34 Evolution of Exports/Imports CNAE 27 & 271



Source: own elaboration based in ICEX(2013)

Figure 35 Evolution of trade balance CNAE 27 & 271



Source: own elaboration based in ICEX(2013)

Having presented and overview of the overall performance of sector traditional sector that feed the wind energy value chain, a deeper understanding of the specific industrial structure and activities related with manufacturing of wind energy technologies is required. As follows, emphasis is put in the diversity of industrial activities developed across the Spanish wind energy value chain.

4.3.1 The diversity of activities and industrial capacities in the Spanish wind energy sector

According to the EWEA perspective on the European wind energy value chain, the activities involves are aligned from wind turbine manufacture to energy distribution. The traditional activities can be decoupled in the different modular technologies related with energy system such as energy distribution and transport. However, a more detailed view in more specific activities of the Spanish wind energy sector[34] reveals that firms engage different activities along the value chain, and a significant part of them (36%) carry out more than one activity (see Table 5 below)[35].

Some technological actors with competences across the entire value chain have turn into integrated IPPs as they are developers but also operate wind farms and sell the energy. The integration of these activities reveals the concentration of segments related with market deployment and operation, which can be strongly based in previews expertise in other markets. According to AEE list, almost 40% of main developers (17 over a total of 44) operate wind farms in 2011. However, the detailed information per firm reveals the importance of two main actors, Iberdrola (utilities) and Acciona (top IPP and big infrastructure company) which carry out the mayor number of activities in the value chain and nearly followed by the main wind turbine manufacturer, Gamesa (also IPP as developer-operator). The performance of these main companies has a correlation with the model of European value chain described before.

[34] Preliminary list of firms (227) in the Spanish Wind energy sector (AEE, 2011) Business Directory of firms of Spanish Wind Energy Sector. http://www.renovablesmadeinspain.es/ficheros/documentos/pdf/guia.pdf

[35] The identified activities are: Wind farm Developer, Wind turbine Manufacturer, Component Manufacturer, Engineering and Civil Engineering, Operation and Maintenance, Consulting, Finance and Insurance, Transportation &Logistics, Technology Centre, Training and Other.

Table 5 Activities in the wind energy sector - Spain 2011

				Type of activity										
Activities per firm	Firm/group of firms	Total firms	Share	Developer	Wind turbine Manufacturer	Component Manufacturer	Engineering	Operation	Consulting	Financing	Transport	Technology R&D	Training	Other
8	IBERDROLA	1	0,4%	1	1		1	1	1	1	1	1		
7	ACCIONA	1	0,9%	1	1	1	1	1				1		1
7	SKF ESPAÑOLA	1				1		1	1		1	1	1	1
6	EFACEC	1	0,9%	1		1	1	1			1			1
6	GAMESA	1		1	1	1		1				1	1	
5	Firms working on 5 activities	9	3,5%	4	0	1	10	10	10	0	1	2	5	6
4	Firms working on 4 activities	12	5,3%	5	1	4	10	8	8	0	1	0	5	5
3	Firms working on 3 activities	25	11,0%	7	2	7	13	16	13	1	2	3	6	2
2	Firms working on 2 activities	33	14,5%	4	2	8	14	10	16	0	1	2	8	4
1	Firms working on 1 activities	144	63,4%	20	8	39	8	14	16	0	5	4	3	27
Total firms		227	-	44	15	63	56	62	64	2	13	15	29	46
Share				19,4%	6,6%	27,3%	24,7%	27,3%	28,2%	0,9%	5,7%	6,2%	12,8%	20,3%

Source: own elaboration based in AEE (2011) and experts interviews

The addition of activities is based in the substantial gains from vertical integration but also from the use of knowledge and expertise in the area that can be recombined and applied in any stage of the sector supply chain. This performance is not exclusive of big firms as there are a substantial number of firms associated with Engineering, Operation and Consulting that develop more than 2 activities. Furthermore, the organizational structure of developers can vary significantly from region to region depending on the regional public-private arrangements in term of exploitation of regional market. These variations imply the creation of different governance mechanism to coordinate competences and activities which may lead to a more significant role of small developers (owners of just one wind farm) not considered in this list. Thus, further analysis on this difference on organizational structures at regional level will be presented after a presenting a better explanation of the institutional aspect of wind energy implementation at regional level.

More specifically, by looking at the type of activities within the supply chain, the data shows that the number and type of activities has evolved over time according to the sector devolvement. The overview of general tendencies on activity developed by industrial sites (IS) shows a mayor increase in the total amount of IS between 2006 and 2013. The industrial capacity has growth four times through significant variations in the total number of industrial sites among five of six categories. The evolution of main categories of industrial activities between 2006 and 2013 are presented in the following table.

Table 6 Evolution of supply change activities by type of industrial sites

Type of industrial site	2006	2007	2008	2009	2010	2011	2012	2013	Growth rate 2006-13
Assembly and logistics	13	5	18	24	25	26	26	29	123%
Blades & Control Systems	12	15	16	12	20	19	23	27	125%
Maintenance		2		9	9	9	30	55	2650%
Multipliers/Gearbox	4	5	4	4	5	6	5	5	25%
Towers and mechanical components	3	16	24	25	27	38	37	41	1267%
Turbines, motors & electric components	3	9	14	16	16	17	21	18	500%
Total industrial sites	35	52	76	90	102	115	142	175	400%
Number of activities involved	10	14	20	26	27	28	29	30	200%
Total firms owning at least one	9	19	40	52	53	58	70	82	811%
HHI concentration index[36] - Firms ownership	0,37	0,20	0,10	0,03	0,06	0,05	0,03	0,03	-92%

Source: own elaboration based on AEE (2006-2013)

Since 2006, regional industrial capacity has grown not only in terms of local involvement in wind energy related activities, but also in terms of variety of actors involved in the supply chain. The number of activities within each type of IS has also increased three times from 10 in 2006 to 30 in 2013. Interestingly, the rate of expansion of IS has not been affected by the economic downturn of the last part of the decade. Rather we observe two types of redistribution. First, the number of actors has outgrown the expansion of activities that each one engages, suggesting a turn towards higher specialization.

This trend is also corroborated by the application of indexes to micro data from the panel of industrial sites. The Herfindahl–Hirschman Index (HHI) captured this diminution in the concentration of activities among firms by revealing a decrease of 92% in the whole period. The number of activities within each type of industrial sites has increase three times in the whole period. A more detailed exploration among activities reveals a specialization trend within

[36] Herfindahl–Hirschman Index is estimated trough $HHI = \frac{(\sum_{i=1}^{N} s_i^2 - 1/N)}{1 - 1/N}$ where s_i is the market share of firm i in the market, and N is the number of firms.

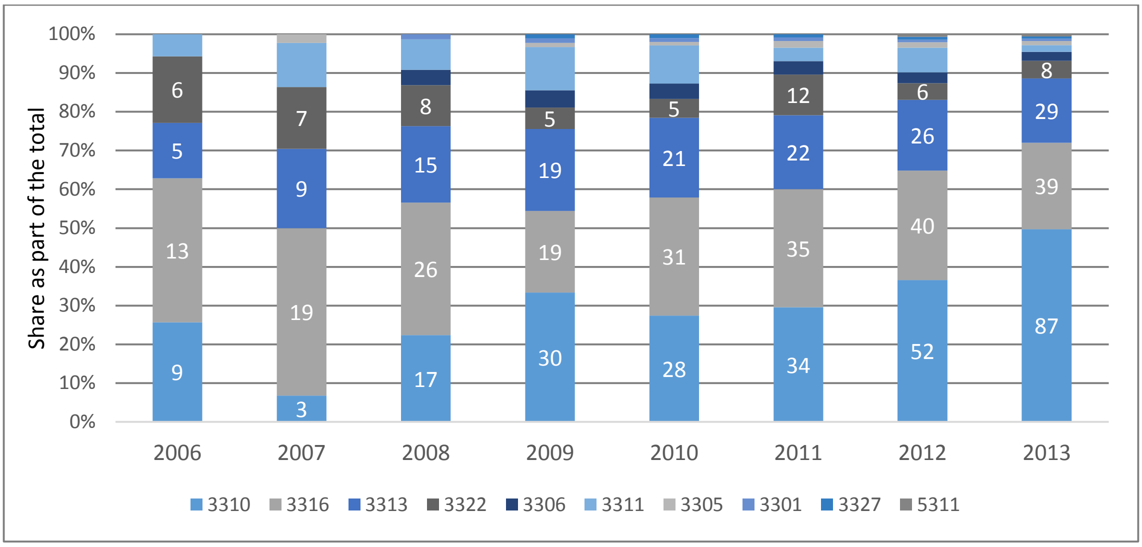
maintenance and assembles focused in specific components such as nacelles, wind turbines, blades as well as towers and other mechanical components (e.g. stairs, elevators). On the other hand, industrial sites specialized in wind plant full maintenance and operation become more significant as part of the whole infrastructure of maintenance service.

Furthermore, the increase in the number of IS has been unequal among categories. The IS on maintenance have presented the mayor increase increased. This tendency can be associated to the degree of maturity of sector and the requirements of the operation of the large infrastructure developed at national level. In the other hand, the increase in the number of IS on Multipliers/gearbox is not significant by comparing with other categories[37]. The trends can be understood as evidence of sequence in the life cycle of the industry where governance mechanism for coordination and searching of complementariness evolve according to the maturity of the sector. The significant increase in competences on maintenance and operation implies a turn to a bigger number of activities related to use of technological knowledge rather than application and combination of knowledge to innovation in new components.

With that respect, the figure 36 shows the evolution of distribution of Industrial sites according to UNESCO nomenclature where main categories Industrial technology 3310 (i.e. Maintenance engineering 3310.04) Technology and metal products 3316 (i.e. Blades, Tower and Nacelles) and Technology and mechanical engineering 3313 (Mechanical components, pumps and Gearbox/multiplier) contain the mayor share of activities in whole period: 2006 (77%) to 2013 (89%).The increasing share of Industrial technology 3310 along time confirm the trend regarding a more mature stage of the industry.

[37] Multipliers/gearbox is a key technological category for wind turbine which is critical in the process of converting kinetic energy into electricity and, thereby, it may have notable impact in efficiency improvements and the simplification of mechanism associated to lower maintenance requirements. For the same reason, according to experts consulted during this study, the current technological trends suggest a further substitution of multipliers and gearbox for direct driven mechanisms (magnets), a reason that may contribute to explain this unequal increase.

Figure 36 Distribution of knowledge areas related to Industrial sites activities by UNESCO nomenclature 2006-2013

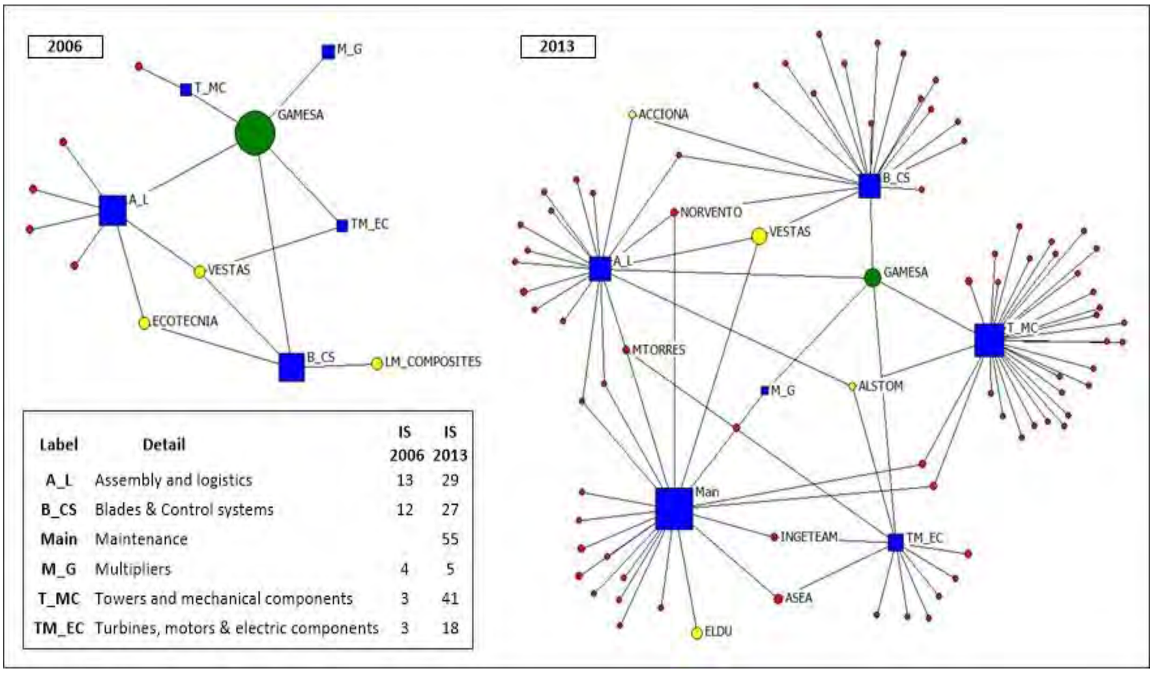


Source: own elaboration based in AEE (2013) and Granell Ruiz (2013b)

Second, the ownership of IS has changed radically in the period. The number of firms involved in the supply chain has increased from 9 to 82 (811%). The IHH concentration index has captured this diminution in the concentration of activities among firms by revealing a decrease of 92% in the whole period. In 2006, only three firms (i.e. Gamesa, Vestas and LM Composites) were holding 77% of activities while in 2013 42 (51%) out of 82 hold the same share of activities (see Fig. 37). Gamesa and Vestas still keep leading positions in terms of amount and variety of IS but the increasing number of new entries has redefined diversity of supply chain in terms of the balance (share of ISs), the variety (number of activities) and disparity (degree of specialization /number of activities per firm). With that respect, the amount of new companies in the sector may reveal low entry barriers by comparing with the EWEA perspective on EU supply change.

Interesting, main wind turbine manufacturers keeps leading positions in the number and variety of IS while the number of actors increase. This position can be understood in changes in the operation an coordination among actors in term of value chain where the removal of entry barriers and the use of modular knowledge has supported the role of system integrators (ie. Gamesa and Vestas) while encouraging diversity in term of actors and activities.

Figure 37 Ownership redistribution of industrial sites among main firms by activity 2006 & 2013



Label	Detail	IS 2006	IS 2013
A_L	Assembly and logistics	13	29
B_CS	Blades & Control systems	12	27
Main	Maintenance		55
M_G	Multipliers	4	5
T_MC	Towers and mechanical components	3	41
TM_EC	Turbines, motors & electric components	3	18

Source: own elaboration based in AEE(2013)

The evolution of distribution and amount of IS showed in Fig 37 can be understood as trajectories that reflect the existing patterns of industry specialization. Since 2006, regional industrial capacity has grown not only in terms of local involvement in wind energy related activities, but also in terms of variety of actors involved in the supply chain. Interestingly, the rate of expansion of industrial sites has not been affected by the economic downturn of the last part of the decade. However, this tendency should be analyse by considering not only wider configurations of the sector in terms of vertical integration and industrial specialization but also the evolving performance in the two man markets, wind energy generation and wind turbine manufacturing, which are described as follows.

4.3.2 Market share and dominant positions

Regarding energy market, the liberalization of energy sector carried out by Spanish national government has determined the jurisdiction of main operators all over the country. From this, according to the resolution of National Commission of Energy in 2006[38], the following firms are the dominant operators in the Spanish Electricity market: Endesa, Iberdrola, Union Fenosa, HC

[38] http://www.cne.es/cne/doc/legislacion/cne02_06.pdf

energia (acquired by EDP in 2005), and Viesgo generacion (acquired by EON in 2008). At the same time, the new regulation introduce new roles and segments along supply chain of electricity.

Having explained the main issues regarding the composition of Spanish electricity market, it is possible to analyse the evolution of market participation in the wind energy sector. The table 3 shows the evolution of the share of developers in the Spanish markets thought three critical years: 2004 (setup of the new Special regime), 2008 (update of Special regime/feed in tariff) and 2012 (block the Special regime incentives). The table presents the list of mayor developers in each year. They are presented by considering fusion and acquisition operations (in different colors) among years which has been tracked through websites and online documents.

Table 3 Share of wind installed cumulated capacity among main developers. Spain 2004, 2008 & 2012

Developer	2004	2008	2012
IBERDROLA	34,51	28,03	24,2
NEO ENERGIA		8,08	
ACCIONA ENERGIA	10,8	17,68	18,8
CESA	4,49		
EDPR			9,2
GENESA	3,88		
ENEL GREEN POWER ESPAÑA			6,2
ENDESA	10,78		
ENEL UNION FENOSA[39]		1,97	
ECYR		8,36	
UF ENEL	3,67		
GAS NATURAL FENOSA RREE			4,2
GAS NATURAL		2,53	
ENEL UNION FENOSA		1,97	
Others	31,86	31,34	37,6

Wind turbine manufacturer	2004	2008	2012
GAMESA	51,63	48,63	52,3
MADE	12,23	8,43	
VESTAS	2,89	14,66	17,9
ALSTOM			7,6
ECOTECNIA	7,79	7,32	
ACCIONA WP		8,21	7,3
GE	7,13	5,93	6,2
SIEMENS			3,4
NAVATINA-SIEMENS		4,03	
Others	18,43	2,79	5,5

Source: own elaboration based in AEE (2013). NOTE: grey colored firms indicated fusion and acquisition by firms above

The data shows a significant increase in the participation of more actors in 2012 by comparing with 2004 and 2008. Iberdrola is the leader of the market but its share has decrease continuously among the whole period. In the other hand, Acciona has shown and increasing participation, mainly because of the acquisition of CESA. Finally, the increasing number of actors is also

[39] Gas Natural Fenosa and Enel in 2010 have broken their partnership in renewable energy, sharing 50% shared assets in the firm Enel Union Fenosa.

characterized by the acquisition done by international actors Enel (Italy), EDP (Portugal) and EON (Germany). Merges and acquisitions are typical mechanism to transfer knowledge from existing sectors to new ones (Dawley, 2013b) and the evidence confirms that strategy adopted by players in energy sector and infrastructure to get into the renewable energy market[40].

Regarding the wind turbine manufacturers, the data shows a significant concentration in few actors as four manufacturers are responsible of more than 85% of wind installed in 2008 and 2012. Regarding the leaders, Gamesa keeps half of the market in the period, position supported by the acquisition of MADE in 2003. Vestas[41] has increased significantly his participation while Alstom has kept the same and Acciona WP has slightly decreased[42].

The interaction between these two markets is based mostly in the long term cooperation agreements between developer and wind turbine manufacturers. These agreements, very often facilitated as regional governments (see chapter 3), support the dominant position of the technological actors. In fact, the data in Table 7 for year 2013 from the Spanish wind Map (AEE, 2013b) reveal a strong cooperation Iberdrola-Gamesa and Acciona –Gamesa as the wind turbines of 90% and 60% of wind farms respectively are provided by the leading manufacturing this result indicates the existence of particular governance mechanism adopted by leading region to coordinate activities in the whole value chain. However, other configurations are possible as developer as Acciona and utilities companies (e.g Enel Green and Gas Natural Fenosa) present a more diversified portfolio. Interestingly is that the mayor share of wind turbines of Vestas (84%) and Alstom (97%) are provided to the 404 small developers operating in the Spanish wind energy sector in 2013.

Table 7 Matrix of relations "wind farm developer/ wind turbine manufacturer" for the Spanish wind energy sector. Total wind farms for main actors 2013

[40] The composition of the wind energy market was drastically affected since the changue in regulation framework in 2012. Key players in the electricity market as Iberdrola and Acciona has cahued the stregy for the mhome market while Gamesa has suffered a significance process of restruturaction towards the exploitation of international market.

[41] Gamesa Wind is set in 1994, of which 51% of the capital is held by Gamesa and 40% by its Danish partner Vestas Wind Systems, a company with a technology agreement exists. Vestas sold his 40% to Gamesa in 2001.

[42] The data also shows a considerable amount of new actors in 2012, most of them international such as Sinovel (China, 2ª wold market), Suzlon (India, 5ª world market), Nordex (US) and Kenetech (US). These last two, together with GE reinforce the presence of American firms, the mayor foreign invest country in Spain after Vestas (Denmark).

			∑ share	50%	67%	74%	79%	100%
			Share	50%	17%	7%	5%	12%
		Promoter	Total	GAMESA	VESTAS	Alstom	ACCIONA WP	Other
∑ share	Share	Total	1055	526	182	75	50	117
13%	13%	ACCIONA	135	76	14		20	16
23%	11%	IBERDROLA	112	102		2		8
26%	2%	ENEL GREEN	23	15	4			4
27%	2%	GAS NATURAL FENOSA RREE	18	4	12			2
100%	72%	Other (404)	767	329	152	73	30	87

The composition of the wind energy market was drastically affected since the change in regulation framework in 2012. Key players in the electricity market as Iberdrola and Acciona has changed the strategy for the home market while Gamesa has suffered a significance process of restructuration. The analysis of the period from 2012 onwards do not take part of this study but means a milestone for the reflection on the period under analysis. Both sectors developers and wind turbine manufacturers, after recovering from a period of significant losses and assets restructuration, have developed strategies towards the exploitation of international market.

Thus, it is relevant the review of performance of Spanish companies in the global market where they have also achieved leading positions in both energy production (i.e. Iberdrola, Acciona) and technology manufacturing (i.e. Gamesa, MTorres, Acciona, Almstom-Ecotecnia) in a relatively short time span. Table 8 provides a synthetic account of their role in the world market. A distinctive trait of these actors is high strategic flexibility that allows them to be both leading manufacturers in the global market as well as “smart developers” at a local level. This is for example the case of companies such as Gamesa and Acciona who are actively involved in different parts of the value chain, and play a different role depending on the demands and the opportunities of the local context.

Table 8: Global market shares of wind turbine Manufacturers (WTMs)

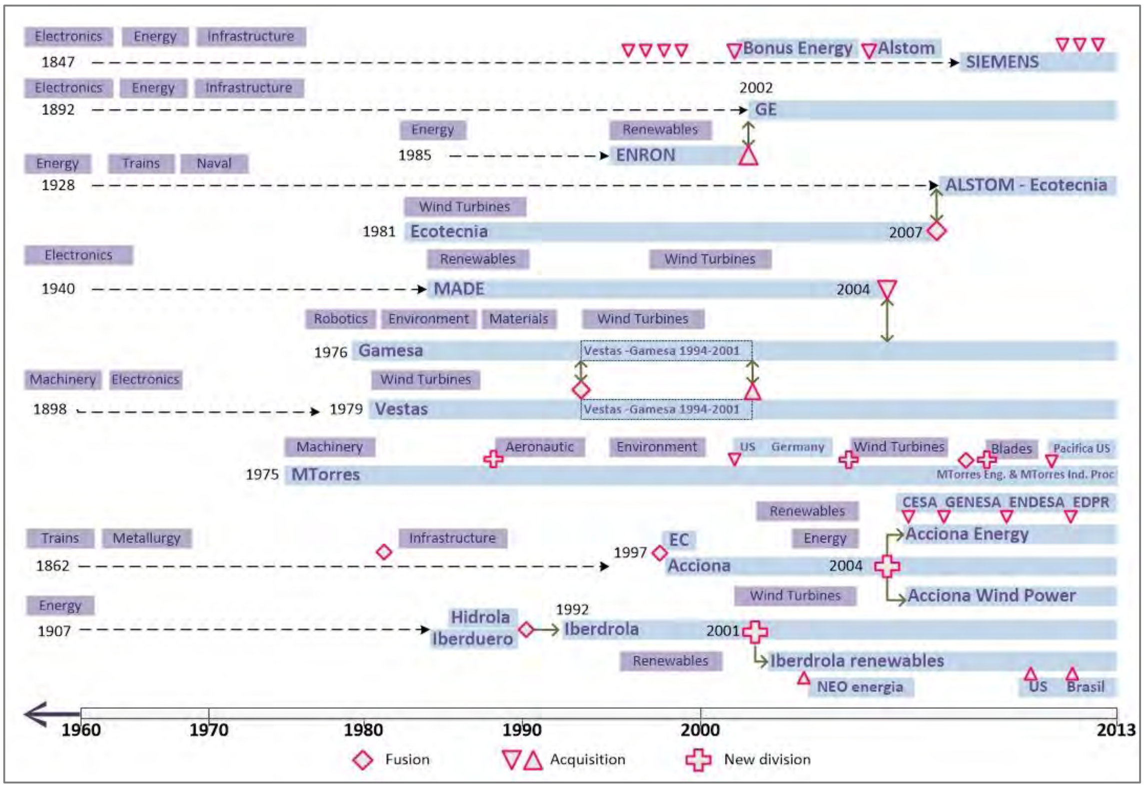
WTMs	2008	WTMs	2009	WTMs	2010	WTMs	2012
Vestas (Den)	19,8	Vestas (Den)	12,5	Vestas (Den)	14,7	GE Energy (USA)	15,5

GE Energy (USA)	18,6	GE Energy (USA)	12,4	Sinovel (CHI)	11,1	Vestas (Den)	14
Gamesa (SP)	12	Sinovel (CHI)	9,2	GE Energy (USA)	9,5	Siemens (GER)	9,5
Enercon (GER)	10	Enercon (GER)	8,5	Goldwind (CHI)	9,4	Enercon (GER)	8,2
Suzlon (IND)	9	Goldwind (CHI)	7,2	Enercon (GER)	7,2	Suzlon (IND)	7,4
Siemens (GER)	6,9	Gamesa (SP)	6,7	Suzlon (IND)	6,8	Gamesa (SP)	6,1
Sinovel (CHI)	5	Dongfang (CHI)	6,5	Dongfang (CHI)	6,6	Goldwind (CHI)	6
Acciona (SP)	4,6	Suzlon (IND)	6,4	Gamesa (SP)	6,6	United Power(CHI)	4,7
Goldwind (CHI)	4	Siemens (GER)	5,9	Siemens (GER)	6	Sinovel (CHI)	3,2
Dongfang (CHI)	4	Repower (GER)	3,4	Guodian Utd (CHI)	4,2	Mingyang(CHI)	2,7

Sources: own elaboration based on data of (BTM, 2012; Deloitte, 2011)

The fast growth and implementation strategy of Spanish manufacturers allow them to be become prominent actors also in the international arenas. This is due to appropriate strategic choices concerning the reconversion of established competences from metallurgy, electronics, and construction towards wind energy. Large Spanish firms have sought joint ventures with foreign giants to spur technology transfer like, for example, Gamesa, specialist in robotics and materials, joining forces with the Danish Vestas, originally a developer of agriculture machinery, electronics and hydraulic cranes. Another example is the merger between Ecotecnia and Alstom, a French firm with experience in train and boat construction. At a different scale, the Spanish firm MTorres shows a trajectories through different sector from machinery and aeronautic to environment and wind industry. Interestingly, global players such as General Electric (US) and Siemens (Germany) followed a similar path, that is, entered the wind energy industry by acquisition of specialized companies (see figure 38).

Figure 38 Main fusion and acquisition among main wind turbine manufacturers in Spain



Source: own elaboration

On the other hand, Iberdrola as one of the biggest utility companies and Acciona a leader in infrastructures, have also followed that path regarding acquisition of wind energy companies to get into the renewables energy markets. These companies have also based the creation of new specialized wind energy/renewables division on the knowledge background on energy and infrastructure. The diversification strategy regarding new products, mergers, and acquisitions is a confirmed strategy in the whole sector where both technology manufacturers and utilities companies has applied the strategy to support

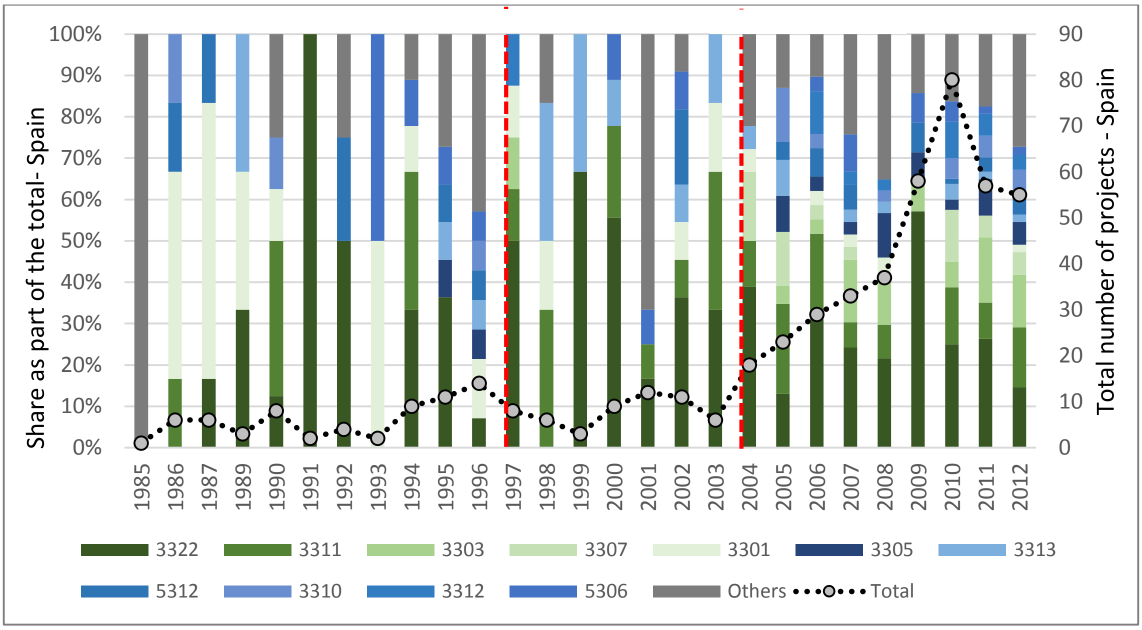
According to experts in the field of wind energy technologies, that background has been also the main input to run R&D activities oriented to develop technology improvements as well as adaptation of existing technologies to new market opportunities (Cano Santabárbara, 2013; Hurtado Pérez & Pérez-Navarro Gómez, 2013; Ugalde Sanchez, 2013). The pathway of knowledge creation and adaptation under this strategy is briefly explained as follows in term of the R&D activities and the main characteristics of the set of wind energy related patents.

4.3.3 Pathways of knowledge creation among the Spanish wind energy value chain

Spanish actors has a large trajectory regarding participation of European projects on energy and renewable resources. Since Spain joined the EU in 1986, many specific initiatives as JOULE, THERMIE and Altener got participation of research organization and the industrial sector. However, the number of projects increase significantly in the FP6 and FP7 programs where specific thematic areas were designed. In fact, according to experts in the field of energy research, Spain got an outstanding performance in research performance on energy fields in these two programs by getting the second position in the EU ranking, just behind Germany (Izquierdo, 2011). The performance in the national research programs has been influenced by the development of short several isolated by specialize initiatives and the laggard incorporation of the energy category in the national research plan. Even that, the increasing number of applied R&D project has been a significant opportunity for industry to establish collaboration with mayor research organizations.

Regarding the set of knowledge areas considered in the project, the trajectories seems to impulse diversification and specialization. The figure 39 shows the evolution of knowledge areas (i.e. UNESCO codes) covered in the set of wind energy related projects funded by national and European programs. The knowledge areas are presented conditioned by the availability of project data so, the first period include only EU funded projects and the second one added the CDTI applied R&D projects. In both periods there is a predominance of Energy technologies (3322), Instrumentation technologies (3311), mechanical engineering (3313 and Aeronautical Engineering and Technology (3301). The final period (2004-2012), which includes all the research programs, keeps the predominance of the former categories but also include Engineering and Chemical Technology (3303), Electronic technologies (3307) in the leading positions. In this period the total number of knowledge areas has increased from average 8 to 18 in the period 2000-2012 and this increase seems to be remarkable in the National research plan rather then applied research and EU granted project.

Figure 39 Evolution of distribution of total wind energy related projects by UNESCO codes



Source: own elaboration [43]

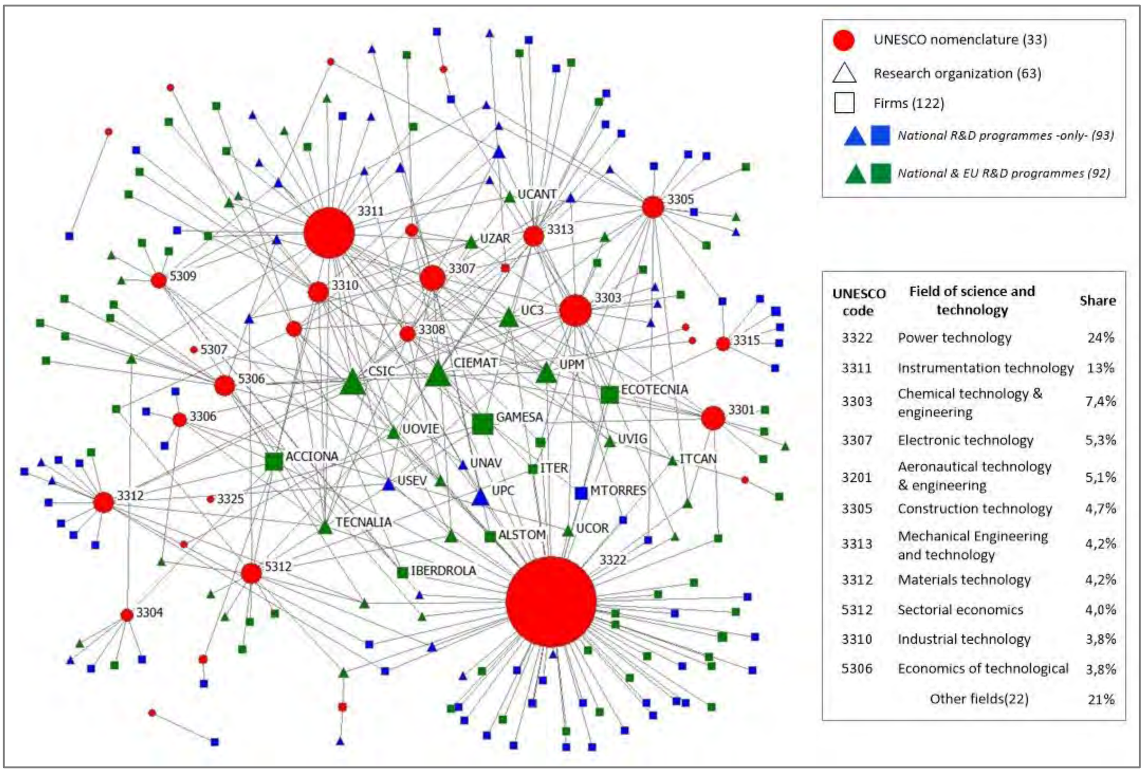
Regarding actors involved in the project, participation among institutions in the NRP is distributed in the following way: 76% universities, 11% CSIC, 7% technological centers and 6% business centers and other public-private associations. The applied R&D, the industry leads the projects through collaborations mostly with universities (41%) followed by technological centers (36%) and public research centers (19%). The average number of academic participants per project is quite stable (between 1.4 and 2 in the whole period). Finally, the R&D projects funded under European cooperation frameworks in the period 1995-2012 were characterized by a dominant participation of firms (51%) far followed by Technological centers (20%) and universities (17%).

The figure 40 shows the participation of mains Spanish actors where the UNESCO codes are illustrated in order to map the diversity of knowledge categories involved in wind energy related projects. Within research organizations, CIEMAT is the leading institution followed by CSIC (with higher presence in 3303) and leading universities such as UPM, UCP and UC3 with strong participation in two first categories (i.e. 3322 and 3311). Among industrial actors Ecotecnia

[43] The data includes wind energy related projects of Spanish National Research Plan, Applied R&D projects managed by CDTI and EU cooperation projects. Data on Spanish Research Plan for the year 2009 is not available and the total number of project under this program has been is estimated by moving average.

(Currently Alstom), Gamesa, and Acciona are in the first positions, however, Ecotecnia shows a significant share of projects on 3301 category while other firms show a more diversify set.

Figure 40 Participation of main Spanish actors in wind energy related R&D project by UNESCO codes 1980-2013



The performance in these knowledge areas supports the technological trajectories proposed in the previews section. In fact, Power technology (3322) is the main category but its works in combination with Industrial technology (3311) and Electronic technology (3307) in the improvement of power capacity of bigger wind turbines. On the other hand, Instrumentation technology (3311) includes all the improvement in a critical issues for maximizing the wind capture capacity: the speed control. Then, class 3311 includes projects on pitch control, stall control and the exploration of new hybrids systems. Finally, Aeronautic technology (3201), materials (3312) and construction technology (3305) are facing the challenge of increasing wind turbine size while reducing weight, improve performance and minimize maintenance and operation cost.

At last, a look at the Spanish performance in wind energy related patent reveals also a clear technological trajectory in the mentioned categories. Since 1990 the new registered patent on wind energy related sectors has been continuously increasing (see figure 41). By far, the total number of patents register has almost doubled each ten years if we consider, for example the years 1992(83), 2003(191) and 2013 (497). On the other hand, three technological classes are the most assigned to the patent dataset[44] . However, even when the main technology referred is Wind Motors, the diversity of technological class has clearly evolved during the last years (see Fig. 20). The main categories founds are:

F03-Machines or engines for liquids; wind, spring, or weight motors One third to the total number of patents correspond to the class.where F03D – Wind motors is the most significant *class*

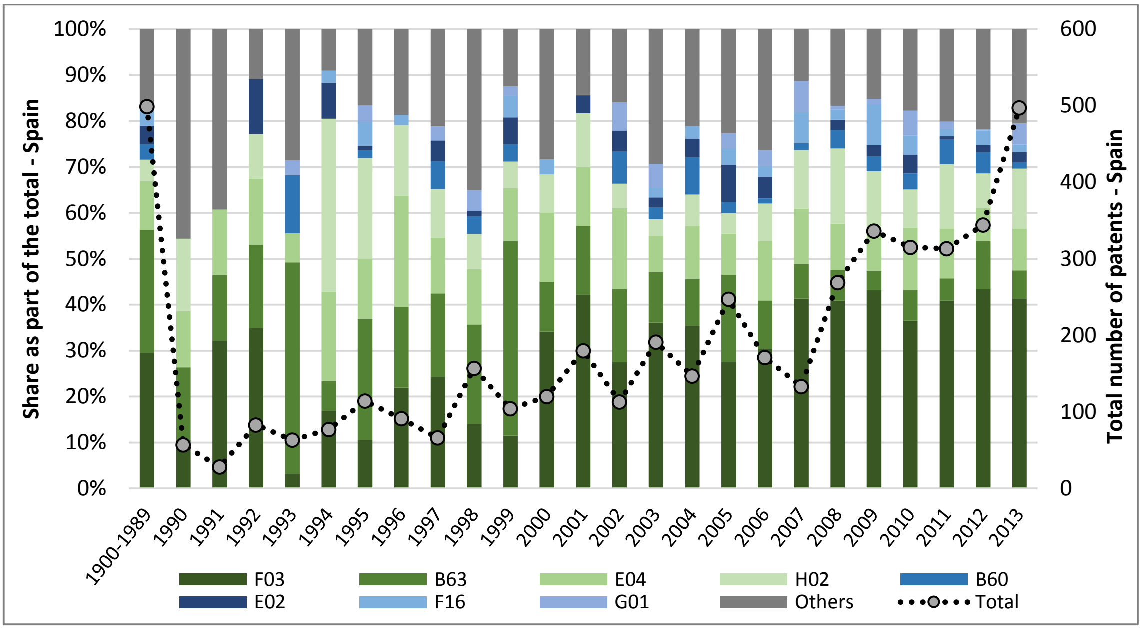
B63 ships or other waterborne vessels (i.e. B63B) where structural components are contained as part of categories such as "Vessels or like floating structures adapted for special purposes" (i.e. onshore and offshore platforms) and "Shifting, towing, or pushing equipment" (i.e. tower and blades structural mechanism).

E04 Building (i.e. E04H Buildings or like structures for particular purposes) include technologies reads not only with the general structure but also with complementary components such as "scaffolding; forms; shuttering; building implements "

Finally, *H02 generation, conversion, or distribution of electric power*. This category is critical in the whole process of electricity generation (i.e. H02K Dynamo-electric machines and H02J Circuit arrangements or systems for supplying or distributing electric power) but in particular in the issues of wind speed control as include classes such as H02P Control or regulation of electric motors.

[44] The data set was designed by a full search on Spanish assignees in the European Patent Office (EPO) by following the criteria on technological classes suggested by the IPC Green Inventory http://www.wipo.int/classifications/ipc/en/est/

Figure 41 Evolution of distribution of total wind energy related patents by IPC technological classes *(Including full list of classes)*[45]

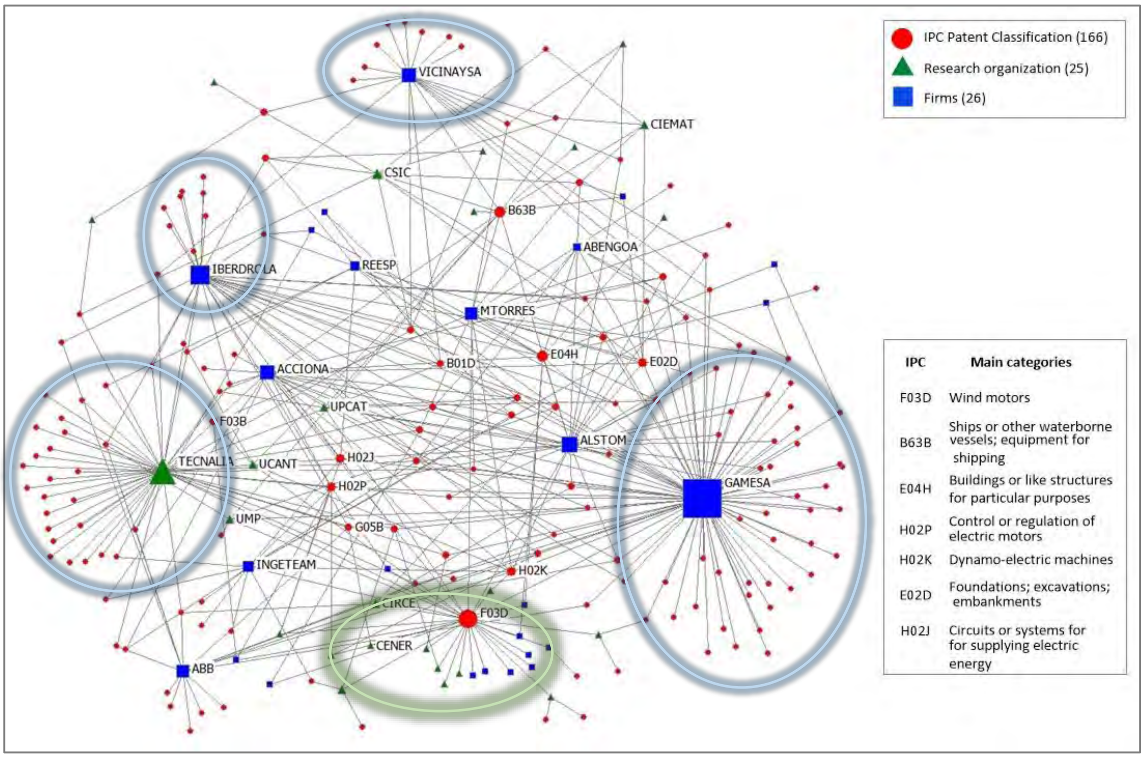


Source: own elaboration base in (EPO, 2014)

The general performance of Spanish firms then reveals the purpose of achieve improvements within the technological trajectories mentioned earlier: 1) Size, weight and materials, 2) Maximizing wind captures and power generation and 3) Increasing wind capacity through speed control. However, a deeper look at patent ownership reveals that some technological actors such as Gamesa, Tecnalia, Iberdrola and VicinaySA shows a cluster of technological categories exploited exclusively with the wind energy technology domain (see fig 42). At the same time, a small group of firms and research organizations seems to be almost specialized in the Wind Motors category.

[45] The data showing in the chart correspond to the full list of technological classes including in each patent. The search includes patents from a specific search for Spain on technological class F03D

Figure 42 Patent ownership by 4-digit IPC class. Main wind energy Spanish actors 1980-2013



Source: own elaboration base in (EPO, 2014)

This characterization of knowledge areas among the main firms reveals that some specific and central technologies as Wind motors are connected with a different set of mutual technologies that can be directly related in term of the wind energy system or being complementary. In fact, the different cluster of IPC technologies surrounded the main technological firms such as Gamesa and Tecnalia may highlight different pattern of combination and adaptation of modular technologies. Further analysis on a deeper understanding on the knowledge coherence among these categories should be developed to better understand the nature of this actor's specialization or diversification strategy.

4.4 Summary and conclusions

The second question of this theses was answered in this chapter: To what extent have specific characteristic of traditional sectors such as metallurgy, electronics and power generation influenced the rate (and speed) and direction of technological developments in wind energy?

The analysis has investigated the different aspect by which the emergence of wind energy industry has been based in the strategic combination of knowledge areas in traditional sectors such as hydroelectricity, naval and aircraft. With that respect, the modular combination of technological components has facilitated a less disrupted advance in the industry (e.g. wind generator from traditional energy generator) while in other areas such as grid connectivity has achieved main advances to support the system expansion at different scales. In that sense, adaptation of technologies to face increasing size and maximizing power capacity has driven the evolution of wind turbine across time.

With that respect the key technological actors has provided experience, knowledge base and background in the process of adaptation of existing knowledge and technologies to the requirement of wind energy generation. This situation has allowed the existence of systems integrators was critical. That background and technical expertise - critical inputs in the basic set up for a wind farm - can be described within the following knowledge areas.

The interaction of different bases has supported the manufacturing on renewables energy technologies by combining knowledge bases in the traditional sector as metallurgy, machinery and electronic equipment. However, the outstanding performance of critical elements such as manufacture of electrical equipment (CNAE 27) has had a critical role in the wind energy value chain with a stable growing trajectory.

More specifically, the addition of industrial activities across time has provided substantial gains in term of the potential vertical integration as there are a substantial number of firms associated with Engineering, Operation and Consulting that develop more than 2 activities. Simultaneously, the supply chain has evolved to a more diversified structure as the number of actors has outgrown the expansion of activities that each one engages, suggesting a turn towards higher specialization.

These pattern of specialisation based in combination of traditional knowledge bases has a pillar in a long trajectory of R&D activities where the performance of main technological actors has remarked the leadership in some technological areas at national and international level.

Chapter 5: Pathways of regional specialization in the Spanish wind energy sector

5.1 Introduction and objectives

This chapter provides analytical evidence on the pathways creation regarding the emergence of the wind energy sector in Spanish regions. The variety of regional settings is analysed by identifying and comparing key technological, economic and institutional factors across regions. This emphasizes the search for a better understand of the way different regional setting and competences may facilitate the pathway creation toward industrial specialization. The focus is on revealing the differences among regions in the development of specialization strategies by highlight different forms of being "smart". Recombination of local resources with the existing knowledge base is the focus of the analytical exercise. The evidence will address Research question 3.

The chapter is structured as follows. The main theoretical ideas are presented in the first section. Regional systems of innovation and evolutionary perspective on industrial agglomerations are discussed around linkages between policy instruments and regional knowledge resources. In the second section, the empirical study is presented. It consists of a comparison of regional competences, focusing on industrial histories the history of the industry and the regional knowledge resources. Variety indexes for the variables related to the wind energy sector and knowledge resources are applied to explore different patterns of specialization among regions. Finally, the main results are explained by exploring the application of the typology based on the concept of related variety proposed by Asheim (2005).

5.2 Fostering creation of regional pathway in renewables energy sector across a multilevel governance system

Renewable energy has been a staple of the international policy agenda since the second oil crisis (1979). The search for alternative energy sources emerged as a result of the scarcity of natural resources combined with the high risks involved in dependence on external energy supply. The need for renewable energy has become more urgent due to increased demand and pressure to counter or at least mitigate the effects of climate change. This has led to a range of policy experiments aimed at promoting alternative energy sources and associated policy actions for industry development.

Since national policy programmes have been coupled to EU Directives and support policies, energy policy and climate change policies have been integrated in central government development strategies and applied by regional governments to search for common solutions. The rationale underlying government interventions is preserving the environment and providing the conditions for the commercialization of new technologies related to the renewable energy industry.

Most of the main instruments are associated with the creation of power capacity by reducing production and commercialization costs and promoting demand through public procurement. Other mechanisms and instruments are addressed to fostering the development of new sectors. Industry instruments support for R&D to cut the costs of innovation, especially in the phases of invention and market introduction and to avoid underinvestment caused by market imperfections. The provision of a regulatory framework establishes approaches to drive the activities along the whole value chain.

Energy policy addresses factors related to energy as a commodity such as security of supply, environmental impacts and reduction of industry costs (P. D. Lund, 2009c), and also creation of employment and export opportunities in the area of energy technologies. Thus, in addition to traditional energy policy measures, there is a set of industry policies aimed at facilitating innovation and commercialization of renewable energy technologies/products. These can be categorized as technology push (R&D) and market pull and are oriented to market deployment and increased opportunities in emergent sectors.

The process of fostering innovation and linkages among sectors and clusters of policies can be understood as part of the systemic dimension of the regional innovation system (RIS) in term of linkages among organizations, sectors and processes where regions play two additional critical roles in the coordination among the higher -European, national- and lower level –locals (Asheim & Coenen, 2005b). Thus, regions provide a governance structure for the economic process by facilitating stages of policy implementation, and a variety of governance mechanism designed to facilitate coordination and knowledge exchange (Antonelli & Quéré, 2002; Antonelli, 2006) though a multilevel and multi-sector governance system (Laranja et al., 2008b)

Several empirical studies highlight the regional properties related to containing a large number of activities within the value chain; while creating interdependencies with regional and national government, location of industrial activities is driven by creating connections to regional knowledge infrastructures. Uyarra (2010) highlights localized bottom up processes of learning by pointing to the evolutionary notion of variety where knowledge sharing networks explore internal and extra regional complementarities in knowledge bases and competences to promote changes to technological trajectories and their associated path-dependent industry history.

This chapter explores the process of pathways creation in emergent sectors as part of a regional strategy in which new sectors emerge from the recombination of knowledge and technologies in existing sectors and regional knowledge resources.

5.3 Benchmarking Spanish region in the pathway of fostering wind energy sector

Regional development of the wind energy sectors in Spain are the result of economic, political and technological factors as well as the availability of natural resources (i.e. wind). Regions show different degrees of specialization in the wind energy sector depending on the creation of different pathways to its development. However, as already explained (Chapter 4), the wind energy value chain includes energy production and the manufacture of renewable energy technologies.

In this section, the focus is on understanding the linkages in the wind energy value chain by exploring the relation between regional industrial setting and regional knowledge bases. In this way, possible pathways creation through knowledge adaptation and modular combination of existing knowledge bases are analysed as part of emergent technological platforms (Asheim et al., 2011; Consoli & Patrucco, 2011) embedded in the RIS (Carlsson, Jacobsson, Holmén, & Rickne, 2002; Uyarra, 2010).

The empirical analysis is presented in three stages. The first stage is a deep analysis of the regional industrial structure elaborated to reveal the industry histories and regional knowledge resources embedded in the technological sectors associated with renewable energy. The second stage explores the increasing variety of industrial and R&D activities to search for evidence of regional processes where new sectors emerge from the recombination of knowledge and technologies. Then, three cases are presented as examples of different regional pathways towards sectoral specialization. In the third stage, the evidence analysed in this chapter is applied to classify Spanish regions using Asheim's (2005) typology. The study is centred on a period of time when energy and innovation policy were implemented under particular policy and market conditions to foster the development of wind energy as a brand new sector.

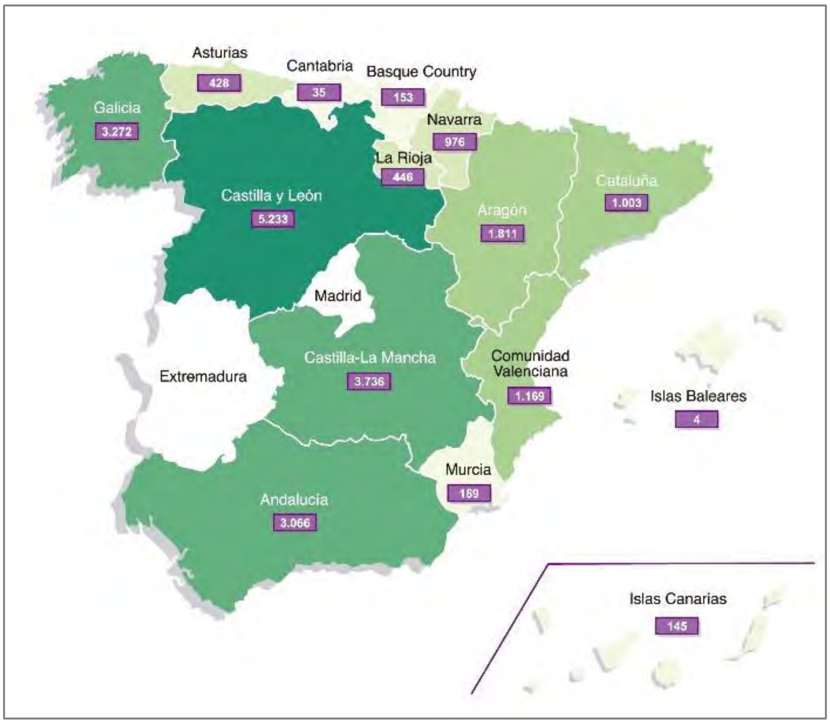
5.3.1 Regional setting and industrial history

Wind energy production in the Spanish regions is determined by the distribution of installed capacity which follows the logic behind the natural potential: availability and quality of wind resource.[46] Thus, wind potential is related to the geographical conditions that favour the concentration of wind energy capacity in regions combining the largest areas and performing well in wind quality indicators. We can identify four categories in the final distribution of wind energy capacity measured in MW: 1) the leaders: Castilla y Leon (5233 MW), followed by Castilla-La Mancha (3736 MW), Galicia (3272 MW) and Andalucía (3066 MW), 2) Medium capacity: regions between 1000 MW and 2000 MW such as Aragon, Valencia Region, Cataluña, and Navarra, 3) low and no capacity: other regions few or no capacity (see Fig. 43). In addition to the size of the leading regions, they also include important Spanish mountain systems (see Annex 3)

[46] The natural resources is based on the availability (extent of technically available area) and quality (stability and speed) of wind. These two characteristics are the key indicators; thus, wind energy capacity is concentrated in regions combining large area and good wind quality indicators. Wind is measured by two linked indicators: 1) extent of the technically available area which is the rural non populated area and off shore continental platforms, and 2) wind speed which is measured by density. The Aeolian map of Spain (IDAE, 2011) indicates that the threshold for optimal operation is speed>6 metres per second at 8 metres altitude.

As explained in the Chapter 4, the evolution of power capacity has seen a significant increase since 2000. The major contributors have been the leading regions which have shown outstanding performance in increasing wind energy capacity (and energy production) and followed trajectories towards RREE specialization within the regional energy balance. For example, Castilla la Mancha, Castilla y Leon and Navarra have got a high relative advantage on wind power (i.e. relative composition of regional energy balance) followed by Galicia, Andalucía and Aragon (Annex 3). This trajectory is based not only on the availability of wind resource but also on the incentives for economic growth and specialized industrial development.

Figure 43 Wind power capacity in Spanish Regions (MW) 2011



Source: own elaboration based in AEE (2013)

In this perspective, the major regional economies in Spain are Cataluña, Madrid and Andalucía which account for half of national GPD, however, if we include middle sized economies such as Valencia region, Basque country, Castilla and Leon and Galicia, these seven regional economies account for 80% of national GDP (Fig 44). The service sector is the major component of the Spanish economic structure, followed by construction and industry. The regions with the most concentrated industrial activities are Cataluña, Madrid, Valencia region and Basque Country, where metallurgy, machinery and electric-electronics-optical are the main subsectors (see Annex 2).

The linkages between leading positions in wind energy production and competences in the technology manufacturing can be explored further by looking at the relative density of industrial centres as well as the availability of relevant competences for the deployment of production infrastructure. Both these aspects have experienced significant change since mid-2000. For example, there was a major increase in the number of industrial centres in the period 2006-2013 when industrial capacity grew fourfold.

According to data for 2013 (AEE, 2013a), there are 175 industrial sites specialized in wind energy technologies in Spain, 70% of which are located in 5 among 16 regions: Galicia (19%), Castilla y Leon (13%), Madrid (13%), Basque country (12%) and Navarra (11%). These five regions have industrial sites in most of the five general technological categories (see Fig. 45), however, the evolution of this capacity has followed different trajectories. Galicia has been the leading region since 2007 with 40% of total industrial sites, Castilla and Leon and Navarra have experienced slower growth. The distribution of supply chain components has become more spread so the Basque Country and Madrid are in leading positions (see Annex 3).

Figure 44 Regional gross domestic product. Spain 2010 (€ Bill)

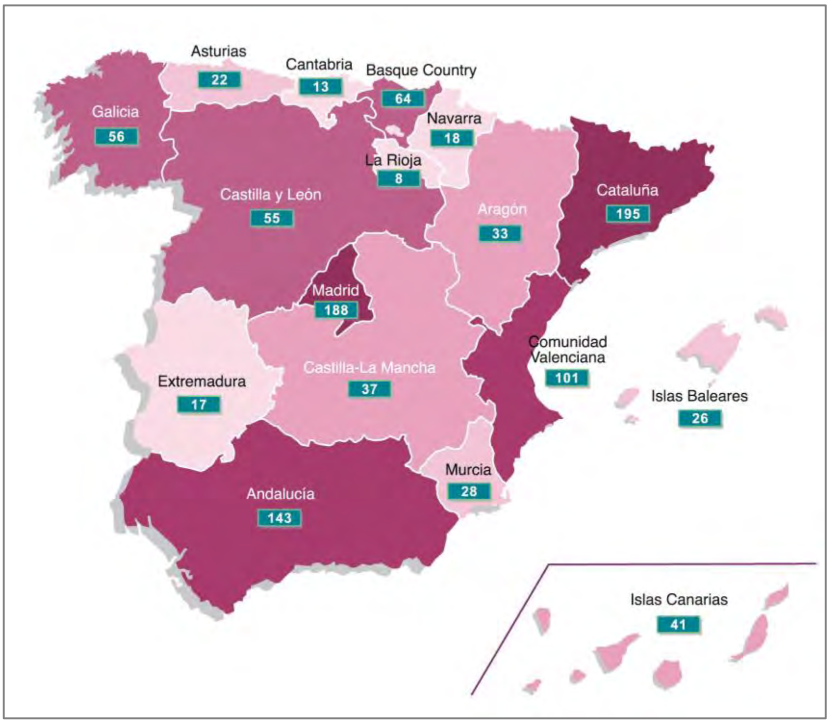
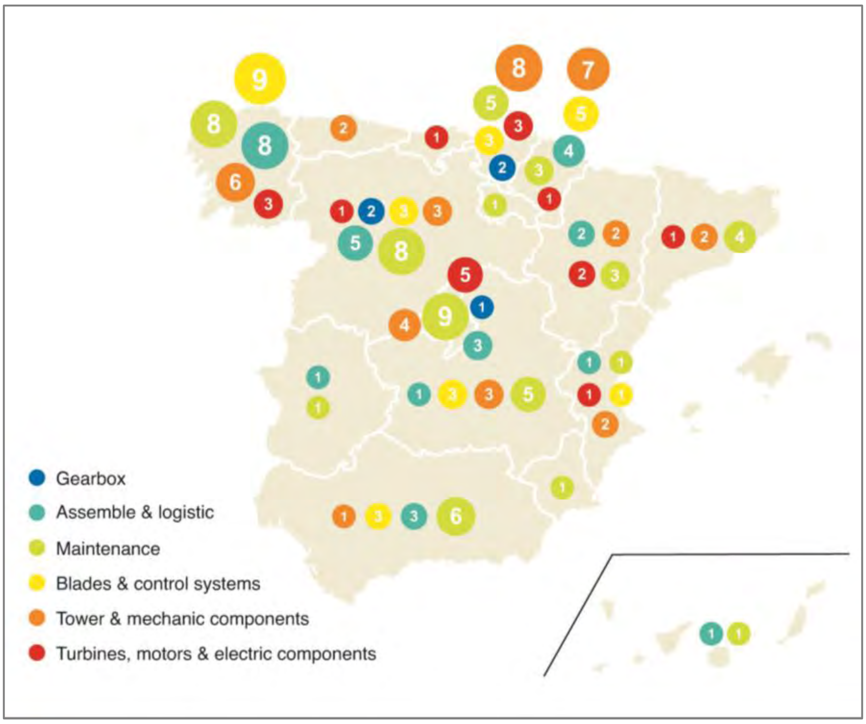


Figure 45 Industrial sites in Spanish regions 2013



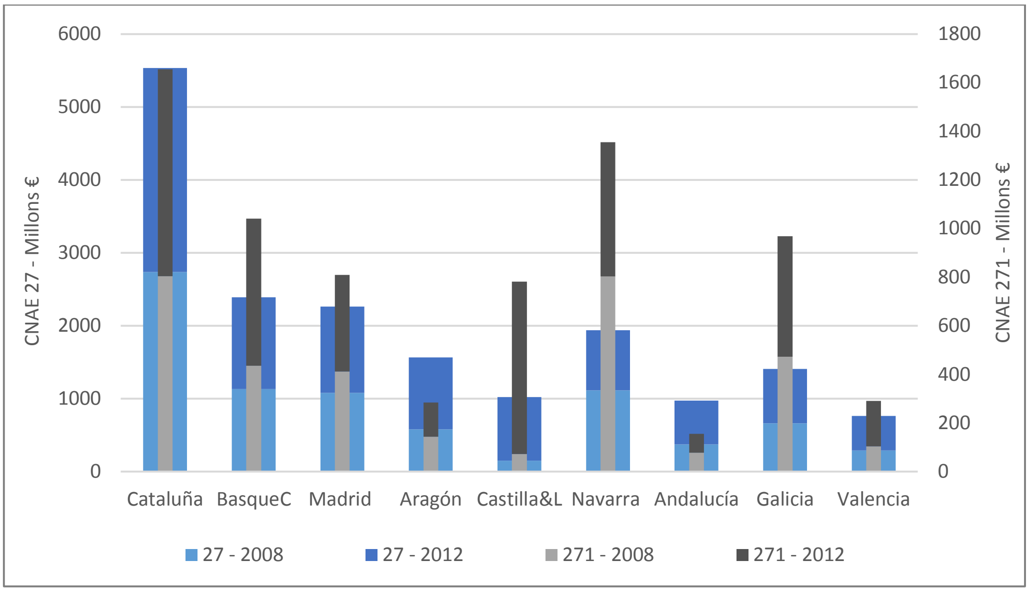
Source: own elaboration based in the following sources Figure 44 (AEE 2013), Figure 453(INE, 2014)

The pattern of industrial activities location has affected the regional variety, since industrial capacity has increased in terms of both local involvement in wind energy related activities and variety of the actors involved in the supply chain. The expansion of industrial sites has not been affected by the economic downturn that began in 2008. Instead, as discussed in the Chapter 4, two types of redistribution can be observed. First, the number of actors has overtaken the expansion of the activities in which each engages, suggesting a turn towards higher specialization. The major increase has been in maintenance, which can be related to the maturity or life cycle of the infrastructure and sector development. At the same time, activities are less geographically concentrated and, although the historical leadership of regions like Galicia and Basque Country has not been undermined, formerly peripheral regions are now part of the main wind energy industry scenario.

Industrial development related to wind energy technologies has had an impact on performance in external markets. Metallurgy (CNAE 24) and Machinery (CNAE 25) – the main subsectors - are dominated by the Basque country, Cataluña and Andalucía while the sector with strongest linkages to renewable energy, manufacturing of electrical material and equipment (CNAE 27), is not significant in comparison. This sector present a performance among leading regions with similar positions to the other ones, however, Based on disaggregated data at the 3-digit level for the category manufacture of electric motors and generators (CNAE 271), the analysis reveals different performance at the general level and among regions (see Fig 46).

The exports of sector CNAE 271 show above average growth (250%) in the period 2000-2013 led by Cataluña, Basque Country and Madrid, however, Galicia, Castilla y Leon and Navarra show outstanding growth rates and uptakes significant positions. The trajectories of the newcomers have change significantly in the period 2004-2010 - a period of strong financial stimulus in the internal market from the feed-in tariff (FIT) scheme – but Cataluña has retained its leading position; Navarra is in second position, the Basque country is ranked third and Galicia and Castilla y Leon are in fourth and fifth place ahead of Madrid which formerly was ranked third (see Fig 46).

Figure 46 Evolution of Exports CNAE 27 & 271. Main Spanish regions 2008 & 2012



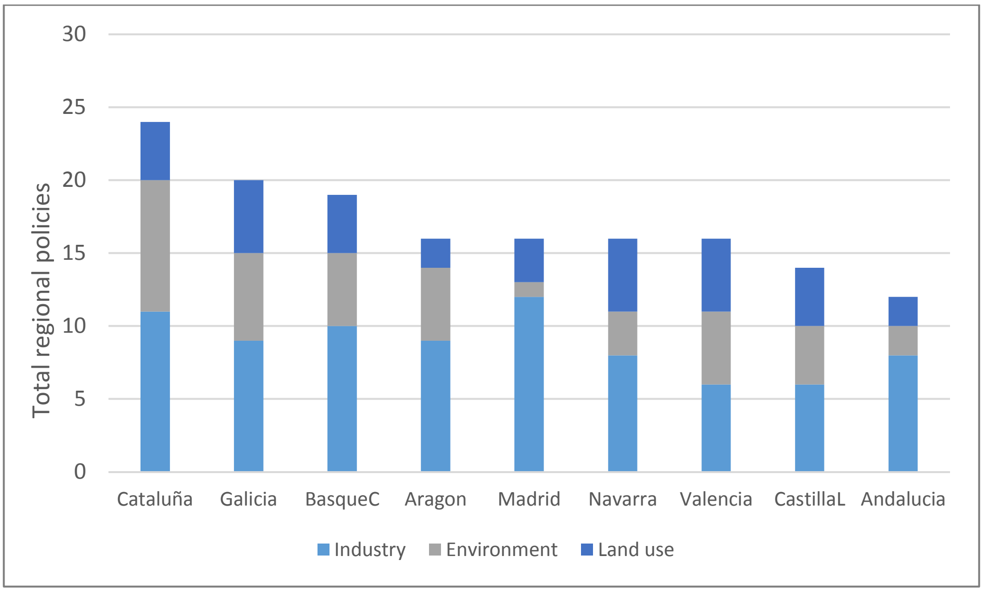
Source: own elaboration based in (DATACOMEX, 2013)

These results are relevant because they reveal significant improvement in performance in manufacturing competences among the leading regions for the production of wind energy through better positions in the commercialization of RREE related technologies in external markets. The linkages between energy production and home market deployment can be traced to the development of regional strategies (i.e. wind plans) as discussed in the Chapter 3. The main regional differences are associated with the linkages between energy production and manufacture of energy technology which determine the organizational features of the entire value chain.

As already explained (Chapter 3), the regional organization of sector relies first, on how the region applies its competences in a set of energy, industry and environmental policy and second, on the existence of actors with dominant positions in the region or with rights to exploit their technology and services. The main regional policy interventions in the wind energy sector are contained in the regional industrial plans, which give the rights to do research, produce and exploit development in new emergent sectors (i.e. RREE), and the wind plans which are long term and confer rights for the exploitation of technical areas for wind energy production.

By 2010, 50% of regional renewable energy related policy was related to industry regulation while the rest was split between the environment and land use (Fig 47). The regions presenting the most regulations are Cataluña, Galicia and Basque Country, but they have long and stable trajectories related to the introduction and implementation of regulations for the renewable sector. The first regions to introduce wind energy plan were Galicia, Navarra and Aragon. Wind plans have fostered interaction between government and private actors towards possible interlinked strategies: home market deployment or industrial development.

Figure 47 Distribution of regional policies on RREE according to main categories. 2010



Source: own elaboration based in (MIETUR, 2010)

As explained in the Chapter 3, the wind plans include formal long term agreements through the inclusion of commitments and rights on the exploitation of wind resources, which set the bases for coordination among regional governments, utilities and manufacturers. The regional movement encompasses different pathways to the management of resources, and decision making mechanisms which can be characterized as centralized or decentralized models. For example, the business model for the regional exploitation of resources can be designed to favour the participation of the main regional companies or more entrepreneurial initiatives such as independent power producers (IPPs) and local public-private management of wind farms. In the first case, the existence of a simultaneous set of industrial policies (e.g. long term policies supporting manufacturing related sectors) can encourage stronger developer-manufacturer linkages as well as a broader variety of industry actors in terms of size and position in the supply chain.

Both interventions are designed and implemented jointly with the purpose of establishing special arrangements for collaboration among the beneficiaries of industry plans (manufacturing firms/wind developers) and the beneficiaries of the wind plans such as utilities and IPPs. Thus, most of interactions between firms such as collaboration between large companies and SMEs and intra-sector collaborations are determined by these instruments; therefore, the structure of the regional market may vary depending on the different policy strategies and industry concentrations.

The performance of developers and wind turbine manufactures was discussed in the technology chapter with special attention to the pattern of concentration among utilities and main manufactures[47], however, the performance among regions shows a significant level of concentration in both wind turbine manufacturers and developers/utilities. Regarding energy producers among leading regions, small IPPS and developers hold the major share of the markets of Castilla y Leon and Andalucía while Galicia and Castilla-La Mancha shows a strong presence of big players (i.e. Iberdrola and Acciona). On the other hand, the markets in regions with medium and low power capacity are mostly covered by small and individual developers. The exception is Navarra where Acciona holds 62% of the market. This result can be explained by the territorial distribution of market competences among utilities companies in Spain.

Regarding wind turbine manufacture, the dominance of Gamesa was discussed in the Chapter 4; however, performance at regional level is not homogenous. By examining the distribution of wind turbines among main regions and wind turbine manufacturers (Figure 48) two main results can be identified. First, Gamesa has 50% of the Spanish market, a clear predominance in the big regions such as Castilla y Leon, Castilla La Mancha, Andalucía and Galicia and a lower (but significant) share in the other regions. Second, the performance of "other" manufacturers presents higher shares in the smaller regions. This result can be partially explained by the government owned and experimental nature of many wind parks in less developed markets such as Canarias and Balearic islands.

Figure 49 shows that the Herfindahl–Hirschman Index (HHI)[48] concentration index is based on ownership of wind farms at the regional level. The index confirms the results presented in the

[47] Data on aggregated Spanish wind energy market (AEE,2013) for 2013 shows that 51% is distributed among the big utilities (Iberdrola, EDPR, Enel green power and Union Fenosa) and Acciona as top IPPs and the other 49% is operated by other/small developers. Regarding manufacture of technology, the leading companies Gamesa and Vestas hold 67% of the total market.

[48] HHI is estimated through $HHI = \frac{(\sum_{i=1}^{N} s_i^2 - 1/N)}{1 - 1/N}$ where s_i is the market share of firm i in the market, and N is the number of firms.

chart for the full list of regions. In particular, if the small regions are excluded (i.e. Basque Country, Cantabria and Baleares), Navarra is the region with highest concentration which can be explained by the fact that most of the wind farms are owned by the local firm Acciona. The lower concentration index for Spain may be explained by the predominance of small developers and IPPs which hold around 49% of national wind power capacity. This distribution may facilitate or make more profitable ownership of wind parks by utilities companies that traditionally operate in the regions. At the same time a market organized with lower entry barriers would facilitate the operation of small developers/IPPs (further explanation of the energy market in Spain is presented in the Chapter 4).

Figure 48 Market concentration in the Spanish wind energy market. Main actors

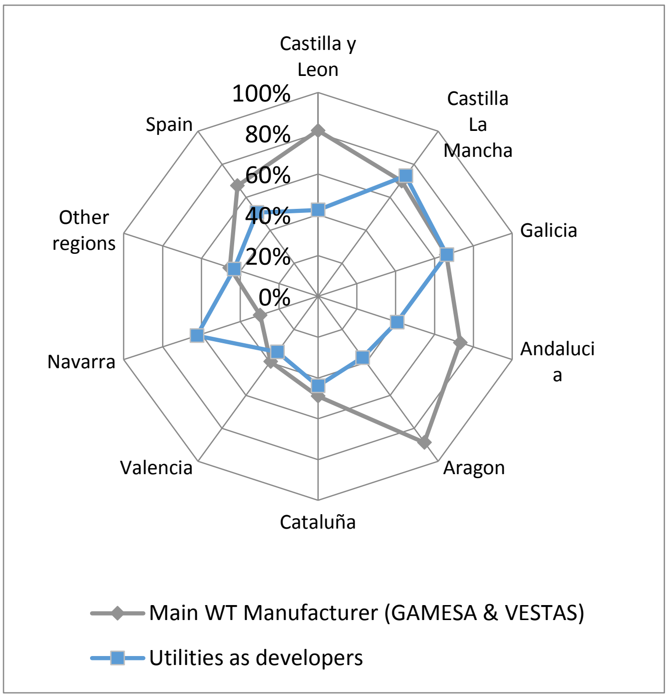
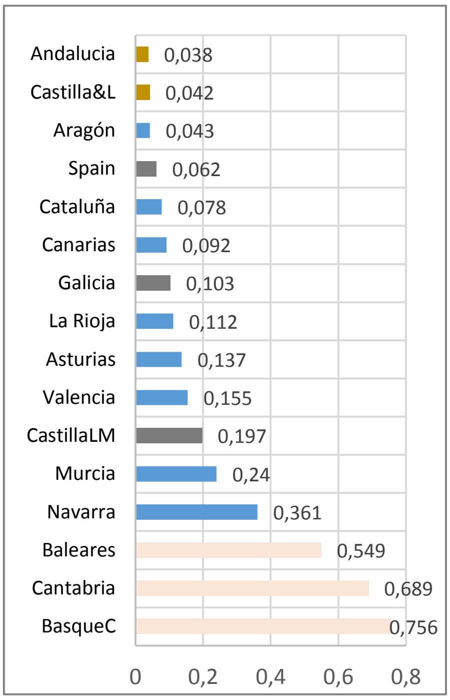


Figure 49 Concentration of wind power capacity at regional level.



Source: own elaboration based in (AEE, 2013b)

To sum up, Spanish regions present competences in key sectors related to technological aspects of wind energy such as metallurgy, machinery and electrical equipment. Some of these regions have a long tradition in the area (i.e. Cataluña, Basque Country, Navarra) and became participants in the renewables energy sector more recently. Other regions with smaller economies such as Galicia, Castilla y Leon and Castilla La Mancha with similar knowledge bases in technological areas have developed competences and specific industrial infrastructure for the wind energy sectors.

These advances have created strong linkages with the energy sector and opportunities for commercialization of new technologies in the international market.

The alignments between technology manufacturers and energy producers, strongly facilitated by regional governments, seem to be important for the pathway creation on regional development of new sectors where local market opportunities and industrial development are complementary. However, further analysis of the location and performance of regional knowledge infrastructures is needed to identify possible interdependencies with the location of industrial activities in order to provide a better understanding of internal and extra regional complementarities.

5.3.2 Knowledge resources and research capacity

The regions provide a governance structure in term of public and private organizations that support innovation through multilevel and multi-sector linkages (Antonelli, 2003, 2006). The connections between the location of industrial activities and regional knowledge infrastructures are critical to explore internal and extra regional complementarities in knowledge bases and competences. Furthermore, the emergence of a new technological field may be based on adaptation and modular recombination of existing traditional knowledge available in both knowledge institutions and industrial sectors (Antonelli & Quéré, 2002; Asheim & Coenen, 2005b; Consoli & Patrucco, 2011; Gawer, 2010) .

In the Spanish regions different indicators reveal different patterns of performance of R&D activities. For example, the major economies, Madrid, Cataluña and Andalucía present the highest R&D expenditure in the last decade, however, the biggest relative increase was in Navarra, Basque Country and Castilla and Leon. This trajectory has allowed Navarra and Basque Country to reach 2% of share of R&D/GDP in 2012 while the Basque Countries has seen a major increase in total personnel assigned to R&D activities (see Annex 4). The three leading regional economies account for half of the total number of knowledge institutions (i.e. universities, technology centres and research centres) and half of the production of publications and patents. However, a look at the regional distribution of R&D institutions according to knowledge areas reveals that Madrid and Castilla and Leon have major regional shares of science and technology institutes while the Basque Country and Aragon have relative better performance in patents than the other regions (see Annex 4). Both results can be considered further linkages between the knowledge infrastructure and the dynamic evolution of the industrial sector.

In the areas of knowledge related to RREE, these linkages rely on the research capacity provided by specialized R&D infrastructures clustered by type and location. Regarding type, there is a set national research organizations including a group overseen by the National Research Council (i.e. CSIC and CIEMAT) and specific scientific infrastructures (ICTS centres). There are also universities and associated centres which are under the jurisdiction of regional government and technology and business centres that are strongly embedded in the regional and sectoral systems which are managed by public private partnerships. These last organizations engage in activities related to business operations so play a critical role in enabling interoperability across wind farm components and higher efficiency.

In relation to geographical distribution and density, four regions account for a majority of the research infrastructure (63%), namely Madrid, Basque country, Castilla y Leon and Andalucía. The Basque Country is host to most technology centres while the other regions show more variety in the research infrastructure. In addition to the concentration in the Basque country, the most important institutions in the field those belonging to CIEMAT which are located in Madrid, Castilla and Leon and Andalucia, and the national research centre on renewable energy, CENER, which is in Navarra (see figure 50).

Regional research and knowledge creation activity in the institutions described above can be identified through their activities within three main programmes: 1) the National Research Plan (NRP), 2) Applied R&D programmes focused on university- industry collaboration for innovation managed by the Centre for Industrial Technological Development (CDTI), and 3) European R&D projects in collaboration with international universities, research centres and companies. The programmes have different objectives in term of knowledge creation, and general performance in the wind energy sector is analysed in the industry chapter. However, there are significant differences in performance across regions.

Basic research data shows an inter-annual increase in the total amount of projects in renewables energy related areas during the period 2004-2012 wherein universities are the main actors and Madrid, Andalucía and Basque country are leaders. For what concerns applied R&D programmes the Basque Country and Navarra perform much better through intensive collaborations with universities (41%) and technological centres (36%) which has developed specific competences in the field (Table 9).

Figure 50 Energy research specialized infrastructure 2013

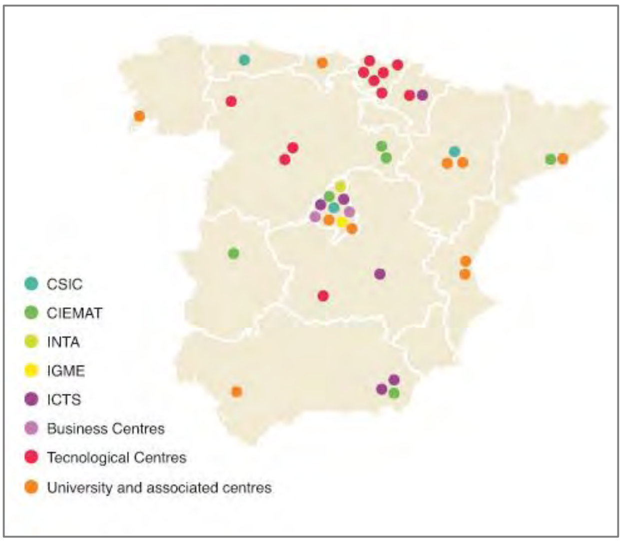


Table 9 Distribution of wind energy related R&D projects. *Spanish Regions 1980-2012*

	R&D CDTI	EU	NRP	Total	Share
Madrid	15%	54%	32%	110	23%
BasqueC	41%	41%	17%	70	15%
Cataluña	7%	56%	38%	61	13%
Andalucia	16%	23%	60%	43	9%
Navarra	63%	19%	19%	27	6%
Aragon	36%	23%	41%	22	5%
Valencia	6%	31%	63%	16	3%
Castilla&L	46%	15%	38%	13	3%
Galicia	9%	36%	55%	11	2%
Other	12%	39%	49%	98	21%
Spain	21%	41%	38%	471	100%

Source: own elaboration based in the following sources Figure 3(López & Moliner, 2012) Table 1 (CDTI, 2013; CORDIS, 2013; MINECO, 2013)

Finally, in relation to the participation of Spanish actors in European collaboration projects related to wind energy, data from EU CORDIS show increasing participation in projects [49] (see Chapter 3 section 3.4.3). The leading regions in this sample, Madrid (25%), Basque Country (16%) and Cataluña (13%) follow the pattern described in the other programmes. A remarkable result is the performance of national research centres belong to CSIC/CIEMAT which account for 15% of total projects granted in the analysed period. With respect to the distribution of knowledge areas among the set of wind energy projects, table 10 shows the distribution of projects in UNESCO categories where there is a clear concentration of R&D activities on general power generation technologies (UNESCO 3322) and instrumentation technologies (3311). The latter is a key category among a diverse set of components including speed control, remote monitoring and security and protection systems. The data do not allow statistical identification of geographical concentration of projects in specific fields; however, Cataluña accounts for the most project

[49] *The projects in the chart were obtained by applying content analysis to the abstract and title. A set of key words related to wind energy technology was used.*

related to aerodynamics and electronic technologies while Madrid has a concentration of projects in the area of economics of technological change (5306).

Table 10 Distribution of wind energy related R&D projects according to UNESCO nomenclature. Spanish Regions 1980-2012

UNESCO / Region		100%	26%	12%	7%	5%	5%	5%	4%	4%	4%	4%	4%	20%
		Total	3322	3311	3303	3307	3301	3305	3312	3313	5312	3310	5306	Other
100%	Total	476	122	59	35	25	24	22	20	19	19	18	18	95
23%	Madrid	111	26	18	6	3	7	4	6	2	5	4	9	21
15%	BasqueC	70	21	6	3	4	2	2	2	3	1	2	3	21
13%	Cataluña	61	13	8	2	8	11	3		4		2	2	8
9%	Andalucia	43	18	6	3	3	1	1	1		2			8
6%	Navarra	28	14	2			1	1	3	2	1			4
5%	Aragon	24	7	2	1		1	1	1	1	3	1		6
3%	Valencia	16	1	3	3	1			2	1		2	1	2
3%	CastillayL	14	3	1	1	2		1	2	2		1		1
3%	Galicia	12	2	2	2	1							2	3
20%	Other	97	17	11	14	3	1	9	3	4	7	6	1	21

Source: own elaboration based in (CDTI, 2013; CORDIS, 2013; MINECO, 2013)

To sum up, the overview of knowledge resources at regional level confirms that the main economies account for most of the R&D activity; however, among the most specialized infrastructures, Basque Country (a region with strong industry capacity in wind energy technologies) and Castilla and Leon (the leaders in wind power capacity) achieve better relative positions. This seems to confirm the linkage between density of specific R&D infrastructure in the area of renewable energy and the location of industrial activity.

In relation to research performance leading regions in energy production do not perform well, while regions with strong industrial capacity such as Basque Country and Navarra show significant results for university-industry collaboration. Finally, Madrid is an archetypical case that can be considered a regionalized national innovation system (Asheim & Coenen, 2005b) since it includes most of the institutional and industrial elements linked to the national and international innovation system.

Data on R&D performance shows some linkages between knowledge resources and industrial infrastructure, however, we need a better understanding of how regional knowledge bases interact with the industrial regional setting to foster the creation of an emergent new sector. These interactions and the commonalities among regions are tracked by applying variety indexes to identify the evolution of industrial and technological capacities among the regions and along time. This allows us to explore the linkages between this variety, regional knowledge resources and the pattern of energy sector specialization.

5.4 *Pathway creation and increasing variety in the regional setting*

In the previews section, we identified key features of the regional setting and the industrial history of Spanish regions to explain the emergence of the wind energy sector (i.e. increasing wind power capacity) and accompanying industrial capacity related to wind turbine manufacture. R&D activities were discussed by characterizing the different research competences and knowledge resources at regional level.

In this section, pathway creation at regional level is explored by considering the regional variety of resources and the patterns of implementation. The first step is application of indexes for variety and specialization in order to map the different and relative positions of regions for variety of knowledge resources, energy and industrial capacity. This will allow us to identify typologies among regions. The second step involves a deeper analysis of the pathways developed by three archetypical regions: Galicia, Castilla y Leon and Basque Country. This should improve our understanding of the different strategies related to combining regional resources for different types of smart specialization.

5.4.1 Measuring variety and specialization in wind energy sector: the regional dimension

Pathway creation on development of new sectors and increasing variety in the regional setting is analysed by applying specialization and related variety indexes (Boschma & Frenken, 2011; Boschma & Iammarino, 2009). The applied indexes are as follows:

Related Variety index

$RV = \sum_{r=1}^{R} P_r H_r$ where $H_r = \sum_{i \in Sr} \frac{p_i}{P_r} \log_2 \frac{1}{p_i / P_r}$ **(1)**

where Pr is the total share for 2-digit product and pi is the share of 3-digit product.

Variety index

$\sum_{i=1}^{N} \boldsymbol{p_i} \; \boldsymbol{log_2}(\boldsymbol{1}/\boldsymbol{p_i})$ (2)

where pi stands for the share of each of activities i in all the wind technology related industrial centres in Spain

Balassa specialization index

$$E_i = (P_{ij}/P_{it})/(P_{nj}/P_{nt}) \quad (3)$$

where P= sector value (i.e. energy produced by wind resources), i: regional index, n: set of regions, j: industrial sector index (i.e. total energy) and t: set of industrial sectors.

The following indicators are derived from these equations:

1. Exports CNAE 24-33 Related variety
2. Energy balance Variety
3. Wind energy specialization
4. Variety of activities in Industrial sites
5. Variety of R&D projects corroding to UNESCO nomenclature
6. Variety of Patents according to IPC classes
7. Variety of Regional Publications according to thematic categories of Scopus® Classification

The indexes are compared first by establishing pattern of relations among technological varieties, composition of energy balance and variety of knowledge resources and using different sets of indexes to run cluster analysis. Methodologically cluster analysis enables classification of regions in different groups, so that there is the greatest possible homogeneity within groups, and some heterogeneity between regions belonging to different groups. We chose a hierarchical cluster model since the number of groups is not known a priori. The cluster model is based on calculation of the similarity / dissimilarity among individuals in the same / different group through Manhattan distance so that if i = (xi1, xi2, ..., xi16) yj = (XJ1, XJ2, ..., xj16) are two p-dimensional vectors of data (17 regions in our case), then the distance between two specific universities is calculated as:

Manhattan distance

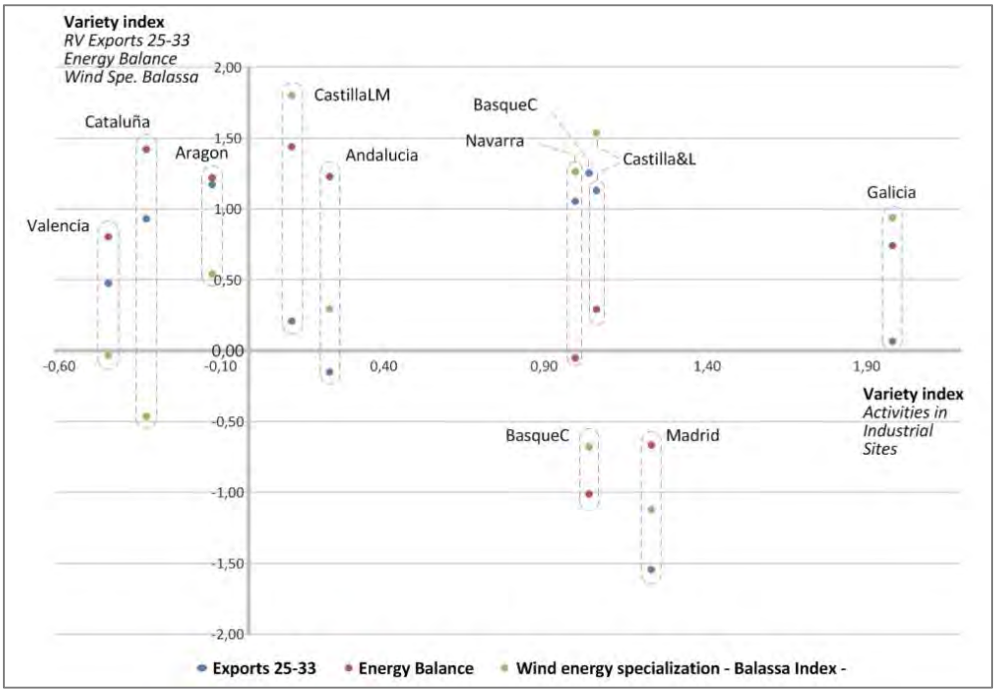
$$d(i,j) = |x_{i1} - x_{j1}| + |x_{i2} - x_{j2}| + \cdots + |x_{i16} - x_{j16}| \quad (4)$$

This procedure seeks to minimize the distance between regions that are similar in terms of performance, and maximize it for those regions that show differences.

5.4.1.1 The results

Regarding the regional industrial setting, the composition and articulation of activities among the value chain at regional level varies in many cases. The regional settings have evolved in variety activities and subsectors within the two principal sectors: manufacturing of renewable energy technology, and energy production. Performance at the regional level for both sectors can support the creation of pathways to different forms of regional specialization or diversification. The internal complementarities between sectors as a key aspect of the systemic dimension, can be explored in terms of the variety of activities and sector composition and then creation of linkages between sectors and the process of the wind energy value chain. Figure 51 shows the relation between the variety and specialization indexes applied to the wind energy variables. The indexes *Related Variety of regional exports CNAE 25-33(RVEX)* applied to the set of industrial sectors associated with the wind energy sector (i.e. metallurgy, machinery and electrical equipment), the *Balassa* ***s****pecialization index on win energy sector (WES)* and *Variety index on regional Energy Balance (VEB)* [7] are presented through comparison with the of *Variety index on industrial activities in industrial sites(VIS)*.

Figure 51 Variety indexes applied to wind energy variables. Spanish regions 2012



Source: own elaboration based in (AEE, 2013a; DATACOMEX, 2013; DEE, 2013)

NOTE: Related Variety of exports (RV), Variety of energy balance, Variety of activities in Industrial sites and Balassa index on wind energy specialization (2012). The indexes are standardized by applying $Z = \frac{Y_i - \bar{Y}}{S}$ where Z is the standardized index, Y_i is the original index, $\bar{Y}$ is the average and S is the standard deviation.

Some differentiated patterns related to the location of regions in Figure 51 can be identified. First, Galicia as one of the leading regions in wind power capacity shows significant variety in industrial performance (i.e. activities and exports). Second, Castilla y Leon and Navarra show high degree of wind specialization, significant level of industrial variety and outstanding performance regarding variety of export components. Third, Castilla La Mancha and Andalucia, both leading regions in wind power capacity, but with higher diversified energy balances (i.e. first and third position in the regional ranking), shows low levels of industrial variety in both activities and export composition. This performance can be explained by the low complexity of wind sector industrial sites mostly involved in assembly, maintenance and operations, which are functions for pursuing home (energy) market deployment.

Fourth, Basque Country and Madrid (located at the bottom right of Figure 51) present similar levels of variety in industrial activities and low (Basque Country) or no (Madrid) wind power capacity and relative less diversified energy balance. These regions have a strong industry background which allows them to be ranked joint first for number of industrial sites, and act as technology suppliers. The Basque Country has the highest index for export variety while Madrid has the lowest, which may indicate a different diversification/specialization strategy. Aragon, Cataluña and Valencia have the lowest variety in industrial activities, but high levels of energy diversification and export variety. Cataluña and Valencia do not achieve significant production of wind energy and are latecomers in development of specialized industrial sites. Thus, both wind energy production and manufacture of renewable energy technology may be part of a diversification strategy.

The changes in the variety index for industrial activities reveals an increase of 50% at national level and significantly higher in the major economies (Madrid, Cataluña and Andalucía) and Basque Country and Cataluña (see also annex 5). Interestingly, Galicia, Castilla y Leon and Navarra have achieved significant increase in the number of industrial sites, but show stable or decreasing variety of activities. In this respect, the evolution of export variety seems to be stable over time with the exception of Castilla y Leon and Castilla La Mancha, which show significant increases, and Madrid which shows dramatic decrease in recent years. Finally, the index for energy balance variety at regional level confirms the evidence presented for a general orientation towards decreasing diversification, with Castilla and Leon and Castilla La Mancha showing remarkable increase in wind energy specialization (see annex 5).

These patterns of industrial performance point to a pattern of specialization. However, a deeper understanding of regional competences is needed to identify clearly regional pathways. In this sense, as already mentioned, the location of industrial activities may be linked to the regional knowledge infrastructure and the exploration of internal and extra regional complementarities between knowledge bases and competences. Figure 52 includes three variety indexes related to knowledge resources: Variety of total cumulative patents on wind energy technologies (by IPC class),[50] and Variety of Publications according to Scopus classification[51] are compared with *Variety index of Total R&D project on wind energy according to the UNESCO nomenclature.*[52]

The resulting distribution of regions according to these indexes does not follow either the overall regional position for knowledge infrastructures or performance in wind energy projects. Only the Basque Country and Madrid retain their leading positions and both perform much better for variety of patents compared to publications. A second group of regions, all with medium wind power capacity, includes Cataluña, Aragon and Valencia which perform relatively well for variety of R&D projects but show different performance for publications and patents.

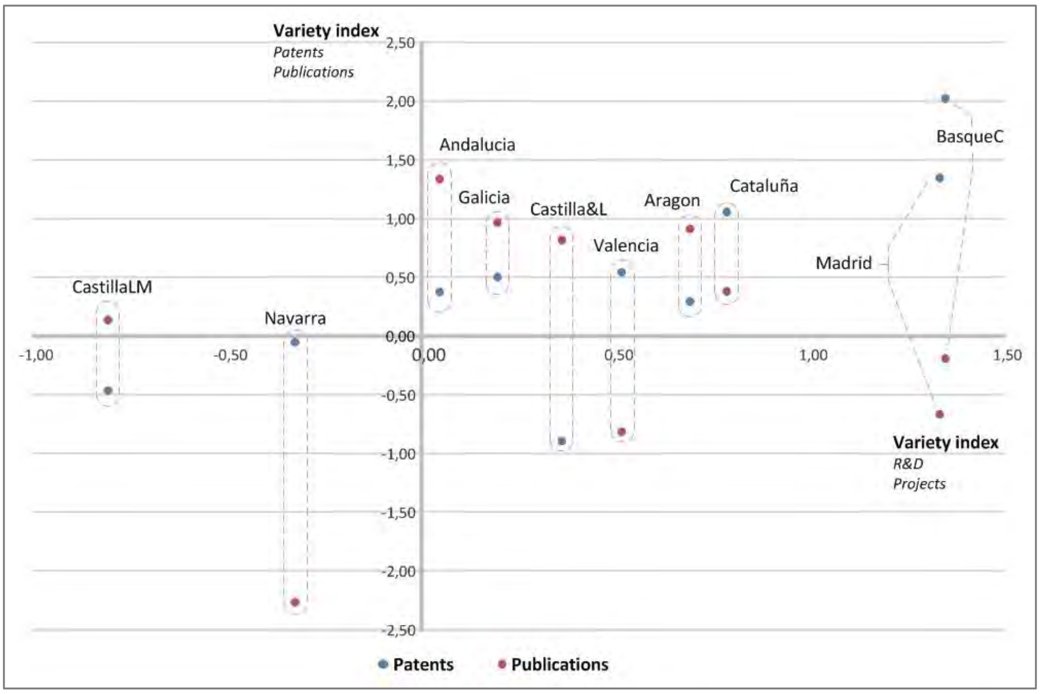
The third group includes the leading regions in wind energy production (i.e. Castilla y Leon, Galicia, and Andalucía). They show low variety in term of project knowledge areas and the same pattern for output, and higher variety of publications than wind energy related patents. Andalucía and Galicia perform better than average for variety of patents. Finally, Castilla La Mancha and Navarra are located on the left of Figure 52, and show the lowest variety for R&D projects and poor performance for variety of both publications and patents.

[50] IPC in European Patent office data (EPO, 2014)

[51] Publications are classified by Scimago according to 27 major thematic categories of Scopus® Classification

[52] Projects in this analysis include R&D applied projects provided by CDTI (CDTI, 2013) which were originally classified as projects in the Spanish national research plan (MINECO, 2013) and European collaboration project (CORDIS, 2013). These last were classified with the assistance of Dr Rafael Granell Ruiz (Granell Ruiz, 2013b, 2014)

Figure 52 Variety indexes applied to knowledge variables. Wind energy sector in Spanish regions



Note: Variety of R&D projects(UNESCO), Regional Patents (IPC class) and regional publications (2011)
Source: own elaboration based on (CDTI, 2013; EPO, 2014; SCImago, 2014) data

Analysis of variety indexes reveals and confirms some regional pathways. Increased capacity in wind power has been accompanied by industrial capacity in wind turbine manufacture in some of the leading regions: Galicia and Castilla and Leon (and Navarra for wind specialization). On the other hand, there are distinctive patterns of specialization in regions highly specialized in wind energy production such as Andalucía and Castilla La Mancha, with lower variety in industrial activities, while the reverse applies to the Basque Country and Madrid. R&D performance is good in the major economies and industrialized regions and delivers a bigger variety of activities and outputs.

Finally, with the aim of representing a combined results a multivariate method, Cluster analyses is applied to the former analysis of indexes. Figure 53 and 54 are two-dimensional diagrams called dendrograms which are showed as part of the results of Cluster analysis. They are tree graphical representations that summarizes the process of grouping a cluster analysis. By applying several steps of estimations of Manhattan distance, hierarchical classifications are produced which illustrates the fusions or divisions made at each stage of the analysis. Then Similar objects are connected by links diagram whose position is determined by the level of similarity / dissimilarity between objects (Everitt, Landau, Leese, & Stahl, 2011).

By considering Variety on industrial setting and knowledge bases, the cluster analysis is run by considering four variables:

- ✓ Three variables for variety of industrial/sectoral setting: Variety of Energy balance (2012) , Variety of Industrial activities (2013), and Related Variety of exports (2012)
- ✓ One variables for variety of knowledge resources: Variety of R&D projects – cumulative projects- (by UNESCO nomenclature)

The first Dendrogram (Fig. 53) is based in a cluster analysis where three variables are included– Variety of Energy Balance, Variety of Industrial activities and Variety of R&D projects – which are entailed to represent the technical set up of the regions. The results show a six preliminary groups where partitions are generated by cutting a Dendrogram at a particular height (sometimes termed the best cut) which involves large changes in fusion levels indicating the best cut[53] (See annex 8). Bu considering this cut (red dot line) and the leading regions, three groups can be identified.

In the group number 4, the middle size regions (Aragon, Cataluña and Valencia) are grouped together in a first step and after further steps (indicated in green and Ψ) the group include Andalucía and Castilla La Mancha. These results coincide with previews results found in Fig. 9 related to the variety of energy balance and industrial activities related with wind energy sector. The group 5 include Madrid and Basque country which are clustered together in the first step. Both regions coincide in the low level of wind energy specialization, the variety of industrial activities and composition of energy balance. Finally, the group 6 include Castilla y Leon, Navarra and Galicia of which the first two are clustered together in a first step and then Galicia is included in a second step (indicated in green and Ω).

The second Dendrogram (Fig. 54) include the former variables and in additional Exports related variety. The result repeat most of the clusters found in the first analyses, however, there are two interesting variations. The group 1 (former number 4), aggregates a first division between middles size regions and the other two regions (Castilla La Mancha and Andalucia). This

[53] This is one of the most applied methods to decide a partition of cluster in a Dendrogram. Clusters obtained are then distant from each other by at least that selected amount, and the appearance of the Dendrogram can thus informally suggest the number of clusters (Everitt, Landau, Leese, & Stahl, 2011).

difference can be explained by the lower level of Exports variety of these last presented already in Fig 9. The second difference in given by the result of Basque Country and Madrid indicated as separated clusters. The explanation can be found in the fact that while both regions share similar levels of variety regarding industrial activities (wind energy), energy balance composition, low wind energy specialization (Fig. 9) and variety of patents, publications and R&D projects (Fig. 10), they perfume very different in term of expert variety where Basque country achieve the highest level and Madrid is located in the bottom.

To sum up, the analysis descriptive of indexes has highlighted some patterns regarding similarities among regions regarding variety of industrial setting and performance of knowledge activities. Those results are also presented through the applications of multivariate techniques (i.e. cluster analysis) from which the main differences has been found by introducing the performance in the external markets regarding the exports related variety index.

Figure 53 Dendrogram using Centroid Linkage – Rescales Distance Cluster Combine
(Variety of Energy Balance, Industrial activities and R&D projects)

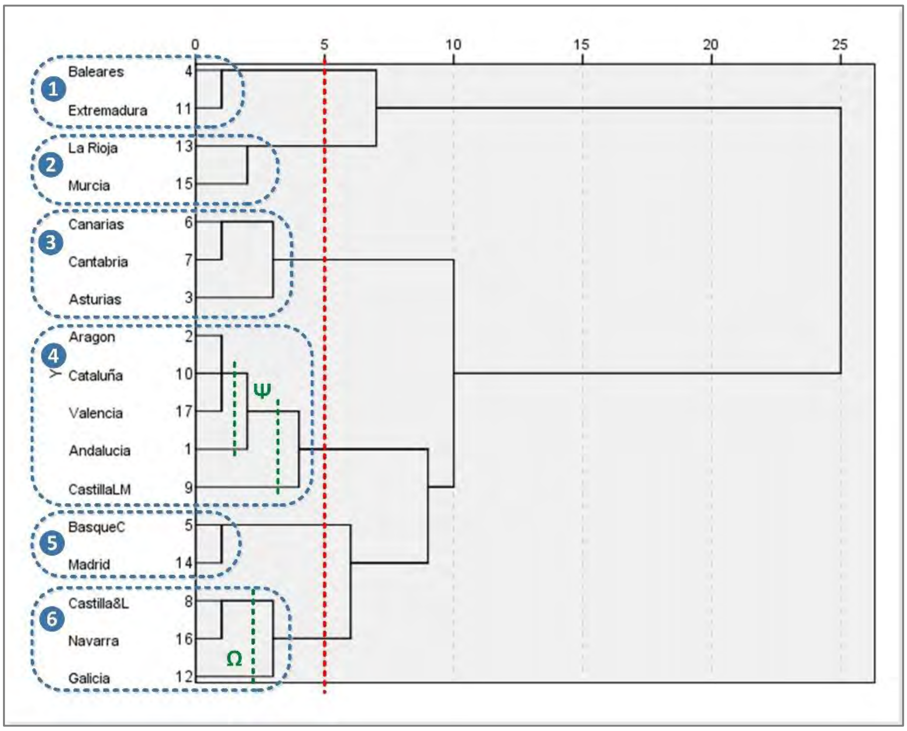
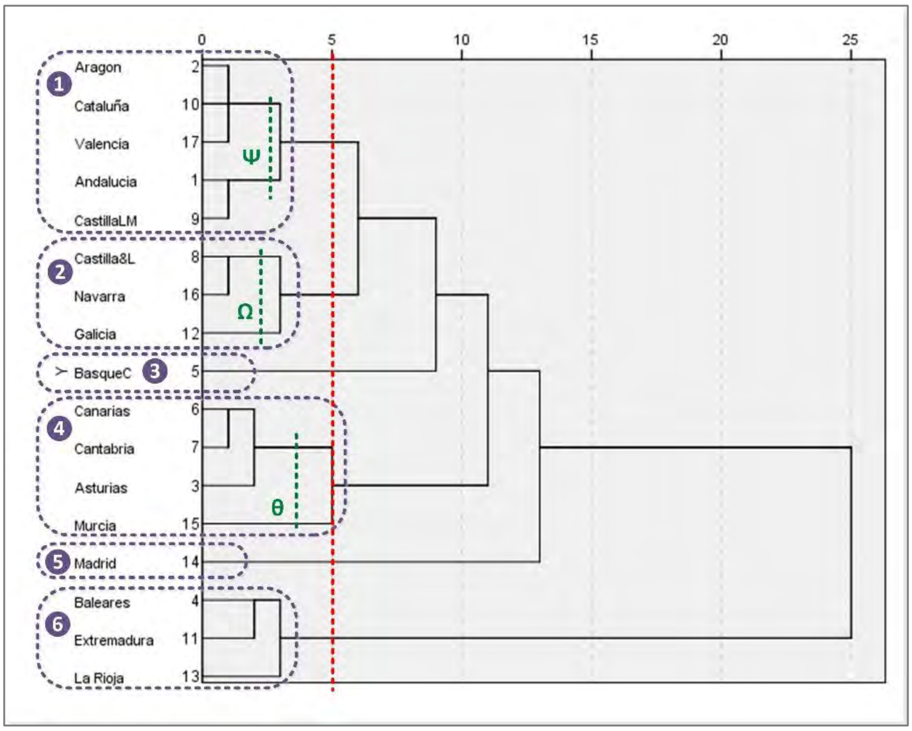


Figure 54 Dendrogram using Centroid Linkage – Rescales Distance Cluster Combine
(Variety of Energy Balance, Industrial activities and R&D projects & Exports Related Variety)



Note: both Dendrogram have been cut at five for a better presentations while according to the fusion coefficients the real cut is lower than five in the Fig 53 and closer to five in Fig 54 (see Annex 8)

The final distribution of regions for energy, industry and research provide a general synthetic picture of the position of Spanish regions in wind energy. It confirms that industrial composition and articulation of activities varies along the value chain. A better analysis of regional pathways is needed for a better understanding of the contexts where change occurs. Below we present a brief narrative of three regions that have evolved in different ways.

5.4.2 Three tales of regional specialization

The specialization pathways have been analysed by focusing on the generation of production capacity (energy production) and implementation of R&D activities by combining regional knowledge resources with the specificity of regional backgrounds such as industrial history and research capacity. These pathways have been facilitated by the regional industrial setting combined with a wide mix of policy instruments. Taking these dimensions as key constructs we identify three paradigmatic cases of regional development, namely Galicia, Castilla y Leon and the Basque Country. These cases provide a wide perspective on the diverse pathways towards sectoral specialization. The following analysis highlights critical actions, and evolution and relative positioning of each region within a changing system of interactions.

5.4.2.1 Galicia

The development of the wind energy sector in Galicia is based on a regional strategy to foster renewable energy capacity while developing industrial capacity in terms of production of local components. The general background to this strategy is the set of national regulations including National Law 40/1994 on the restructuring of the national energy system and the National Energy plan 1991-2000 to foster development of renewable energy and establish specific targets on RREE quotas. The strategy was introduced in the 1995 sectoral regional plans aimed at fostering new regional industry sectors. However, critical actors in wind energy such as ENDESA, IDAE and Ecotecnia had already begun negotiations the regional government on the exploration of significant Galician wind potential (FERREIRA, 2011; Ferreira & Garcia, 2010).

The Galicia wind energy plan was introduced in 1995 and identified areas for exploitation and mechanism to assign the rights to develop wind energy capacity. The strategic wind plans (SWP) - later called business wind plans- were the main instruments (Carballido Roboredo, 2013). The land use and environmental protection regulation was introduced much later so it has not impacted directly in the development of wind capacity[54]. In that sense, the lack of a specific law on alternative land use (i.e. forestry) was a significant driver of wind exploitation through the implementation of the SWP (Ferreira & Garcia, 2010).

The general design of the SWP includes a set of rights and commitments that apply to the SWP holder (i.e. firms responsible for the SWP implementation and exploitation) regarding the development of infrastructures and the use of energy potential in the selected areas.[55] The commitments include research activities on wind energy and transfer of the results to the regional government, developing a specific volume of wind energy capacity and executing economic investment in components and technologies. Regarding this last, a specific share of the total investment was assigned to Galician firms, but the share of wind turbine components is specified in the amount of this investment (Miguez et al., 2006). SWP holders were responsible also for delivering industry plans -developed on their own or with third parties- with the purpose of promoting new industrial activities and supporting development of the photovoltaic industry.

Some SWP holders designed and implemented their own industry plans to comply with the commitment to produce wind technology components locally. The industrial plans include the necessary industrial infrastructure (owned or from other associated firms), estimated employment and time and the specific share of investment in Galician firms (average 80%) and share of wind turbine components (average 65%) (M. M. Muñoz, Fernández, Fernández, & Rodríguez, 2010). The new industry capacity in wind turbine components created by these firms was used by other SWP holder to achieve the required share of Galician investment.

In addition to SWP holders, two other actors operate in the Galician wind market. First, private developers can access the market by operating just a single wind park and second, private /public developers can have either industrial or domestic use (e.g. co-owned by local governments) under the modality of Singular Wind Parks (SGWP) to generate energy for their owners' consumption. This category was valid only between 2001 and 2007. These categories increased

[54] 90% of the SWP were assigned between 1995 and 2001 (M. M. Muñoz, Fernández, Fernández, & Rodríguez, 2010)

[55] These rights were described as "preferred" under the first law of 1995 but became "exclusive" following publication of the new law in 2001.

the variety of actors, however, in 2010 wind capacity developed under SWP represents around 90% of total wind capacity in Galicia (Ferreira & Garcia, 2010; M. M. Muñoz et al., 2010).

The local manufacture of components for the development of wind capacity is based on the different activities proposed in the industrial plans developed by the SWP holders. The local metallurgic industries obtained a new market related to wind turbine frames following the first stage when the major technological components were produced outside Galicia. In the period 1995-2007 industrial sites related to assemble, blades, towers, materials and maintenance were developed by Danish companies including LM, and Spanish companies such as Gamesa and Acciona[56] (M. M. Muñoz et al., 2010). In 2007, the industrial infrastructure in Galicia had increased considerably to 21 industrial centres, 40% of total Spanish sector (AEE, 2013a).

The regional strategy to promote the wind energy sector in Galicia was based on two critical factors. First, the Galician law establishing specific investment in Galician firms to manufacture wind turbine components locally. Second, SWP holders which have also implemented industrial plans has provided technology for their own use and for the wind parks of other SWP holders with no industrial capacity from 1995. These developments were critical for the evolution of Galician industrial capacity and the market configuration of developer-manufacturer relations,[57] and drove significant growth in wind power capacity, transforming the energy balance composition (IGE, 2014; INEGA, 2014). The energy sector trajectory included creation of new firms and industrial infrastructures based on locally manufactured components

5.4.2.2 Castilla y Leon

The early stage of development of wind energy in Castilla y Leon was guided by long term planning for the energy sector. The regional energy plan for Castilla y Leon 1995-2000 introduced lines of action related to energy saving, cogeneration and renewable energy. According to official

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[56] Gamesa was part of joint venture with the Danish company Vestas from 1994 to 2003; Acciona developed its own technology in collaboration with other companies and increased its industrial capacity by acquiring Ecotecnia in 2003.

[57] The market present a significant level of concentration in wind energy production with 2 out of 72 developers (Acciona and Iberdrola) accounting for 39% of the total number of wind parks, 50 (69%) developers owning just one wind park and 15(20%) owning two. Regarding wind turbine manufacture, the concentrations are even higher with one provider, Gamesa-MADE, accounting for 43.8% of the Galician market followed by international providers: Danish Vestas, German Siemens and the French/Spanish Alstom-Ecotecnia.

documents, the main objectives, actions and initiatives were based on experience in other Spanish regions, but also actions started in 1989 as part of national and European renewable energy programmes (e.g. Valoren, Plan for energy efficiency PAEE). The development, coordination and implementation of these initiatives relied on the regional energy agency (EREN), decentralized at the provincial level.

The actions in the wind energy sector began in 1997 with the law on regional renewable energy targets for 2010 and regulation for the development of wind parks. In 2001, the Regional wind plan for Castilla y Leon was introduced by emphasizing the role of provinces in the implementation process (Ciria, 2012). The industrial plan considers a series of stages for implementation in each province. The plan has two main parts. In the first, the number of facilities, features and locations are defined and in the second, industrial, technological, socio-economic and business development are described.

Secondary instruments supporting wind energy include a grant scheme for small scale wind turbines based on security of supply for isolated areas and the potential of advances in this technology (i.e. vertical wind turbines). Regional government also facilitated a series of installations for experimenting with the new technology before introduction to the market.

Regional government sets the priorities for local manufacture of most of the wind turbines installed in the region though the introduction of mandatory purchase of regional components through the connection between the wind plans and industry plans. The regional strategy is aimed at increasing investment and employment through production of 85% of components locally. More specifically, the regional government has signed commitments with top wind energy manufacturers (Made, Nordex, Enron, Ecotecnia, Neg-Micon, Gamesa, LM Composites) which have installed industrial facilities for component manufacture (e.g. blades, towers, machinery) and assembly and logistics centres (CECALE & IDEM, 2002).

The result of this strategy has been significant growth in wind power capacity (from 28.7 to 5505.1 MW) and energy produced (from 32.06 to 5059 GWh) in the period 1998-2013 and expansion of wind energy related industrial centres in Castilla y Leon. As already discussed, the number of industrial sites increased from 8 to 22 in the period 2006-2013. Most of this infrastructure is associated with the original industrial plans promoted by regional government, which, according to EREN (González Mantero, 2008), generated 3,500 jobs by 2008 in industrial areas such as blades, brakes, components manufacturing, electrical components, metallurgy, multipliers, nacelles, towers and mechanical components, as well as wind turbine assembly and manufacturing.

The regional government perspective is based on the assumption that the wind turbine manufacturing companies are mostly big companies that share 30% of the industrial structure. The other 70% of companies are SMEs which develop activities in engineering, installation and wind farms (CECALE & IDEM, 2002). Thus, from a regional perspective, the new industrial installation may benefit from further exploration of related industrial sectors (not only wind turbines) such as machinery, naval and aeronautic industries, and the search of new external markets for wind turbines.

5.4.2.3 Basque Country

The initiatives to foster wind energy in Basque Country began in 1984 with a programme to explore opportunities related to small wind turbines. In subsequent years, the regional government introduced energy strategies within long term programmes setting RREE as a priority. In 1996, the regional government created the state-owned company -Eolicas de Euskaki- with the participation of Iberdrola,[58] which became fully owned by Iberdorla in 2007 when the government decided to leave development to the private sector (Boveda, 2013a). Despite the regional government's initiatives to support wind energy the target proposed in 1997 for 2005 was not achieved by 2011. According to the Basque Country energy agency –EVE-(Boveda, 2013b), the reason for this failure to foster wind energy was delay in presentation of the Sectoral Wind Plan in 2005, which established the technically available areas, and the barriers to its implementation. The main barrier was low acceptance of the technology at regional level from environmental groups.

The initiatives related to technology demonstration and participation of the government in the sector were eventually accepted by civil society; however, the implementation process was stopped at provincial level. Some of the provinces refused to continue after the first initiatives; other provinces did not accept the development of wind infrastructure for environmental, aesthetic and alternative land use reasons. According to EVE (Boveda, 2013b), the current strategic energy strategy is aimed at advances in new technologies manufactured regionally for

[58] The company is responsible for the four wind parks in the Basque Country

the implementation of local wind capacity. However, changes to the national law context do not provide a conducive environment.

Regional government was concerned the limitations (i.e. natural resource and social acceptance) on wind energy and emphasized the development of technological capacity in the manufacturing sector by supporting R&D and internationalization activities. The policy instruments focused on the development of industrial capacity followed the dynamics of international trends and exploited external market opportunities. Table 11 describes the main instruments and areas of action in the policy portfolio.

Table 11 Summary of regional policies to support industrial development – Basque country

Policy instruments	Strategic projects	Strategic research projects	Experimental projects	Process innovation	Innovation in products and services	Organizational and market innovation	Training
Lidera	■						
Etortek		■					
Etorgai			■				
+Innova			■	■	■	■	■
Gaitek					■		
ALDATU						■	

Source: own elaboration based in (Parrilli, Elola, Alvarez, Lorenz, & Rabellotti, 2012)

The characteristic of this instrument - strategic or experimental - is related to the priorities of regional government in terms of industrial development. Most instruments- including the R&D based Etorgai, Etortek and Gaitek - are designed as non-recoverable subsidy. According to EVE (Boveda, 2013b), projects for improvement of wind turbine components, management and monitoring and control and preventive maintenance of wind parks were funded by these instruments. However, more recently these instruments have been focused on large wind turbine and offshore capacity projects.

The recent evolution of the wind energy value chain in the Basque Country has determined a more significant focus on internationalization of production and search for transformations in the wind energy value chain in order to be competitive in the global market. This change can be related to a strategic response to the slowdown of the local onshore market, a rising external offshore market and an evolution to modular and relational technologies (Parrilli et al., 2012). The offshore market is supported by regional government through the development of an experimental maritime platform to provide infrastructure for experimenting in different RREE technologies. The first experiments will be in wave technology, but it is planned to be used for several ongoing R&D projects on floating platforms for offshore wind energy developed by Iberdrola, Gamesa, Acciona and Tecnalia.

5.5 Summary and conclusions. Towards a taxonomy

This chapter was aimed to answer the third research question: How do the different regional industrial settings influence the pathways of specialization observed in the wind energy sector?

The empirical evidence from the study of Spanish regions and analysis of their industrial settings and processes of knowledge creation reveals different trajectories in wind energy home market deployment and development of wind technologies. Regions with significant developments in technology production show good results for commercialization of related technologies in external markets. Deeper analysis of knowledge resources at the regional level provides evidence of a clear geographical concentration of knowledge infrastructures in leading regions which have performed well in research activities related to the application of different types of knowledge.

Asheim’s (2005) typology is applied to clarify the positioning of different Spanish regions regarding path creation in the wind energy sector. The exercise is based on analysis of two main dimensions: characteristic of the knowledge base and degree of connectivity of regions in terms of intra and extra regional flows of knowledge and technology. The regional system perspective is considered in relation to the linkages between energy production and manufacturing technology addressed to exploitation of market opportunities in the energy sector by matching the objectives of multiple actors. The alignment of regional mechanisms such as industrial plans and wind plans has facilitated path creation within a broader multi actor (i.e. government, technology manufacturer, developers, utilities, IPPs) and multi scalar policy (i.e. European, national, regional) context.

More specifically, regarding industrial development and wind market deployment, the empirical benchmarking exercise and application of variety indexes show significant differences in competences for technology manufacturing and patterns of specialization in wind energy production. All the regions with high levels of specialization in wind energy production have developed competences in deployment of production infrastructure.

Different regional policy strategies have facilitated linkages along the wind energy value chain and though different governance mechanism to coordinate actors and process. For example, managing government tendering for technically available areas affects the operations and development of wind energy market regarding the volume assigned and the conditions for technological development. In fact, IPPs market position can vary between the ones that have capacity to operate and manage a large number of wind farms and other operators with a single or few number of wind farms. Castilla y Leon and Castilla La Mancha, the most specialized regions, have lower levels of firm concentration in wind developers. The levels in Navarra and Galicia are higher which can be explained by the territorial distribution of market competences among utilities companies in Spain. Beside the different strategies, the four cases are considered fully integrated regions in terms of wind energy value chain.

Regions with integrated operation in terms of wind energy value chain (i.e. technology manufacturing- wind farm development- operation and maintenance- electricity production) have got high level of specialization in wind power capacity and complementary industrial capacity (mostly in maintenance) that allows the reduction of inefficiency and lost related with failures and mal functioning. The Basque Country and Madrid are technology suppliers. Both regions have a long history in the industry and have developed competences in the production of infrastructure (continuous increase of industrial sites) but have little or no wind power capacity.

Regarding the search of knowledge complementarities, the evolution of competence in production infrastructures is characterized by two main features. The increasing number of activities associated with industry infrastructure and improvements in regional performance in related industry categories (i.e. CNAE 271 manufacturing of electrical material and equipment). For production capacity, the number of actors and regions has evolved in line with the variety of activities. Regarding the external market, regional differences occur in the related variety index associated with exports in metallurgy, machinery and electrical components.

The regions that show better performance for increasing variety of industrial activities and the variety set in external markets, such as Basque Country, Castilla y Leon, Castilla La Mancha and Navarra, can be considered learning regions because they have developed endogenous capacity to adapt and transform their previous industrial setting to innovate in a new sector. Galicia, Andalucía and Madrid have achieved significant market deployment, but related variety in industrial exports may indicate a weak impact of regional learning processes. Finally, Valencia, Cataluña and Aragon can be considered diversified regions in terms of high export variety and energy balance, but secondary players for number of industrial centres in the sector and variety of activities.

Finally, for knowledge resources at regional level, and the benchmark of shares of projects granted under applied research schemes and projects granted under the National research plan, the results confirms the positions of Basque Country and Madrid as leading regions for research. Both regions are also leaders in applied research projects and EU funded projects. In this case, the right-upper quadrant provides a proxy estimation of the degree of interactions with local (i.e. university-industry interaction) and external agents in the process of creation and adaptation of existing knowledge. The application of variety indexes to knowledge categories for R&D projects, regional patents and regional publications confirms this performance among regions.

To sum up, some patterns of regional specialization are defined by natural resources endowments (i.e. wind availability and technically available areas), differences in regional industrial settings and infrastructure and dynamics in the regional process of creation and application of knowledge. The analysis in this chapter suggests different pathways of regional development with regard to wind energy. Table 12 presents the main archetypes that emerged and their compatibility with Asheim's typology along two dimensions: 1) application of synthetic and analytical knowledge, and 2) relevance of internal and external linkages between actors and sectors, namely connectivity

Table 12 Classification of Spanish regions according to Asheim typology (2005)

<table>
<tr><td></td><td colspan="4">Knowledge application</td></tr>
<tr><td>Connectivity</td><td colspan="2">Synthetic</td><td colspan="2">Analytical</td></tr>
<tr><td>Low</td><td>Andalucía</td><td colspan="2">Territorially embedded innovation system</td><td></td></tr>
<tr><td>Medium</td><td>Castilla - La Mancha
Galicia</td><td rowspan="2">Territorially embedded innovation system</td><td>Navarra
Basque country</td><td>Regionally networked innovation system</td></tr>
<tr><td>High</td><td>Castilla y León</td><td>Madrid</td><td>Regionalized national innovation system</td></tr>
</table>

Castilla y Leon, Castilla La Mancha, Galicia and Andalucía are categorized as "Territorially embedded innovation system" because they follow similar pathway creation in the development of the wind energy sector, but mainly through the use and adaptation of exiting knowledge (i.e. synthetic knowledge according to Asheim approach). They have developed strong industrial capacity that has contributed to market deployment of the wind energy sector. In comparative terms, these regions do not present strong research capacities with the exception of Andalucía which has performed relatively well under the national research plan.

The regions present different levels of internal and external linkages, for example, the strong industrial leadership of Galicia and Castilla and Leon is exemplified by the amount and variety of activities. Both regions perform well for exploitation of external market, while Castilla and Leon presents wider variety in the set of regional exports.

Navarra and Basque Country are considered “Regionally networked innovation system” because they present strong connections between the industrial sector and knowledge institutions, for example traditional collaborations in the sector are Gamesa-Tecnalia, Iberdrola-Tecnalia and CENER/CIEMAT-Acciona in Navarra. Also, the pathway of development of the new sector is supported by a wider set of regional government instruments and initiatives.

Madrid is considered a regionalized national innovation system. The region has no power capacity, but is one of the leaders for number of industrial centres. The geographical agglomeration of innovation activities is clearly connected to the wider set of research infrastructures available which give the region to ranking for all the funding schemes considered. Thus, university-industry linkages are a critical element in internal and extra regional complementarities.

To sum up, the pathways creation process involves the combination of different capacities that influence each other. Regional strategies have an internal logic that has impacts on the activities of actors and sectors depending on the regional setting. More specifically, strong industry leadership translates into strong market deployment, as in Galicia and Castilla y Leon, and strong R&D orientation, such as in the Basque Country, Navarra and Madrid, opens up global market opportunities. It should be noted that this analysis does not include inter-regional patterns of collaboration, knowledge and technology flows. Thus, the complementarities among regions should be considered potential factors in the creation of regional pathways.

Chapter 6: Discussion and Conclusions

6.1 Introduction

The case of the diffusion of wind energy in Spain provides a good illustration of the extent to which coordinated multi-level policy can successfully promote the emergence of new sectors. The European Union has provided a favourable policy background for that process through the promotion of renewable energy developments since the mid 1990s. Standards and regulation have been designed with a view to aligning incentives and opportunities across member states to provide an attractive and equitable playing field. This has spurred a variety of responses and modes of implementation with distinctively local character.

Based on a series of supranational and national directives, Spanish regional governments have designed and implemented development strategies that exploit locally available knowledge bases and natural resources. This has resulted in differential growth of industry, research and policy capacities across regions, and a rich spectrum of development trajectories that leverage and feed region-specific tangible and intangible assets. This process has occurred within a context of major expansion in world cumulated wind energy production capacity, which increased fourfold in the 2000s. Against the backdrop of changing industrial and regulatory landscapes, Spain has become a world leader in the wind energy market, and in the global energy industry.

This remarkable expansion is due to the intersection among various processes. On the one hand, EU regulation has provided a platform for harmonizing incentives and exploiting opportunities. On the other hand, demand for alternative energy has grown significantly and, together with the opening of new peripheral markets, this has engendered significant transformations and recombinations of knowledge resources in the structure of the wind energy value chain. Finally, a critical aspect related to the point of delivery is the variety of regional responses based on two main strategies, home market deployment or industrial development, which have resulted in multiple governance mechanisms to foster the interactions between government and private actors.

This study was driven by three research questions: 1) How has the policy mix for energy and industrial instruments supporting renewable energy been combined with Science, Technology and Innovation (STI) instruments in order to support the development of the Spanish wind energy sector? 2) To what extent have the specific characteristic of traditional sectors, such as metallurgy, electronics and power generation, influenced the rate (and speed) and direction of technological development of wind energy? and 3) How do the different regional industrial settings influence the pathways of specialisation observed in the wind energy sector? Three conceptual dimensions were applied to provide a better understanding of the emergence of the wind energy sector in Spain where knowledge is defined as the driver of change based on the use and recombination of knowledge influenced by market forces and technology developments.

Four dimensions (policy domain, governance, geography and time) are used to explain the way in which the policy mix and the factors related to policy implementation seek to influence those forces to foster the creation of new technological sectors. The analysis used a mixed method approach to identify linkages among different levels of and policy domains. We analysed technological trajectories which revealed the emergence of governance mechanisms to coordinate activities and market operations within a multi-actor value chain. We adopted the concept of related variety to analyse the regional dimension and identify patterns of specialization based on combinations of locally available resources such as natural resources, industry structure and knowledge. These results are briefly discussed below

6.2 Reflections about policy mix on wind energy within the multilevel environmental governance system

The chronological study of the multi-level context shows a sequence of stages in the creation of a more competitive energy market at the base of the multi-level, multi-actor and multi-sector interactions that have encouraged the expansion of the renewable energy sector. EU policies established a series of objectives and instruments by coupling the promotion of renewable energy markets (e.g. EU Directives in the early 2000s), the introduction of an emissions rights regime, and a variety of measures to promote market competitiveness.

The implementation of that policy mix is set against a background of Europeanization of national and regional policy-making through the shaping of informal structures such as business-government relations in the energy market. Liberalization of energy markets is the main background process against which new structures (i.e. new segmented energy value supply chain) are aimed at providing the required capacities to solve problems and identify particular regional needs and problems. The development of problem solving mechanisms involves identifying, inducing, shaping and modulating the actions required in each region, and additional actions each region might offer. Governance mechanisms (e.g. national energy plans, regional wind plans) were introduced in the environmental system to coordinate actions among different actors.

The search for links between market opportunities and technical improvements has been supported by the coupling of European (e.g. JOUL, THERMIE, ALTENER, SET Plan) and national (i.e. Spanish National Energy Plans) policies against a background of decentralization of competence and market liberalization to create more competitive conditions. Building on this platform of supranational and national directives and newly acquired competences, Spanish regional governments have designed development strategies around locally available assets (i.e. wind plans). Their final implementation relies on regional strategies for market deployment and industrial development through a set of mechanisms that involve different domains such as industry, energy and the environment, and science and innovation policy.

6.2.1 Matching objectives and instruments

The diffusion of wind energy in Spain demonstrates the existence of a coordinated multi-level policy to promote the emergence of new sectors. The implementation of policy instruments to foster renewable energy technologies requires interactions among multiple policy domains such as innovation, industry and environmental policy responding to different objectives. The historical sequence of context-process in the energy field combine early challenges related to the creation of an EU energy market (1990s) and security of supply with environmental commitments related to the climate change agenda (EU Dir. 2001 and 2003).

This study has shown that both objectives show links with the innovation process aimed at developing technologies, and market deployment based on R&D support. The policy portfolio for renewable energy encompasses a broad array of mechanisms. “Direct” support mechanisms include R&D and instruments to facilitate commercialization, which rely mostly on the state of technological maturity and background processes and institutional conditions. This type of support dates back to 1980 with the inception of specific support measures to basic research through the National Research Plan and applied research co-funded by EU and national programmes managed by the Centre for the Development of Industrial Technology (CDTI).

“Indirect” mechanisms favour market pull to induce demand via two main mechanisms - targets and the feed-in-tariff (FIT) scheme. Both instruments require coordination between the national and regional levels to provide permits and allowances for the development of new energy capacity. In practice, targets have provided the long run scenario for investment in infrastructure (i.e. wind power capacity) while the main financial stimulus has been FIT which was implemented at an early stage (before the EU normative) and then was adapted to this normative (2001). FIT implementation was characterized by flexibility enabled by a sequence of adaptations and maintenance of a temporal horizon of 15 to 25 years. However, the co-occurrence of the financial crisis and tariff deficits forced national government to make drastic modifications to the incentive mechanism from price to financial incentives (cost plus contract) in 2013.

This study has revealed significant evolution in the adoption of direct support mechanisms related to R&D by combining a trajectory of increasing public-private actor collaborations in applied research, and international collaboration projects where Spain has achieved a relevant position in the EU context (Izquierdo, 2011). Regarding direct mechanisms, in addition to the instability of the FIT scheme, increasing wind power capacity has revealed that the combination of clear targets (quotas) and FIT have created and continuously increased market volume. Spain is the first country where wind becomes the major source of energy (El País, 2014b). However, the change in the FIT scheme has caused a rift in the renewable energy sector (El País, 2014d). This mismatch in results and timing can be understood in term of the rationale for the policy mix to pursue multiple objectives.

In relation to the first research question, the policy mix for energy and industry instruments combined with STI instruments has been aimed at achievement of compatible objectives such as market deployment and technology developments. The provision of long term targets encouraged the industry sector in the process of market deployment, which was facilitated by regulation aimed at removing the barriers to the electricity market. The application of regulation in the form of financial stimuli (i.e. FIT scheme) has improved the economic conditions for investment in RES-E power capacity and industry developments related to renewables manufacturing. R&D support has been oriented to the creation of technical capacity to provide solutions for new markets and environmental commitments. However, technology maturity and its evolution over time have been rather overlooked.

A better analysis of the technology maturity may contribute to understand the way the sector has evolve through the creation of market volume supported by some instruments while, at the same time, improving technologies though learning by doping process with the final aim of exploring other markets (i.e. developers and wind turbine manufacturers). However, the lack of a focused value chain approach may be a critical factor in relation to the vulnerability of the sector to unpredictable policy changes and. therefore, lack of capacity of the sector to be fully competitive. The overall result for the wind energy sector as a whole should be considered within a deeper analyses of technology development and the regional dimension.

6.3 Technological trajectories in wind energy technologies

The evolution of wind energy technology hinges on the continuing search for materials and techniques aimed at improving the capacity and the efficiency of power generation through the capture of air currents. The modular combination of technological components has facilitated industry progress, and in other areas (e.g. grid connectivity, offshore platforms) has achieved major advances to support system expansion on different scales. In this sense, the search for increased size and maximum power capacity has driven the evolution of wind turbines over time. On the other hand, the broad trend in the European wind energy value chain has exhibited significant diversification and fragmentation through the search for greater efficiency in capturing emerging markets and greater competitiveness in increasingly contested markets.

Against this backdrop, Spain has enjoyed unprecedented scaling-up in the wind energy market in Europe and in the global industry. More specifically, and related to the second research question, this result is related to a mixed strategy based on the process of knowledge transfer from existing to new sectors, allowing the specific characteristics of traditional sectors to influence the rate (and speed) and direction of technological development of wind energy. On the one hand diversification strategies with established industries have involved mergers and acquisitions (e.g. Vestas- Gamesa, Almstom-Ecotecnia) and creation of new divisions (e.g. MTorres). On the other hand, the reconversion of existing capacity in metallurgy, electronic, power generation and infrastructure (i.e. Iberdrola, Acciona) has accelerated the transition from an emergent to an established industry.

In a relatively short time, Spanish companies have achieved leading positions in global markets for wind energy production and wind energy technology. This has fostered the growth of industrial capacity in wind energy related activities, and the variety of actors involved in the supply chain. Also, the rate of expansion of industry sites has not been affected by the economic downturn at the end of the 2000s, and several actors has outgrown the expansion of industrial activities regarding manufacturing wind technologies components that each one engages, suggesting a turn towards higher specialization. In the Spanish wind energy market, the market structure and the removal of market barriers has favoured three types of actors: utilities – which have better conditions in terms of market share and regional markets; independent power producers – which have maximized competences for modular combination of technological knowledge; and wind farm developers. The three types of actors act both as system integrators of existing components and as pioneers in search of new opportunities.

A key element in wind energy sector expansion is the interaction between the electricity market and technology developers, which is based mostly on long term cooperation agreements between the developers and wind turbine manufacturers. These agreements, along with regional governments, have supported the dominant position of the technological actors which have provided the expertise required to explore international markets especially following the tariff deficit crisis and downturn in the FIT scheme. Technology actors such as Acciona, Gamesa and Iberdrola, accumulated technological and organizational competences during the period of emergence of the Spanish wind energy sector. The crisis pushed them to reorganize their local market in terms of volume and activities, but the technological capabilities acquired allowed restructuring for major exploitation of both external markets and offshore technologies.

6.4 Regional setting and pathways of specialization

Implementation of environmental, energy and industry policies requires the active participation of the local system of governance in the form of regional strategy, and articulation between public and private stakeholders. In the case of regional policy, the linkages between the transfer of competences and management of regional resources have driven the evolution of the normative portfolio where most regional level renewable energy related policy is related to industry regulation (50%) with the remainder split between the environment and land use. More specifically, the role of regional policy has been critical for the process of implementation of renewable energy policy set by the introduction of government tendering (i.e. regional wind plans) introduced as a form of “public procurement” to provide a temporal horizon to the deployment of new markets and reorganized RES-E value chain operations in relation to the importance of local components and interaction between electricity generators and manufacturers.

In this respect, the features of the regional governance system regarding the level of communication and the ways of interacting between government and private actors are important for each of two main strategies, home market deployment and industrial development. The wind plans include formal long term agreements with commitments to and rights on the exploitation of wind resource, which set the basis for the coordination between regional governments, utilities and manufacturers. The regional strategies are aimed to foster the creation of includes various pathways for development new sectors through new mechanism for the management of resources, and the decision making processes, based on centralized of decentralized models. Empirical evidence from the study of Spanish regions and analysis of their industrial settings and knowledge creation processes reveals different trajectories in wind energy home market deployment and development of wind technologies. Regions with significant developments in technology production show good results for the commercialization of related technologies in external markets. Deeper analysis of regional level knowledge resources provides evidence of a clear geographical concentration of knowledge infrastructures in leading regions which have performed well for research activity related to the application of different types of knowledge.

Different regional policy strategies have facilitated linkages along the wind energy value chain and through different governance mechanisms to coordinate actors and processes, taking natural resources availability as the starting point. Castilla y Leon and Castilla La Mancha, the most specialized regions, have lower levels of concentration of wind developer firms. The higher levels in Navarra and Galicia can be explained by the territorial distribution of market competences among utilities companies in Spain. Despite their different strategies, the four cases are also considered fully integrated regions in terms of the wind energy value chain. The Basque

Country and Madrid are technology suppliers; both have a long history of this industry and have developed competences in the production of infrastructure, but have none wind power capacity.

The regions that show better performance for increasing variety of industrial activities and variety in external markets, such as Basque Country, Castilla y Leon, Castilla La Mancha and Navarra, can be considered learning regions because they have developed endogenous capacity to adapt and transform their previous industry setting to innovate in a new sector. Galicia, Andalucía and Madrid have achieved significant market deployment, but related variety in industrial exports may indicate a weak impact of regional learning processes. Finally, Valencia, Cataluña and Aragon can be considered diversified regions in terms of high export variety and energy balance, but secondary players for number of industrial centres and variety of activities in the sector.

This study applied Asheim's (2005) typology to identify these different patterns in order to address the third research question on the influence of different regional industry settings on the specialization pathways observed in the wind energy sector. Based on the characteristics of the knowledge base and degree of connectivity of regions, the results suggests different pathways to regional specialization defined by natural resources endowments (i.e. wind availability and technically available area), differences in regional industrial settings and infrastructure and dynamics in the regional process of creation and application of knowledge. Regional strategies have an internal logic that has impacts on the activities of actors and sectors depending on the regional setting.

More specifically, strong industry leadership translates into strong market deployment, as in Galicia and Castilla y Leon. Thus, these regions are categorized as "Territorially embedded innovation systems" because they follow similar pathway to the development of the wind energy sector, mainly through use and adaptation of existing knowledge. In regions with a strong R&D orientation, such as the Basque Country, Navarra and Madrid, have exploited global market opportunities. Thus, Navarra and Basque Country are considered "Regionally networked innovation systems" because they present strong connections between the industrial sector and knowledge institutions, while Madrid is considered a "Regionalized national innovation system". The region has no power capacity, but is among the leaders for number of industrial centres.

These results reveal that a pathway of specialization strategy may not be fully articulated. This may be due in part to the complex nature of the governance involved in smart specialization, especially when policy design refers to multi-level decision-making in multi-actor contexts. However, it also confirms the relevance of the capacity to use, adapt and combine local available assets and abilities to define the development of a new sector through the process of knowledge transfer from existing to new sectors. In this respect, evidence on the success of strategies for market deployment and technology development and their combination, suggest that there is no single route or pathway. In other words, there is no one way for regions to be "smart" and become specialized by using and transforming existing capacities to develop a new technological sector.

6.5 Lessons learned and challenges to pathway creation

The present study confirms that while international commitments act as a guiding force in establishing long-term environmental perspectives, national governments provide the right market signals, financial support and the broad regulatory framework to shape the emergence of renewable energy sectors. It shows that regional institutions act as a powerful selection mechanism to differentiate actors and their capacities, and the long-term trajectories of capacity development in power generation, scientific research and technical expertise reveal distinctive implementation patterns across regions. In addition, the broad policy background allows for simultaneous decentralization of competences to regions and general liberalization of energy markets, which facilitates the orchestration of a wide variety of actors in different componentsof the energy sector. Overall, this dissertation research shows the interplay between public intervention and the articulation of systemic dynamics in a new market, and provides a critical reflection on the research policy challenges associated with the emergence of new sectors, and particularly the nature of industry evolution to respond to pressing societal needs.

However, it also has raised new questions about the role of public intervention to stimulate the creation of new sectors. First, the unexpected turning point in the FIT tariff scheme in the Spanish case which was the result of the lack of long term planning oriented to creating stability, no clear competitive criteria for market development and inappropriate use of flexibility regarding each of policy domains. Second, the different responses in term of market deployment and technology development at regional level when considering the variable of regional setting and possible multiple pathways to specialization in a new technological sector.

In relation to the first issue we need to know how governments can design a policy mix such that technology is competitive without any kind of public intervention? And, also, what are the most appropriate objectives - creating market volume? Creating competition? Or both, but simultaneously or one at a time? A possible starting point to explore these questions would be to investigate the stages of sector development. From the perspective of the maturity of the technology, value creation might depend on how the policy instruments are implemented in terms of flexibility and stability to promote a long term horizon for planning and risk management for the technological and industrial actors involved. Then the pathway creation process may be stimulated by a trade off between provision of suitable conditions for innovation and flexibility in the policy instrument designed to foster competitive market conditions which, in practice, means a gradual reduction of financial incentives (i.e. FIT scheme). A main challenge in this process is the creation of instruments within the orbit of private sector (e.g. venture capital, risk management mechanism) to support the soloing stages of development.

There are different needs depending on the domain and level of implementation considered. Energy targets are policies that provide a long term market horizon; R&D support might involve mid term objectives while financial incentives are critical for market development. The evolution of this last involves the gradual reduction of financial support in a flexible but predictable way, which in practice can be use as clear indicators to manage the risk involved in long term investments. With that respect, the mitigation of uncertainty during the implementation process arise as a main challenge in scenario of policy implementation where there a trade-off between predictability of policy evolution and long term adaptation vs. discretionary policy implementation and the generation of possible market shocks (i.e. crisis in Spanish renewable energy after the downturn of the FIT scheme). The key question becomes the timing of reductions to financial stimuli. The Spanish case shows there is a needs for agreement among key actors such as system integrators about timing and stages of evolution of public support and the needs to introduce additional privates mechanisms in order to achieve positive results and avoid huge economic and societal (i.e. jobs) losses (El País, 2012, 2013, 2014a, 2014c).

The selection of the right timing for managing financial incentives according to sector maturity Timing reductions in financial incentives is difficult; scenarios can be draw based in primary results from the implementation of these instruments: achievement of relative targets or increasing market volume. For example, the market volume facilitated by the FIT schemes can pursue both home market deployment (i.e. meeting societal needs) and supporting the creation of technological capacity and expertise to exploit new market opportunities. This research has showed that the regional setting and industrial histories can generate variety of specialization strategies. Then it would not be logic to expect a convergence to a particular pathway of specialization in term of sequence of action or specific combination of locally available assets. For example, it might be wrong that the regional efforts for supporting pathway creation on a new sector development seek the unique goal of fostering technology developers for exploiting external markets or, in other words, regions should find own pathways of development rather than expecting a convergence to handbook profiles such as Basque country. However, foresights about pathway convergence toward home market deployment or penetration of external markets may provide guidelines in relation to the policy intervention cycle but it is not possible to anticipate the results on the setting of targets or the general application of policy instruments.

In relation to the second issue, the role of the state in supporting and inspiring entrepreneurship has been thoroughly debated in the STI policy literature. Regional approaches highlight geography in relation to the process of transfer of knowledge from existing to new sectors. For example, in the case of Spain, the challenge lies in the search to possibilities to replicate success in the development of renewable energy sectors by using available knowledge in mechanical engineering, electronics and power generation. The energy sector has received special attention because of environmental commitments and security of supply, but it is not clear whether the experience of fostering market deployment and technology development can be replicated with similar (or better) results in other emerging Spanish sectors such as nanotech (Alonso Andaluz & Sanchez Paramo, 2006; IMDEA, 2014; Rivera, 2012; Serena, 2014; Zafra, 2012) and biotechnology (AFP, 2014; ASEBIO, 2014; EFE, 14d. C.; HYPER, 2014; La Razon, 2014; Nassivera, 2014; A. Powell, 2014).

The results from this study provide food for thought on the development of new technologies regarding the use and combination of locally available assets and knowledge bases (i.e. traditional industries) as well as the search of next generations of technologies (e.g. floating offshore wind platforms). This results has been also expressed by EU policy officers and technology experts during the interviews so they are relevant for discussions of EU level policies regarding potential instruments to foster coordination and cooperation in many domains (energy, research, industrial development)

The top policy level may not be any more a responsible for influencing the direction and main actions on technology development but it would rather be a facilitator to providing response to what demand can ask. In relation to demand driven innovation policy, it needs to be bottom up rather than responding to the interests and lobbying of industry leaders. On the other hand, this study has showed that key technological actors are very important as system integrator so the feedback loops on policy design and implementation process are critical.

In relation to the top down-bottom up perspective the difficulty lies in identifying key segments of the value chain. The recombination of technological knowledge make possible the riding of new generations of technologies but it depends on the ability to focus and get control of dynamic and diverse trajectories of current technologies. In a bottom up approach, technological diversity is not a problem so, the EU policy level should impose governance mechanisms to manage the bottom up process and take account that the results may differ in different contexts. Contextual factors favour regional development of the wind energy sector; however, the existence of historical strategy has been a critical element in the pathway creation analysis in this research. For example, endogenous process as early wind plans in Galicia in 1995 has been critical for the market deployment while in the case of Basque country different public acceptance of wind energy has influenced key actors to rely on long trajectories on regional RD support to explore opportunities in technology development.

Thus, governance mechanisms should reinforce bottom up processes and the identification of actors that might act as system integrators and facilitate collaboration, integration and cooperation. This could be applied at a higher level to facilitate transnational networks to resolve specific problems and implement technology developments such as industrial platforms, R&D funders to coordinate (i.e. EU-National-Regional R&D programmes) and maximize knowledge creation activities and regional organization for design and implementation of policy instruments and local governance mechanism, interacting within a multilevel governance system.

6.6 Limitations and further research

The main purpose of this last section is the identification of the limitations regarding theoretical and methodological elements of this study as well as future lines of research.

From theoretical point of view, this research has been based in the combination of three bodies of literature to explore the wider phenomenon of the emergence of a new sector. As conceptual tools, literature on innovation and technological trajectories has been used to present the key elements regarding the dynamics of knowledge resources underpinning the pathway creation for the development of new markets and technologies. On the other hand, the complexity of the policy background has been studied by applying concepts such as policy mix and multilevel governance while the regional dimension has been explored based on regional setting, related variety and specialization strategies. All these conceptual elements has been applied to pursuit the study on development of the wind energy sector in order to provide a wide view aspect of the phenomena under study.

With that respect, the framework presented in the Chapter 2, even when it has been applied to an exploratory study, presents limitations in the potential for a further complete integration. With that respect, improvements may be considered by analysing similar approaches from the ecological economics (Del Río González, 2009) literature and history of technology (David, 1985; Kline & Rosenberg, 1986). These approaches may provide a broad description of the ecology of actors and elements in the system which may help for a better build-up of narratives on technology development. On the other hand, further research aimed to improve the understanding of path creation for the development of new sectors should emphasize the in sequences of stages and variety of directions that can take these processes along time (Cooke, 2012; Dawley, 2013a; Ron Martin & Sunley, 2006).

Another critical aspect of this dissertation is related with the application of a mix method approach. The approach seeks to provide empirical elements to study a complex and multifaceted phenomena by providing flexibility in term of instruments and points of views. By doing so the integration of different results provide a whole picture of the phenomena but it suffer of a lack of deeper analysis in each of these dimension and underestimate particular insights that each of the methods may provide. With that respect and regarding the empirical study of Chapter 3, the historical analysis of policy background may be further develop though further research based in a deeper content analysis of public but also private documents (e.g. annual reports of key companies, consultancy studies, industrial magazines) regarding favorable position to different decisions and actions as well as linkages across different action points. This analysis may lead to advance understanding of policies reformulations toward further alignments between public goals, private motivation and a competitive environment as well as policy misfits and boundary judgments of each group of actors involved.

Secondly, technology development studied in Chapter 4 has highlighted relevant aspect regarding industrial evolution based on the linkages between energy sector, manufacturing industries (e.g. metallurgy, electronics, and mechanical engineers) and infrastructure sector through a value chain approach. However, there is still the need of better explanations on the way knowledge network structures evolve and operates towards effective transformation of knowledge into commercial technology. Deeping into a dynamic network analysis of cooperation between academia and industry may allow the identification of relation between endogenous network development and external source of knowledge and learning process.

More specifically, a better assessment of the modes of knowledge production can be done by looking at the governance structure of the knowledge system (Antonelli & Quéré, 2002; Giuliani & Bell, 2005; Kaiser, 2003) supporting the learning process which may lead to the identification of system integrators (Consoli & Patrucco, 2011) and key gatekeepers (Steward, Tsoi, & Coles, 2008) who could potentially contribute to the achievement of effective technological development and diffusion in emergent markets. This further research should consider spatial organization of knowledge interdependencies (Roman Martin & Moodysson, 2013) regarding different types knowledge bases and process of transfer of knowledge from existing to new sectors (Dawley, 2013a; Ron Martin & Sunley, 2006) but also the variety of regional settings and local available assets (Antonelli, 2000; Quatraro, 2010b).

In that respect, Chapter 5 presents the first step on the empirical study of the Spanish regional and industrial histories which has allowed a distinction according to the variety of knowledge and technological resources supporting the different specialization strategies on wind energy sector. Even that, the understanding of coordination of actions and alignments of different actors require a further research on the design and implementation of governance mechanism (Antonelli & Quéré, 2002) in order to highlight how those different specialization strategies are driven by new direction followed by regions towards specializations (Boschma, 2014) or response to structural elements regarding typologies of regional innovation system (Asheim & Coenen, 2005b).

Finally, future research could deeply explore the implementation aspects of an entrepreneurial state by dealing with the struggles between national and regional competence through a critical study of public and private competences, instrument and resources in the support of new emergence sectors.Results presented here provide interesting insights on the design and implementation of policy to push technology implementation but it has also left open questions on effective design to guide those technologies to become competitive without any kind of policy intervention. Thus, future analysis should incorporate a broader analysis in term of added value in technological sectors to better understand whether segments of value chain or stages of technology development require different type of support. With this additional research, some of the propositions in this research could be challenged in terms of the role of public and private sector at any sector to support process of pathway creation of new technological sectors.

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Annexes

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8.1 Annex 1: Key technological aspects of wind turbines

Part A. Design approaches of wind turbines: The evolution of design and approaches and patterns of commercialization has been driven by the distinction of vertical and horizontal axis and the simultaneous search if bigger and more powerful turbines. This key issues are briefly explained below.

Since the beginning of the Wind mills and the early stages of wind turbine for electricity, design can be mostly divided in two main approaches: Vertical (VAWT) and Horizontal (HAWT) axis wind turbine. Design has evolved over time and each of them has been proved to be more effective in different conditions. Most of current wind turbines are horizontal because less technical problems (simplicity). However, vertical are currently considered for small scale and innovative offshore design. Vertical turbines seem to have a better indicators in term of density (mw/m2) and probably more suitable for residential use and low scale (EWEA, 2009) (scale & cost-benefit).


Horizontal – 3 Blades


Vertical Darrieus


Vertical - H

Number of blades. The market is currently dominated by three blade and cylindrical tower designs as they are lighter and the supporting structure has lower cost. The rotor is easier to understand and people think is visually nicer (simplicity). Two blades turbines can be used to increase flexibility, they are cheaper but noisier and less aesthetic. Two blades design is similar to three blades but rotor of 2 blades is less efficient as more blades minimize loses. Finally, one blade design is the most structurally efficient for rotor blade but has many other technological problems (Şahin, 2004; EWEA, 2009). Regarding the HAWT as Dominant design, the number of blades is an incremental innovation that has characterized the blades as core component oriented to the search of efficiency. These issues are summarized below.

The Wind Energy conversion systems (WECSs) depend on aerodynamic drag and aerodynamic lift. Modern wind turbines are predominantly based on the aerodynamic lift divided according to the orientation of the spin axis as horizontal axis and vertical-axis turbine types (Şahin, 2004).

The **evolution of wind turbine size** has been based in mechanical, physical and economics principles which may fall in a general cost benefit criteria facing the challenges on the search of power efficiency, optimal weather conditions and system economics. The table 6 shows the evolution of this variable and the expected results in the next years.

Table 13 Development of wind turbine size between 1985 and 2002

Year	Capacity (kW/MG)	TDM
1985	50	15
1989	300	30
1992	500	37
1994	600	46
1998	1500	70
2001	2000	72
2002	2500	80
2005	3500	126
2010	7,5MG	150
2015	10MG	178
2020	20MG	250

The mechanical and physical principal has allowed an increase in rotor capacity much significant than diameter. Since 2000, this exponential relation became clear when the commercialization of big turbines force the technology development to improve power capacity and efficiency at higher rates. In that decade the diameter of more advanced rotors has increased around 105% while the capacity more than 270%.

At the same time, by 2009 the average size was 1, MG and the current leading technologies are about 2, 5 MG with the bigger ones between 5 and 6MG (Bilgili et al., 2011). The progress made in the technology was based in the experience where small commercial wind turbines were steeply up scaled gradually and from 55 kW in the early 1980s to 500–2500 kW in the beginning of 2000s as well as the rotor diameter increased from 15 to 70–82 m and the hub height from 22 to 60–80 mts (Şahin, 2004).

The increase in the turbine size comes together with reduction in weight and efficiency. For example a 24 m tower decreased from 32 kg/m2 in the early 1980s (55 kW wind turbine) to 5.026 kg/m2 in 2000s (500 kW wind turbine) and the rotor weight decreased from 1.8 kg/m2 (55 kW wind turbine) to 0.5 kg/m2 in the same period (500 kW wind turbine). Regarding, efficiency improvement, the rotor efficiency increased from 35–40% in the early 1980s to 48% in the mid-1990s.

The upscale of wind turbine has generated significant improvements in performance through the development of higher towers which increased the wind capture and, thereby, the electricity production (kWh/m2). But the design styles of wind turbine include orientation (vertical vs horizontal) and the number of blades and materials as well as the control and better use of different wind speed depending of different technologies and conditions. The following aspects of the wind turbine technology are the most analyzed in technical literature and reports.

Part B. Key components of the wind turbine: The increasing the size of wind turbines affect mainly the structure (blades, tower and nacelle), power capacity (generator), and maximizing wind capture (speed control systems). Their main characteristics and trends are briefly described below.

Blades. The operation principle is mainly the capture the wind power to create kinetic energy. According to the main technological principle, the longer the distance from rotation axis, more rotation under the same force (wind), however, longer blades mean more material, heavier blades and more mechanical stress in the structure so materials became more relevant.

HAWT has been the main design since the beginnings of 20th century characterized by heavy steel blades (mostly 80´). The introduction of aluminum in 90´ may be considered as the starting point of a very competitive search of new materials and composites for blades. Nowadays, most of innovations are associated to combination of fiberglass, carbon fiber, aluminum, steel, wood epoxy and glass-reinforced plastic and epoxy based composites. Advance blades will be of softer and flexible materials to search for a good combination of weight and strength.

Other important issue is the increasing size of the blades that generate operational cost for installation and maintenance (simplification). In that sense, a top innovation in 2010 introducing by Gamesa is a model of two parts joined on the place where turbine is situated.

Tower. The tower is a critical part of the wind technology in term of allowing bigger turbines (cost benefit), operation issues (efficiency and reliability) and not less important aesthetic issues. Early wind turbines were based in guyed pole towers which allows weight saving but limited to small turbines. They have similar cost to traditional but require more surface and shows vulnerability/dangerous issues. Lattice towers was dominant in the 80´ as they need less than the half of material but it has bad visual appearance and its use was discontinued.

Today most of the large wind turbines are 20-30 meters tubular steel towers, conical instead of cylindrical mostly because aesthetic issues. New developments of Gamesa are a prefabricated mix of concrete and steel. It provides strength needed to higher towers over 120 m and holding 64 mts blades, a very critical advance for the offshore industry.

Nacelle. It is the box/skull containing the main components for electricity generator and control. Advances and Innovation trend has to do with increasing the strength and reducing its weight. Modern nacelles are based in yaw mechanism to allow full rotation. The maintenance is a critical factor by which new designs (VAWT are cheaper than HAWT) are being reconsidered for small scale applications.

Power generation. The operational principle of this component is the conversion of kinetic energy to electricity. The most significance advance in term of electricity Generator is the movement to simplification by switching from constant speed to variable speed at first and then innovate (90´) in the elimination of gearbox (2000). The reasons behind in reduce the complexity and maintenance cost but also increase the efficiency by reducing the process of electricity generation. There are two main categories on electricity generators applied to wind turbines.

Asynchronous generators (induction): they are based in the principle of inductors motors. They require operating a second leading voltage which can be done by connection to an electrical grid. Its advantage relies on a soft connection to the network frequency which benefits the operation between rotor and generator; however, it shows efficiency problems during low wind speeds

Synchronous generators (direct driven): they are based in direct driven mechanism by which the magnetic field of the rotor is produced by permanent magnets. They are more expensive than induction generators with a similar size and they present disadvantage related to restriction to fixed grid frequency so they can just be applied in stand-alone systems sometimes.

Most wind turbine manufacturers use induction (asynchronous) generators, however, large synchronous generators are used most for power generation because of their advantage of allowing voltage control. The challenge seems to be to move to direct-driven generation without the gearbox, mostly based on permanent magnet generator (PMG).

Speed control System. There are three main factors affecting the power control of wind turbines: wind power availability, power curve of the machine, ability of machine to respond to wind fluctuations. Most wind turbine operates with fixed rotational speeds where maximum performance is available at just one particular speed. If turbine speed can be adjusted more power can be generated.

Variable speed allows matching wind speed and rotor speed to increase the efficiency below and above rated power. Thus, variable speed is attractive but it is more expensive and still not very reliable. Power can be regulated by to technologies: stall or pitching control.

Stall regulated means that speed is regulated by the aerodynamic design of the rotor, in particular, the blades design with no moving parts. It includes devices such as stall strips, vortex generators, fences and gurney flaps. The connection of the speed generator to the grid keeps the speed of the turbine nearly constant. Following the simplification trend, stall regulation is the most recognized innovation of the sector, allows good performance under high wind without producing exceeding power or changes rotor geometry, however, they cannot resist certain wind speed.

Pitch regulation means turning the blades about their axis so it can operate in wider range of wind but are more complex and cost. Automatic controls are essential for the efficient and reliable implementation of wind power system. Most wind turbines (specially the largest wind turbines) are operated at constant speed by pitch control and active turbine control are becoming a standard. The system requires the use of multiples techniques and complementary technologies such as wind simulator and modeling software. Pitch control is the most applied at the moment.

Future developments look for combining both technologies to allow increase efficiency in bigger wind turbines (i.e. offshore) but also in term of adaptation to different wind conditions.

Part C. The economics of wind energy

The **economics of wind energy** is directly related to the capacity installed and, as any other economic activity. According to (Blanco, 2009) the cost can be differentiated in capital cost and variable cost. Additionally, other main parameters in the economics of wind energy may in include Electricity production/average wind speed, turbine lifetime and discount rate (EWEA, 2009). As the wind energy does not need any kind of fuel to operate most of the cost are related to investment/ capital cost and therefore, financial cost, while the mayor variable cost is the operation and maintenance.

The turbine represent then the mayor cost followed by the connection to the grid, for example, in Europe the average investment cost for a 2MW turbine by 2006 was around €1,23 million/mw where the turbine represents the 76% of the total (see table 8).

Table 14 cost structure of a typical 2 MW wind turbine installed in Europe (2006-€)

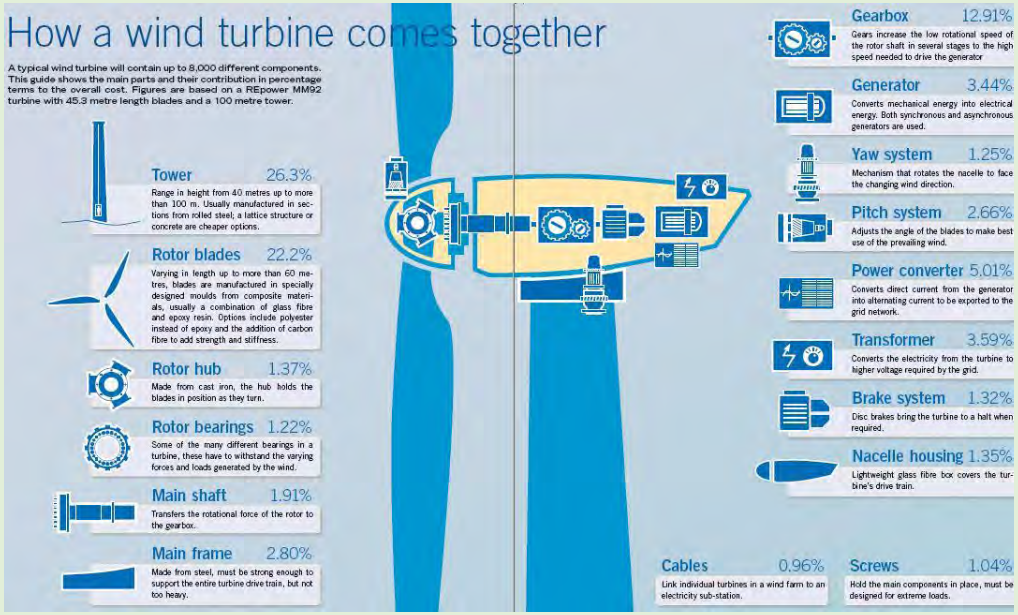
Type of cost	
Capital cost	Variable Cost
The turbine (including components, transport and installation)	Operation and maintenance
The grid connection (cables and additional infrastructure)	land and sub-station rental
Civil works and construction (including foundations, roads and buildings)	insurance and taxes
Other capital cost (including, engineering, permits and consultancy)	management and administration (including audits, forecasting and remote control)

Component	Investment (€1000/MW)	Share (%)
Turbine	928	75.6
Foundations	80	6.5
Electric installation	18	1.5
Grid connection	109	8.9
Control systems	4	0.3
Consultancy	15	1.2
Land	48	3.9
Financial costs	15	1.2
Road	11	0.9
Total	1227	100

Source: (*EWEA*, 2009)

Cost benefit criteria (i.e. increasing size) and simplification (cost efficiency) are the main dimensions of success in the design approach. Materials seem to be a key transversal issue, however, that may not allow economies of scope in terms of the possibilities in several components as blades, tower and nacelle because of the highly fragmented structure of the sector (see figure 2). According to data of EWEA, after two decades of stable reductions the capital cost start to increase in 2009 in European projects but with different performance in China, US and America by considering the diverse impact of financial cost, connection to the grid and civil works (Blanco, 2009)

Figure 55 Share of main components to the overall cost in a 5MW wind turbine



Source: (EWEA, 2007)

Regarding cost of **maintenance and operation**, they are calculated as a size relation of the total annual costs of a WT which can reach 10%-15% when the WT is new and then increasing to at least 20%-35% by the end of its life. For example, the report of EWEA (2009) identify the different categories of operation and maintenance cost for German turbines (average for 1997-2001) where the share of cost is distributed as follow: Services and parts (26%), Administration (21%), land rent (18%), Insurance (13%), Power form the grid 5%) and Miscellaneous (17%). The cost presented may not represent the new models of wind turbines arising in recent years. However, according to (Blanco, 2009) the tendency on manufacturing has been driven to designs which require less maintenance and increase productivity as the wind turbines got economies of scales in term of the declining investment per KW, similar economies of scale in O&M cost but reduced than older and smaller turbines.

8.2 Annex 2: Overview of Spanish Economy and key patterns on regional performance

Since Spain joined the EU, the economy has been significantly influenced by the exploration of new markets and significant flows of foreign direct investment (Chislett, 2002; Neal & Garcia-Iglesias, 2004; C. Powell, 2003). Since 2000 the Spanish economy has experience a continuous and significant growth until the staring of economic crisis in 2008. In 2009, the economy has got a significant decrease of 14%. The effects in the size and structure of the economy has been unequal with respect to sectors and the regional dimension. In fact, during the period 2000-2008, the GDP has growth 73% while the Industry around a half, 37% (see Fig. 56). Regarding the economy structure, the service sector was the mayor contributor to the GDP by 2008 (69%) following so far by Industry (14%) and Construction (11%), see Fig. 57.

Figure 56 GDP and Industry Billons of EU Spain

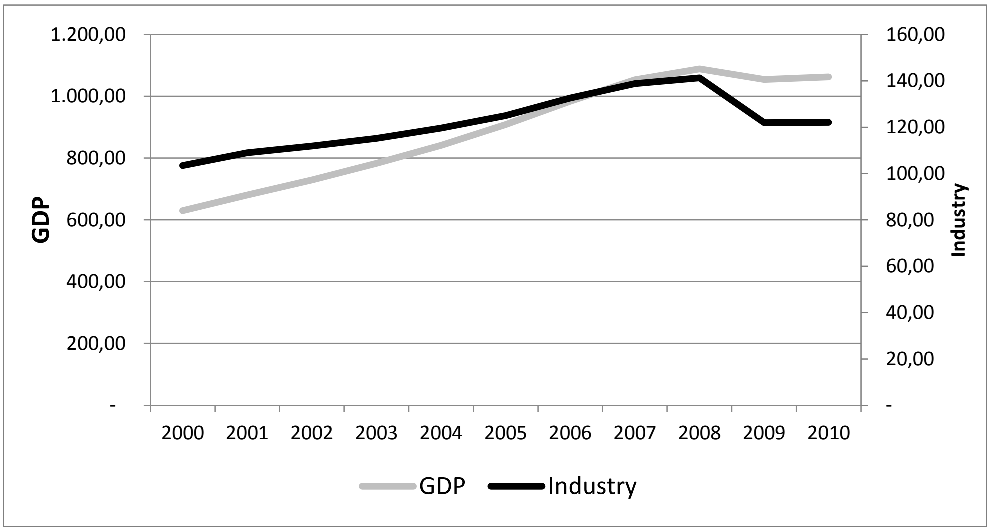
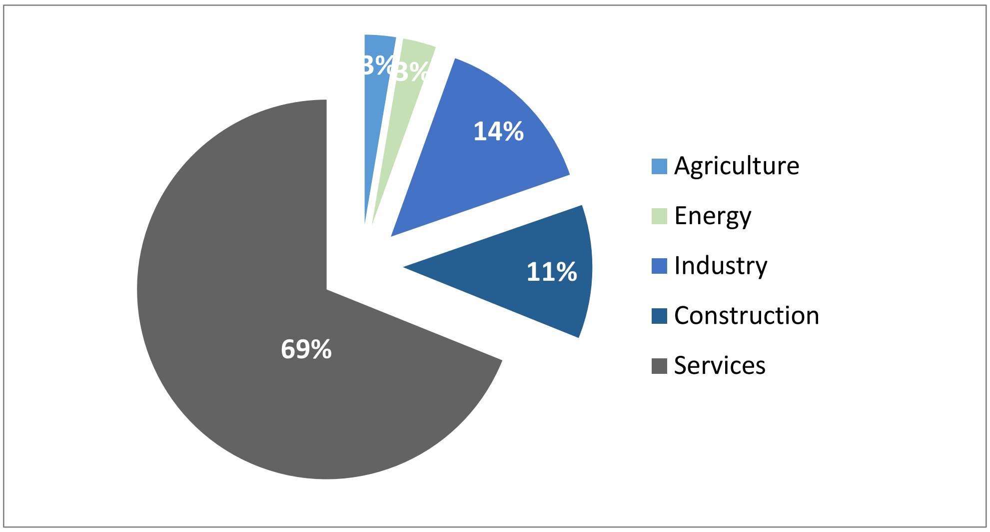


Figure 57 Economy structure - Spain 2008



Source: own elaboration based in (INE, 2014)

Regarding size, the mayor regionals economies are Cataluña, Madrid and Andalucía with represents around 50% of GDP. They are followed by middle size economies as Valencia region, Basque country, Castilla and Leon and Galicia. These 7 out 17 regions holds around 80% of Spanish GDP and their size and evolution has been historically stable (see Fig. 58). However, the regions with mayor industrial activities are Cataluña (25%), Madrid (13%), Valencia region (11%) and Basque Country (11%) while Andalucía presents relatively bigger shares in Construction and Agriculture (Fig. 59).

Figure 58 Evolution of Spanish regions economic activity 2000-2010

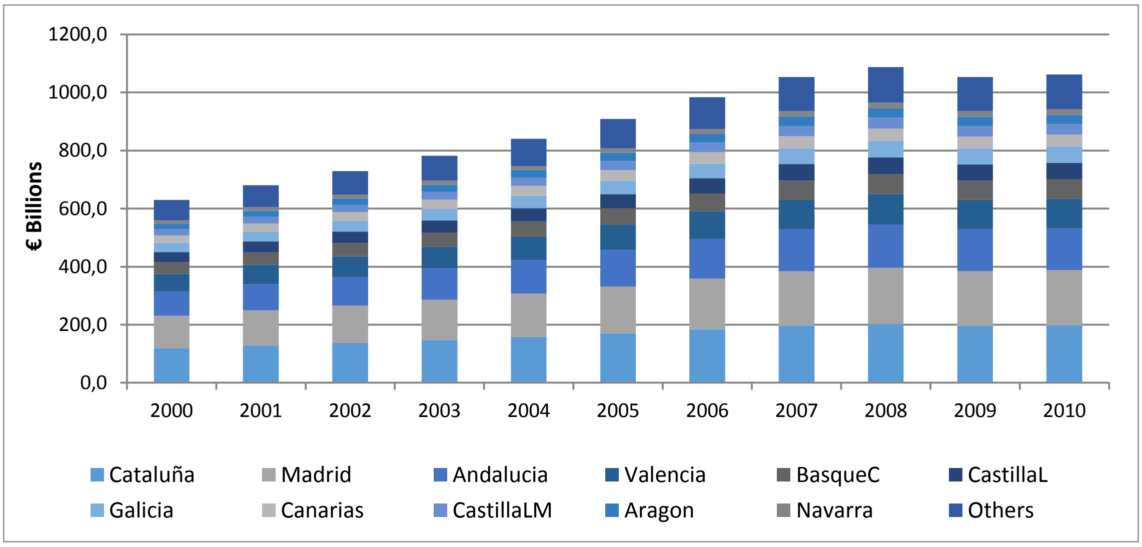
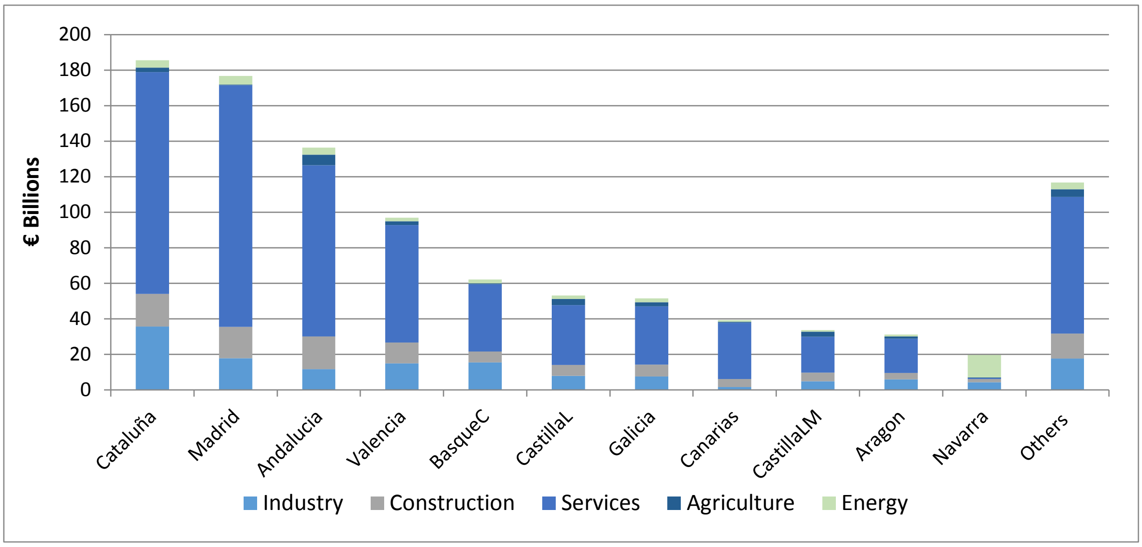


Figure 59 Economic structure of Spanish regions 2008



Source: own elaboration based in (INE, 2014)

Regarding the industrial structure, regions with mayor industrial activities are Cataluña, Madrid, Valencia region and Basque Country where Metallurgy, Machinery and Electric-Electronics-Optical are identified as main subsectors (Fig 60). The performance of Metallurgy, Machinery and Electric-Electronics-Optical subsectors at external markets follows similar regional characteristics than the mentioned for both size and the pattern of specialization. Metallurgy (CNAE 24) and Machinery (CNAE 25) – the main subsectors - are dominated by Basque country, Cataluña and Andalucía . However, there is a particular pattern of historical specialization among northern regions in these activities which got high regional GPD specialization index in those sectors, in particular Navarra and Aragon (see Table 15)59.

[59] Balassa specialization index: EI = (Pij / Pit) / (Pnj / Pnt) where P: GDP by sector, i: regional index, n: set of regions, j: industrial sector index and t: set of industrial sectors.

Figure 60 Industrial structure of Spanish regions 2008

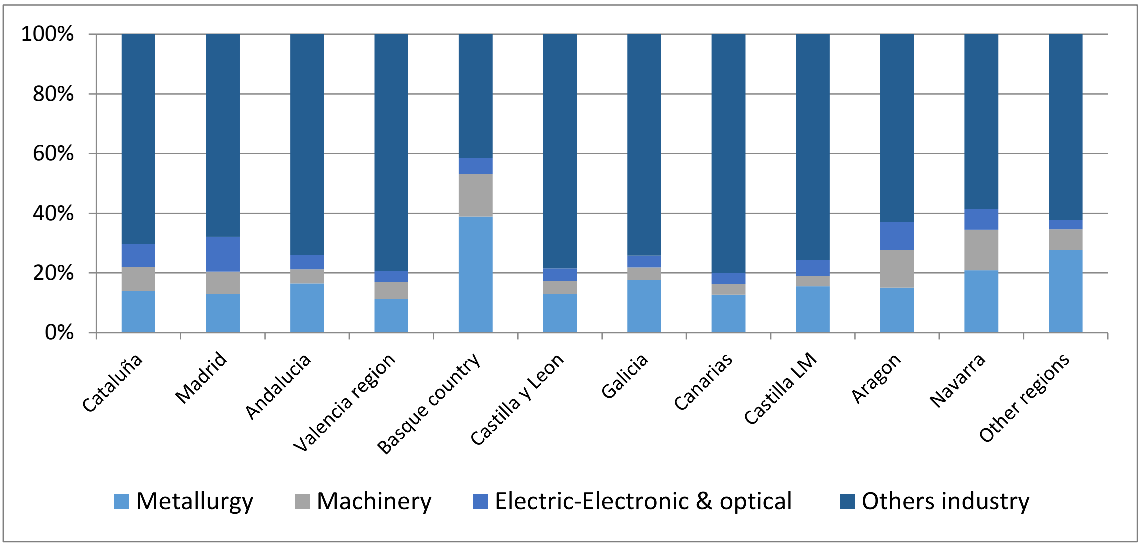


Table 15 Regional GPD specialization index. Spain 2008

Region	Industry	Metallurgy	Machinery	Electrical, electronic & optical equipment
Navarra	1,82	1,14	1,75	1,08
BasqueC	1,76	2,14	1,83	0,84
Rioja	1,62	0,77	0,81	0,49
Cataluña	1,35	0,76	1,05	1,21
Aragon	1,34	0,83	1,62	1,46
Cantabria	1,25	1,90	1,03	1,20
Asturias	1,19	2,75	0,77	0,35
Valencia	1,09	0,62	0,73	0,58
CastillaL	1,06	0,71	0,55	0,67
Galicia	1,04	0,96	0,55	0,62
CastillaLM	1,02	0,85	0,46	0,82
Murcia	0,91	0,74	0,98	0,35
Madrid	0,71	0,71	0,96	1,84
Andalucia	0,60	0,91	0,61	0,75
Extremadura	0,46	1,01	0,97	0,35
Baleares	0,35	0,85	0,61	0,25
Canarias	0,30	0,70	0,45	0,58

Source: own elaboration based in (INE, 2014)

The performance of Metallurgy, Machinery and Electric-Electronics-Optical subsectors at external markets follows similar regional characteristics than the mentioned for both size and the pattern of specialization. Metallurgy (CNAE 24) and Machinery (CNAE 25) – the main subsectors - are dominated by Basque country, Cataluña and Andalucía . In the other hand, the sector with strongest linkages with renewables energy, manufacturing of electrical material and equipment (CNAE 27), is not significant in the general amount by comparing with the main ones. This sector follows the same positioning among leading regions, however, the data disaggregated at 3-digit for the category Manufacturing of electric motors and generators (CNAE 271), revels a different performance at general level and among regions (see Fig 62).

Figure 61 Total cumulative regional exports of CNAE 24, 25 and 26-32. Spain 1997- 2012

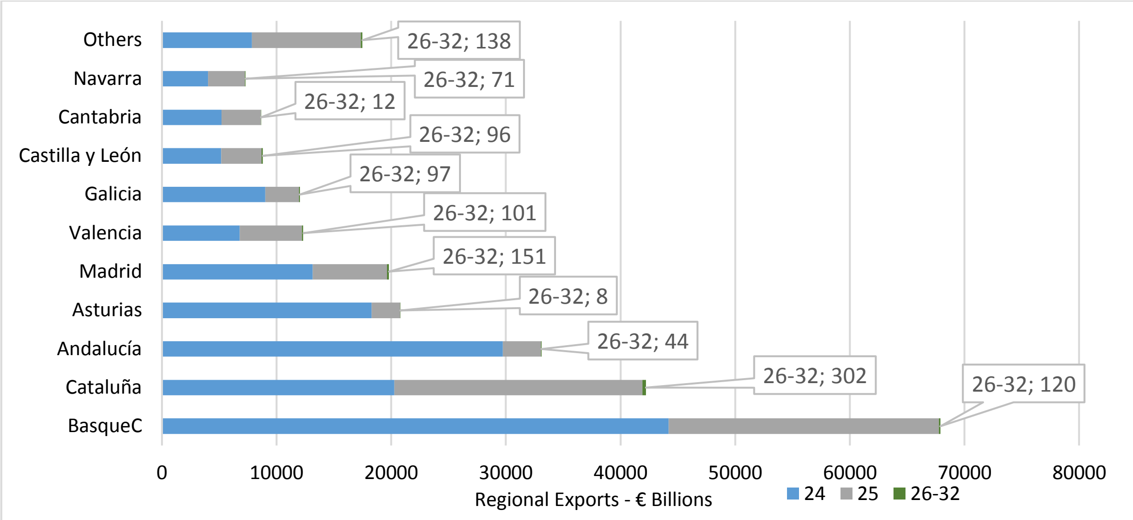
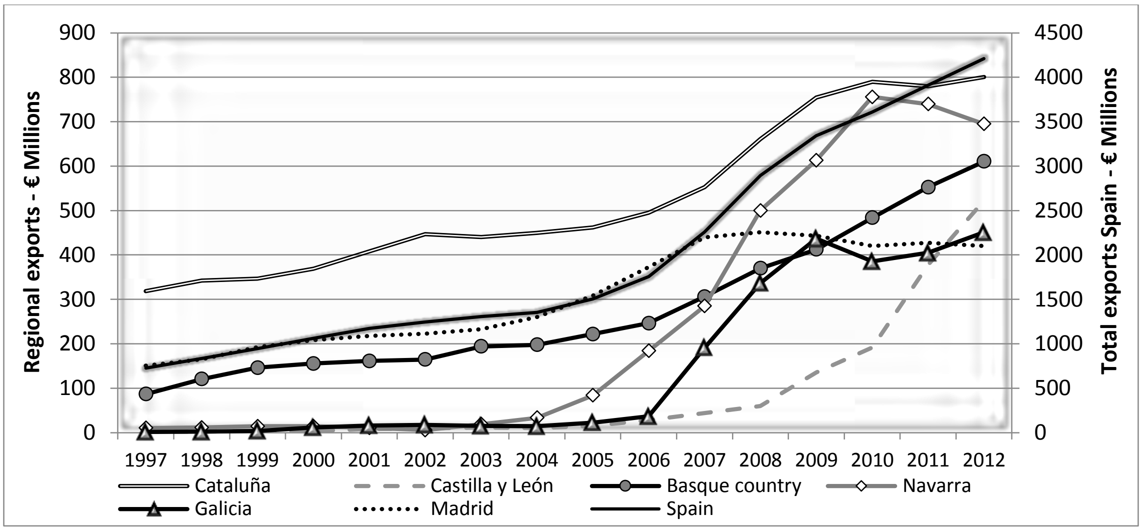


Figure 62 Evolution of regional exports of CNAE 271. Spain 1997- 2012



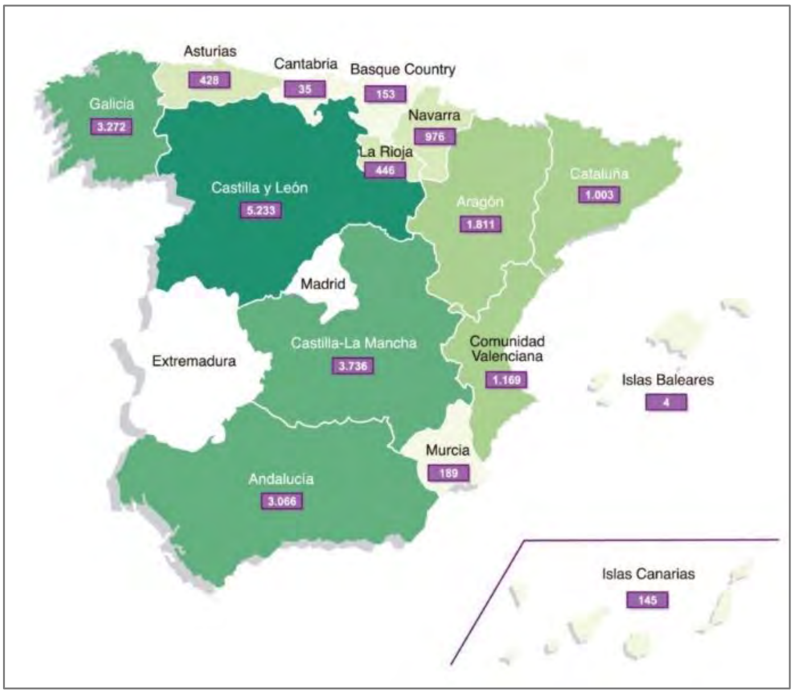
Source: own elaboration based in (DATACOMEX, 2013)

The exports of CNAE 271 shows a growth rate over the average (250%) for the period 2000-2013 leading by Cataluña, Basque Country and Madrid, however, Galicia, Castilla y Leon and Navarra shows outstanding growth rates and uptakes significant positions. The trajectories of the new comers have change significantly in the period 2004-2010 - a period of strong financial stimulus in the internal market by the feed-in tariff scheme - when Cataluña keeps the leading position; Navarra got the second position, Basque country keeps the third and Galicia and Castilla y Leon get the fourth and fifth place by leaving behind Madrid which use to be in the third position (see chart).

8.3 Annex 3: Wind energy in Spanish regions – Key performance indicators

The wind energy production is based in the availability and quality of the natural resource (i.e. the wind), therefore, the performance in this energy area has clearly linkages with the localization of natural resources that drives the attention toward the management of those resources at regional level. By 2013, around 70% of production of electricity by wind resources in Spain were located in the leading regions: Castilla y Leon, Castilla- La Mancha, Galicia and Andalucía (see Fig. 63). The natural conditions that support these positions can be explained preliminary by two linked indicators: 1) The extension of the area in which the resource is technical available (i.e. rural non populated areas and off shore continental platforms) and 2) The wind speed that can be measured also by density (i.e. meter per second)[60].

Figure 63 Wind power installed capacity (MW). Spanish regions 2011



Source: own elaboration based in (DEE, 2013)

Regarding extension, the biggest regions such as Castilla and Leon, Castilla – La Mancha and Andalucía clearly show the best positions in the list, followed by medium regions as Galicia, Aragon, Extremadura and Cataluña. However, beside the extension of these regions a key

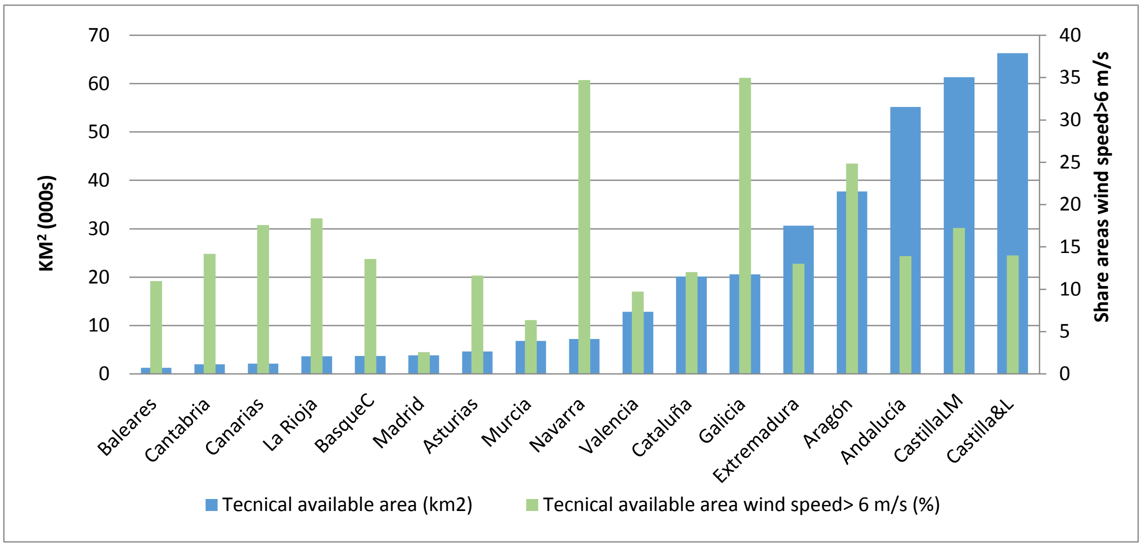
[60] The study of Aeolian Atlas of Spain developed by IDAE (IDAE, 2011) indicated that the threshold for optimal operation is speed>6 meters per second at 8 meters high.

element is they contain the most important Spanish mountain systems (see fig 64 below). For example, Sistema Bético (Andalucía and Castilla La Mancha), Sistema Ibérico (Aragón, Castilla- La Mancha, Castilla y León) Sistema Central (Extremadura, Castilla Y León), Cordillera Cantábrica (Galicia y Castilla y León) y Macizo Galaico (Galicia) and Pirineos (Navarra). Bigger extensions of high lands allow better conditions to capture wind because of both the wind stability (i.e. there is more turbulence in lower highs) and the mayor speed. The Figure 65 shows the technical available area km2 (light blue) for the Spanish regions sorted from lowest to highest. The chart also shows the share of technical available areas with speed>6 m/s in the total technical available area is considered (green), where the ranking of regions regarding wind potential differ significantly. Galicia and Navarra got the first positions with similar share of 35% and Aragon 25% while the big regions get much lower shares: Castilla La Mancha (17%), Castilla y Leon (14%) and Andalucia (14%). This last means that middle size regions got a comparative relative advantage in term of the wind speed quality.

Figure 64 Spanish mountain systems and wind atlas. Wind speed > 6 m/s

NOTE: (1) Sistemas Béticos, (2) Sistema Ibérico, (3) Sistema Central, (4) Cordillera Cantábrica, (5) Macizo Gallego and (6) Pirineos. Source: own elaboration based in (IDAE, 2011; ITE, 2014)

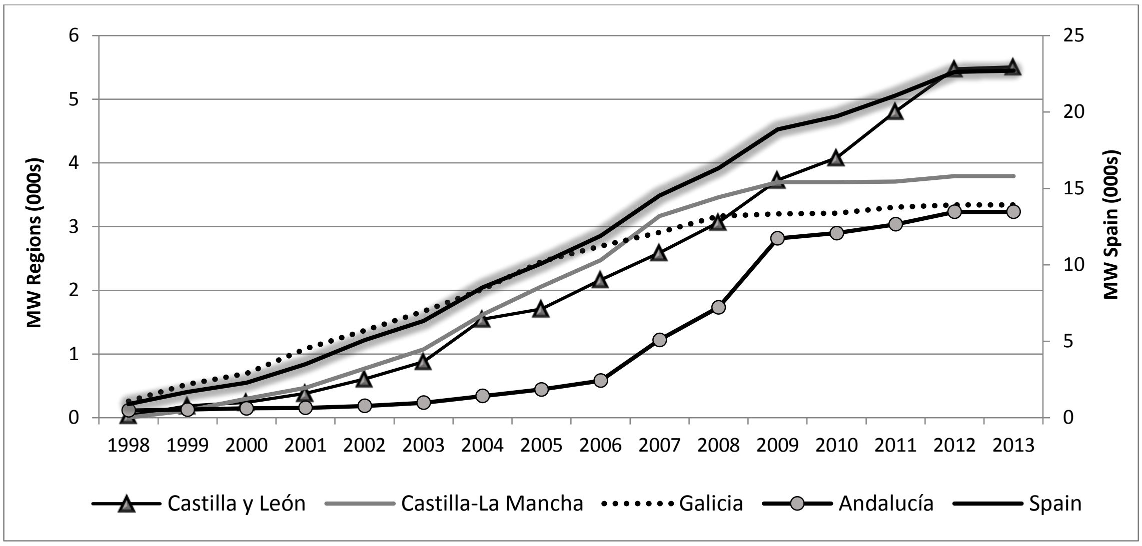
Figure 65 Wind potential in Spanish regions. Technical available areas



Source: own elaboration based in (IDAE, 2011)

These conditions has been one of the pillar of the expansion of the installed capacity over time in the last decade. According to the data from regional energy balances (see figure X), the two biggest regions, Castilla y Leon and Castilla-La Mancha, shows a similar rising trajectory from 2002 to 2009, then the first one kept the same tendency while the second turned to a stationary trajectory. The total growth for the period 2002-2011 was 724% and 404% respectively, both over the total for Spain (324%). In the other hand, Galicia shows a softer tendency given by decreasing interannual growth rates while Andalucía has experienced a big increase (292%) in its capacity in the period 2006-2009 and then follows a more stationary tendency (see figure 66).

Figure 66 Evolution of wind power installed capacity in Spanish regions 1998-2013



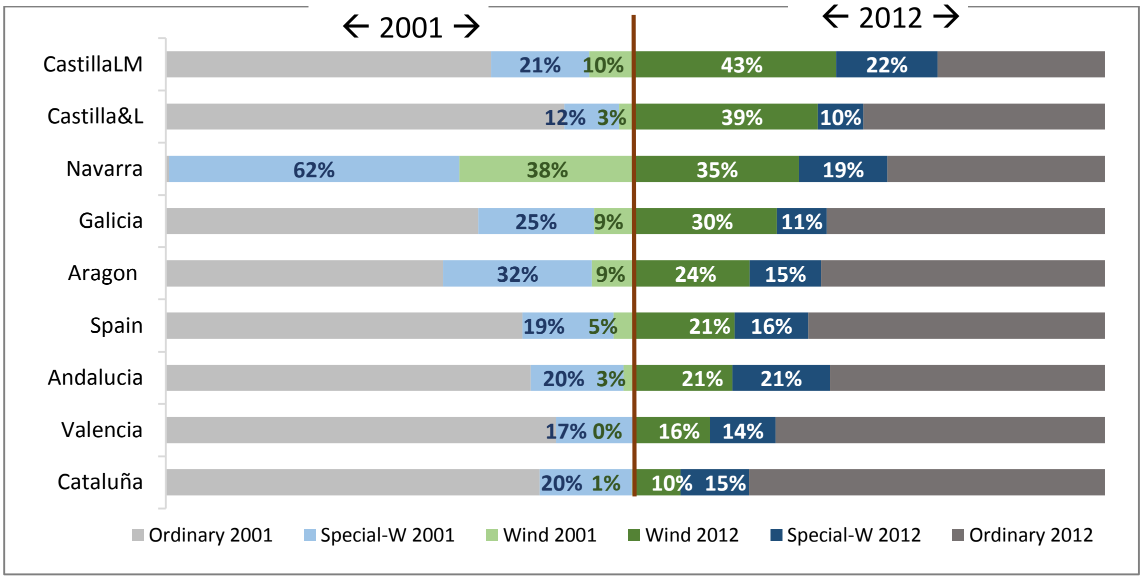
Source: own elaboration based in (DEE, 2013)

On the other hand, regarding medium capacity regions (not shown in the chart), two significant cases can be pointed. First, Valencia region holds with highest grow rate for the whole period given by a big jump (1300%) during the period 2006-2009 while Navarra has kept a small interannual growth rate and a total increase for the whole period of 41%. As a general remark, the period 2004-2009 was characterized by significant increasing growth rates while during the last period the interannual growth rates keeps decreasing. However, in order to understand the evolution in comparative terms with the other energy alternatives, the installed capacity should be analyzes as part of the energy balance of each region. That comparative evolution can be analyzed trough the distribution of energy balance among ordinary and special regime by tracing the share of wind energy production along time.

The energy balance in Spain has changed significantly since the introduction of special regime to foster renewable energy production. Capacity under the normal regime increased 42%, while capacity under the special regime reached 522% leading by wind, cogeneration and solar energy (see Fig 9). More specifically, total wind power capacity rose by 3,820% in the period 1997-2008 based in the increase in the number of infrastructures (i.e. wind farms) or the upgrade of installed capacity (i.e. introduction and replacement of wind turbines). However, by looking at the performance of regional energy balance, two situations can be identified.

First there is tendency to improve the diversity of regional energy set towards an increasing share of technologies under special regime. For example, more than the half of the energy production in Castilla La Mancha, Castilla and Leon and Navarra comes from technologies under the special regime followed by Galicia, Aragon and Andalucía with shares around 40%. However, some trajectories are more particular as Madrid which has kept similar shares among regimes or Navarra which increased the share on technologies belonging to the ordinary regime. Second, it is possible to confirm that the share of wind energy production has increased considerably in all the regions with previews wind energy installed capacity.

Figure 67 Share of ordinary regime, special regime and wind power as part of regional energy balance 2001 &2012



Source: own elaboration based in (DEE, 2013)

Regarding this last point, the changes in the regional energy balance from 2001 to 2012 can be described in term of different trajectories by considering the comparative advantage of wind energy. This comparative advantage has been identified by developing the Balassa index of revealed comparative advantage (RCA)[61] that can reveals comparative advantages in wind energy if this indicator is higher than 1. The main results are: Castilla LM (2,02), Castilla y León (1,84), Navarra (1,65), La Rioja (1,47), Galicia (1,43), Aragón (1,15) and Andalucía (0,98). From this results, four categories may be defined: 1) high advantage in wind power, with high shares in both special regime and wind energy: Castilla-La Mancha, Castilla y Leon and Navarra, 2) medium advantage of wind power: Galicia, La Rioja, Andalucía y Aragon 3) high advantage in special regime but low/non wind power production: Cantabria and Madrid and 4) wind power non significance: the rest of the regions.

Finally, after having analyzed the evolution of installed capacity, the changes in the distribution of regional energy balance and the comparative advantage of wind energy of regions, the second pillar of the wind energy sector should be presented: the specialized industrial capacity. The supply chain in the Spanish wind energy sector (already analyzed in the Industry chapter) has experienced significant changes between 2006 and 2013. The general evolution of industrial centers has revealed a mayor increase in the total amount of industrial sites characterized by a significant increase on maintenance and a decreasing concentration of activities among firms even when there is more consolidated trend on vertical integration.

Regarding geographical distribution of industrial centers, the evolution of supply chain has presented different trajectories among Spanish regions. Three regions concentrated almost 70 % of industrial centers in 2006: Galicia (23%), Navarra (23%), Castilla y Leon (23%), however, while these have been increasing their capacity other regions as Basque country, Madrid and Navarra became more significant. In 2013, Galicia and Castilla y Leon are still the leading regions in term on amount of industrial centers, however, the distribution of most of activities in the supply chain (68%) has become more distributed among more regions. In fact, the number of regions with industrial centers has increase more than twice - from 6 to 14- but also the number of firms owning at least on industrial center has multiplied by almost 10 times while the number of different categories on industrial activities has increased three times in seven years.

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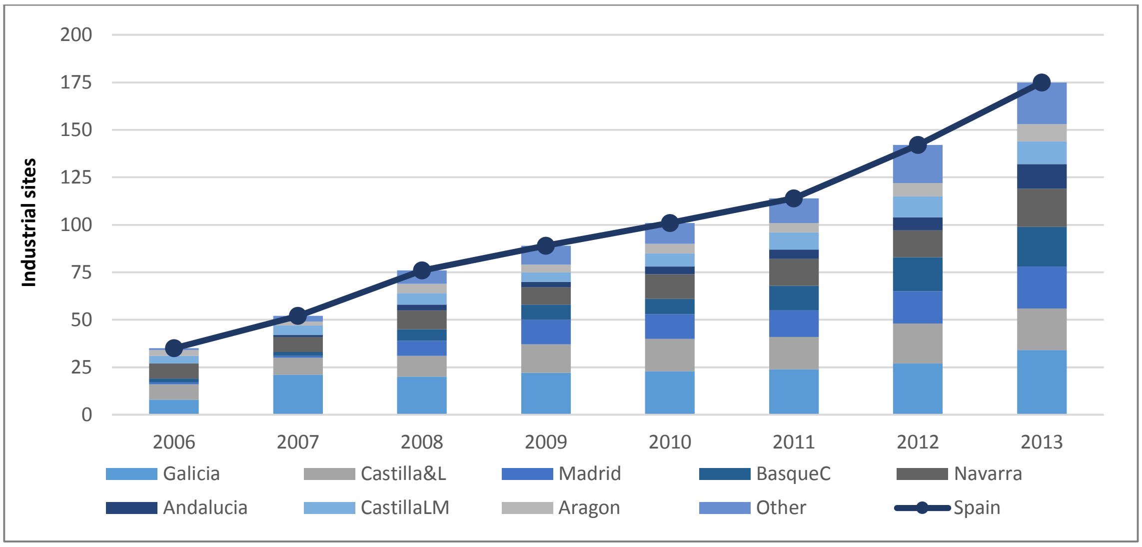
[61] Balassa index of revealed comparative advantage $\boldsymbol{RCA} = {(\boldsymbol{E_{ij}}/\boldsymbol{E_{it}})}\big/{(\boldsymbol{E_{nj}}/\boldsymbol{E_{nt}})}$ where E is the energy produced by different sources, i is the regional index, n is the set of energy sources, j is the source index and t is the complete portfolio of sources at the energy balance

Figure 68 Evolution of total number of industrial sites on wind energy technologies. Main Spanish regions 2006 - 2012



Source: own elaboration based in (AEE, 2013a)

More specifically, even when there is evidence about a significant increase in the number of firms and industrial categories, the final system integrators in the supply chain are the wind turbine manufacturer. As we have explained in the policy chapter, the regional normative may determine different patter of arrangements between wind turbine manufacturer and developers of wind farms.

8.4 Annex 4: Key regional indicators on Science, technology and Innovation

Table 16 R&D expenditures. Total and share of GDP. Spanish regions 2000-2012

CCAA	2000		2005		2010		2012		2000-2012	
	Total	R&D/ GDP	Total	R&D/ GDP	Total	R&D/ GDP	Total	R&D/ GDP	Δ Total	Δ R&D/ GDP
Spain	5719	0,9%	10197	1,1%	14588	1,4%	13392	1,3%	134%	43,4%
Madrid	1752	1,6%	2913	1,8%	3855	2,1%	3434	1,9%	96%	17,7%
Cataluña	1262	1,1%	2302	1,4%	3227	1,7%	2991	1,6%	137%	46,6%
Andalucía	542	0,6%	1051	0,8%	1727	1,2%	1480	1,1%	173%	64,8%
BasqueC	460	1,2%	829	1,5%	1306	2,0%	1431	2,2%	211%	94,3%
Valencia	431	0,7%	868	1,0%	1081	1,1%	1008	1,0%	134%	46,1%
Castilla&L	223	0,6%	437	0,9%	608	1,1%	617	1,1%	177%	77,5%
Galicia	209	0,6%	405	0,9%	532	0,9%	488	0,9%	133%	38,0%
Navarra	95	0,9%	258	1,7%	366	2,0%	347	2,0%	266%	124,7%
Aragón	134	0,7%	221	0,8%	374	1,1%	313	1,0%	133%	40,5%
CastillaLM	119	0,6%	127	0,4%	255	0,7%	231	0,6%	94%	14,5%
Murcia	104	0,7%	170	0,7%	256	0,9%	228	0,9%	119%	25,1%
Canarias	119	0,5%	214	0,6%	255	0,6%	211	0,5%	77%	11,7%
Asturias	115	0,8%	138	0,7%	238	1,1%	196	0,9%	71%	8,2%
Extremadura	57	0,5%	103	0,7%	152	0,9%	128	0,8%	127%	44,6%
Cantabria	36	0,5%	52	0,5%	158	1,2%	126	1,0%	251%	117,1%
Baleares	35	0,2%	62	0,3%	110	0,4%	90	0,3%	158%	60,0%
La Rioja	27	0,6%	44	0,7%	85	1,1%	69	0,9%	153%	56,3%
Ceuta y Melilla	-		3	0,1%	4	0,1%	3	0,1%	81%	-6,1%

Source: INE (2013)

Table 17 Evolution of total researchers in Spanish regions 2000-2012

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Var. 2000-2012
Madrid	1752	1974	1323	2346	2447	2913	3416	3584	3892	3899	3855	3763	3434	96%
Cataluña	1262	1334	1113	1876	2107	2302	2614	2909	3286	3284	3227	3104	2991	137%
Andalucía	542	538	204	903	883	1051	1214	1479	1539	1578	1727	1648	1480	173%
BasqueC	460	561	441	667	778	829	959	1217	1346	1347	1306	1397	1431	211%
Valencia	431	447	178	632	732	868	913	978	1114	1120	1081	1044	1008	134%
Castilla&L	223	296	169	367	423	437	511	621	740	629	608	574	617	177%
Galicia	209	240	113	338	366	405	450	556	584	524	532	526	488	133%
Navarra	95	114	90	178	257	258	317	334	359	388	366	384	347	266%
Aragón	134	140	101	169	180	221	263	297	352	371	374	322	313	133%
CastillaLM	119	72	43	111	117	127	156	214	266	238	255	259	231	94%
Murcia	104	101	35	134	138	170	193	248	244	241	256	234	228	119%
Canarias	119	137	41	168	199	214	255	267	269	239	255	243	211	77%
Asturias	115	99	38	113	116	138	188	212	230	226	238	218	196	71%
Extremadura	57	66	9	81	57	103	117	129	156	155	152	144	128	127%
Cantabria	36	46	20	44	46	52	98	117	141	149	158	142	126	251%
Baleares	35	38	9	46	55	62	71	87	97	100	110	96	90	158%
La Rioja	27	23	17	37	41	44	75	90	81	85	85	82	69	153%
Ceuta y Melilla	-	-	-	2	2	3	5	6	6	6	4	3	3	81%
Spain	5719	6227	3944	8213	8946	10197	11815	13342	14701	14582	14588	14184	13392	134%

Source: INE (2013)

Figure 69 Total R&D institutions by area of knowledge[62]. Selected Spanish regions 2014

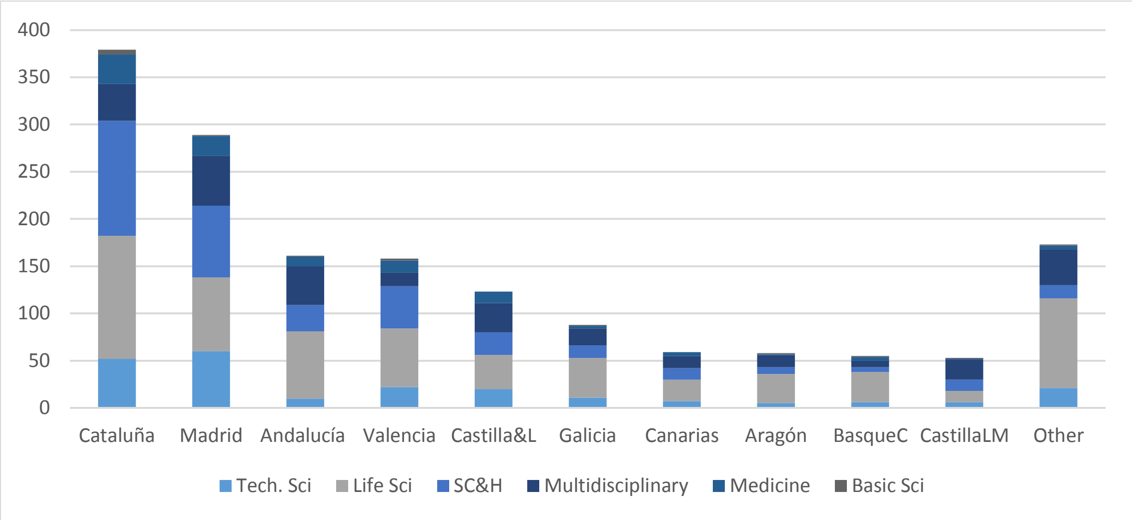
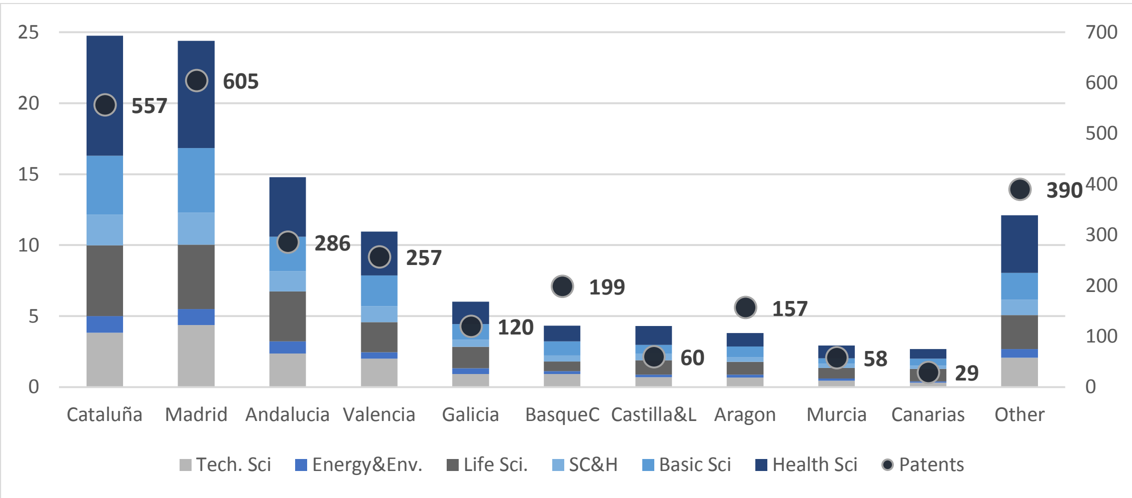


Figure 70 Total publication by area of knowledge and total registered patents. Selected Spanish regions 2011[63]. (000s)



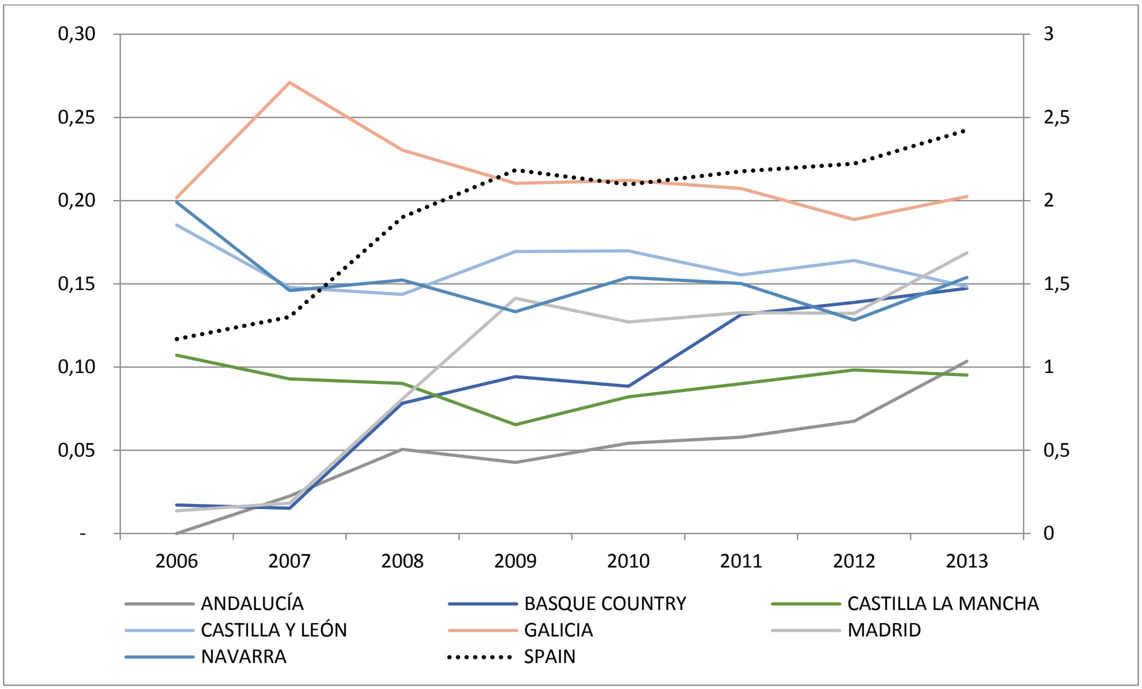
Source: own elaboration based in the following sources Figure 8 (FECYT, 2014) and Figure 9 (SCImago, 2014)

[62] Knowledge areas are defined as follow: 1) Basic Sciences: Physics and Space Sciences, Transport (including Aeronautics), Chemistry, Mathematics; 2) Life Sciences: Plant Biology and Animal Ecology, Earth Science, Food Science and Technology, Agriculture, Fundamental and Systems Biology and Livestock; 3) Medicine: Clinical Medicine and Epidemiology and Biomedical; 4) Social Science & Humanities: Social Science, Philology and Philosophy; Education Science, Law, Economics, History and Arts and Psychology; 5) Technological sciences: Multidisciplinary, Technology Transfer, Computer Science and Information Technology, Materials Science and Technology, Chemical Technology, Civil Engineering and Architecture, Electrical, Electronics and Automation, Engineering, Electronic Technology and Communications and Mechanical, Naval, and Aeronautical Engineering

[63] Knowledge areas are defined as follow: 1) Basic Sciences: Chemistry, Mathematics and Physics and Astronomy; 2) Energy/Env: Energy and Environmental Science 3) Life Science: Agricultural and Biological Sciences, Biochemistry, Genetics and Molecular Biology, Earth and Planetary Sciences and Veterinary 4) Health Sci: Dentistry, Health Professions, Immunology and Microbiology, Medicine, Neuroscience, Nursing, Pharmacology, Toxicology and Pharmaceutics, Psychology; 5) Social Sciences and Humanities (SC&H): General; Business, Management and Accounting; Decision Sciences; Economics, Econometrics and Finance, Arts and Humanities and Social Sciences; and 6) Technological Sciences: Chemical Engineering, Computer Science, Engineering and Materials Science

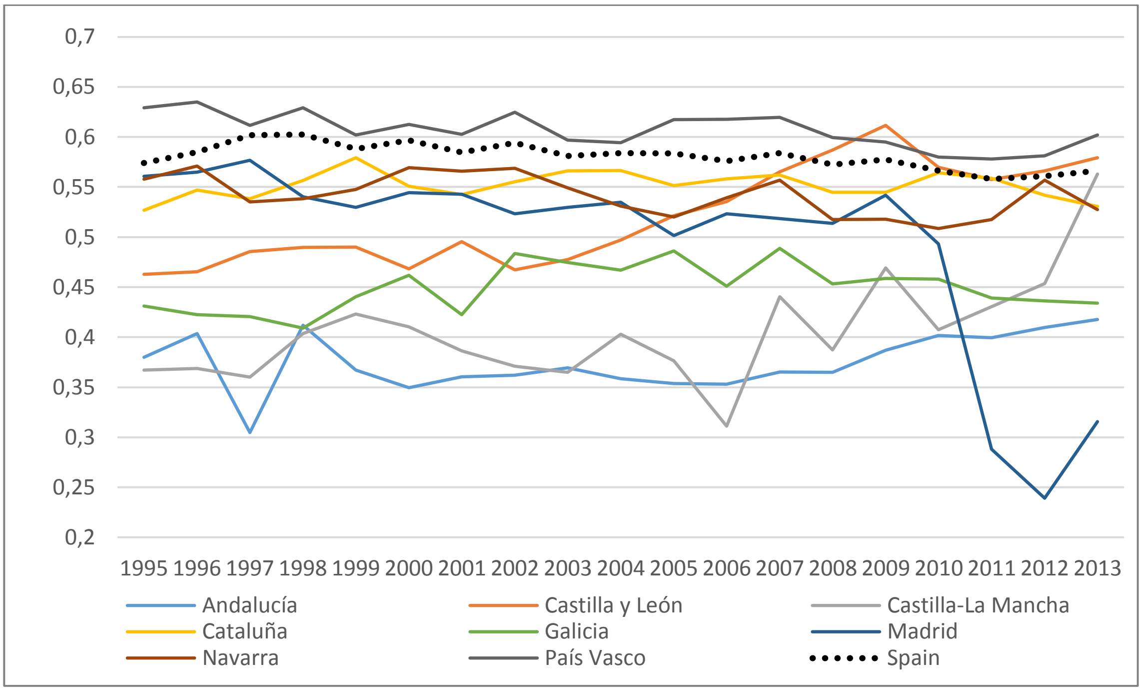
8.5 Annex 5: longitudinal results of specialization and related variety indexes

Figure 71 Evolution of index on variety of industrial activities – Spanish regions 2006-2013



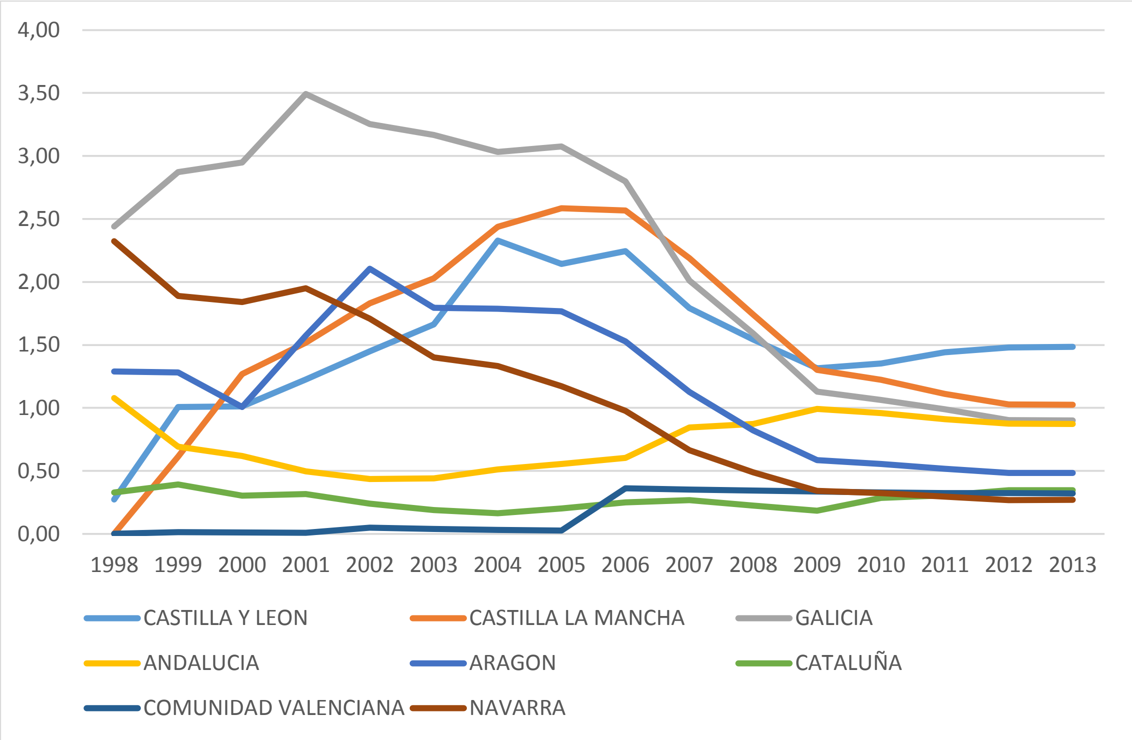
Source: own elaboration based in data of AEE(AEE, 2013a)

Figure 72 Evolution of Index on related variety of exports – Spanish regions 1995 - 2013



Source: own elaboration based in data of (DATACOMEX, 2013)

Figure 73 Index of wind specialization (Balassa) – Spanish regions 1998-2013



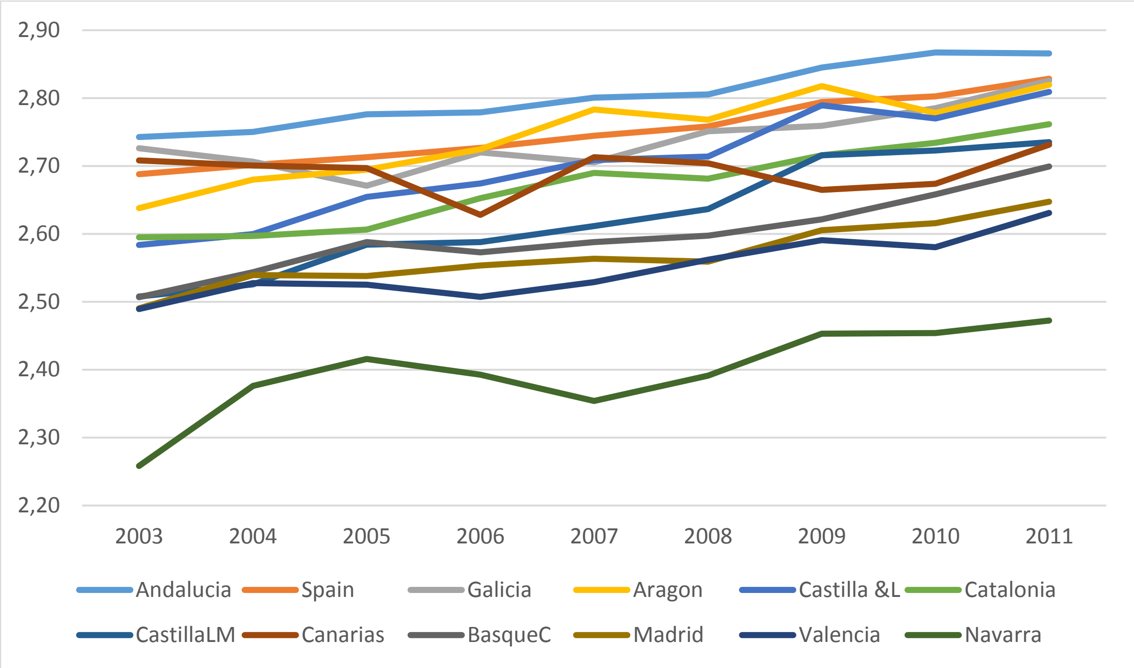
Source: own elaboration based in data of(DEE, 2013)

Table 18 Index on variety of Energy Balance – Spanish regions 2001 &2012

CCAA	EBH_2001	EBH_2012	Variation
CastillaLM	1,87	1,83	-2%
Cataluña	1,65	1,82	11%
Andalucia	1,65	1,76	7%
Aragon	1,66	1,76	6%
Valencia	1,44	1,64	13%
Galicia	1,72	1,62	-6%
Castilla&L	1,37	1,49	8%
Asturias	0,90	1,41	56%
Navarra	1,19	1,38	17%
Baleares	0,82	1,30	58%
Extremadura	0,74	1,26	72%
Madrid	1,49	1,20	-20%
Cantabria	1,13	1,15	2%
La Rioja	1,36	1,14	-17%
BasqueC	1,44	1,10	-24%
Canarias	0,62	1,01	62%
Murcia	0,43	0,91	115%

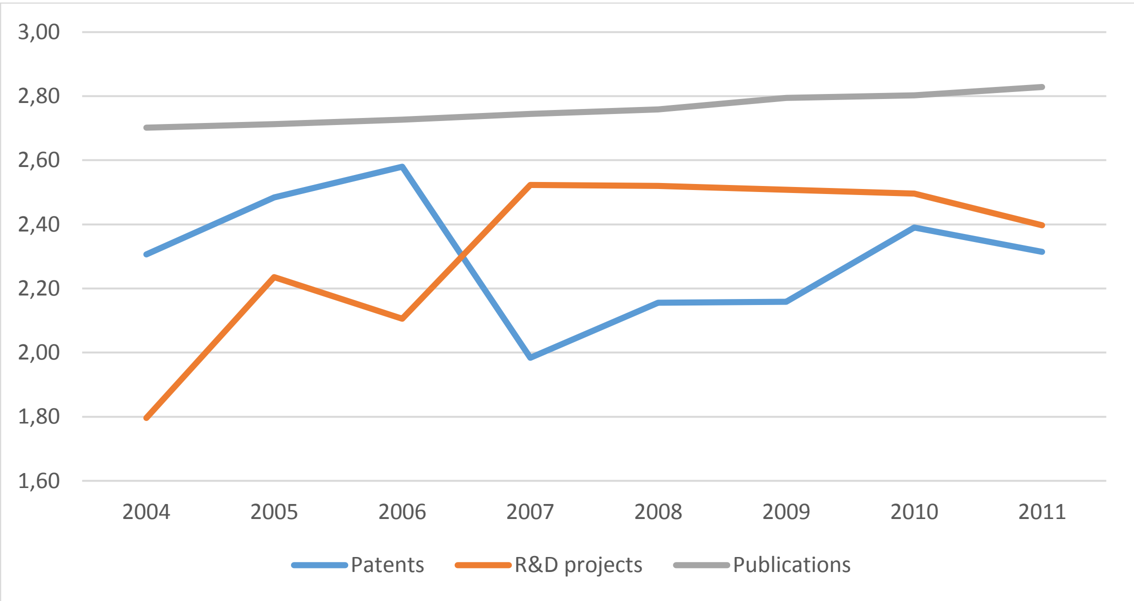
Source: own elaboration based in data of(DEE, 2013)

Figure 74 Index on variety of publications according to knowledge areas – Spanish regions 2003-2011



Source: own elaboration based in data of (SCImago, 2014)

Figure 75 Index on variety of R&D projects according to UNESCO nomenclature – Spanish regions 2004-2011



Source: own elaboration based in data of (CDTI, 2013; CORDIS, 2013; MINECO, 2013)

Tabla 1 Index on variety of total R&D projects according to UNESCO nomenclature and total patents on RES-E sector – Spanish regions

	Proy_R&D	EPO
Andalucia	1,94	2,29
Aragon	2,28	2,23
Asturias	2,03	1,59
Baleares		1,42
BasqueC	2,62	3,56
Canarias	1,91	1,26
Cantabria	1,69	2,31
Castilla&L	2,11	1,31
CastillaLM	1,49	1,64
Cataluña	2,33	2,82
Extremadura		0,56
Galicia	2,02	2,39
La Rioja	0,69	0,99
Madrid	2,62	3,04
Murcia	1,10	2,21
Navarra	1,75	1,96
Valencia	2,19	2,42

Source: own elaboration based in data of (CDTI, 2013; CORDIS, 2013; EPO, 2014; MINECO, 2013)

8.6 Annex 6: List of documents and sources for policy and content analysis

Table 1 .Policy documents and other resources for content analysis

Global International level	European Union			
	EU directives	Other		
Brundtland Report (1986)	96/92/CE	EU White paper		
Rio Earth Summit UN (1992)	EU 18/12/97	EU Res. 18/12/97		
UNFCC Kyoto Protocol (1997-99)	DE 2001/77/CE	EU Green paper 2000		
Union National Environmental Program (UNEP)	2003/87/CE	Lisbon Strategy 2000		
	DE 2009/28/CE			
Spain National Level				
National Strategic Plans	Research Plans	Support Mechanisms		
1991/2000 National Energy Plan	National R+D+I 2004-2007	Ley 82/821980	RD 436/2004	
2000/2010 Plan for the Promotion of Energy	National R+D+I 2000-2003	RD 1217/1981	RD 661/2007	
2002 Infrastructure Plan	National R+D+I 1996-1999	Ley 40/94 LOSEN	RD 1558/2008	
2005 National Reform Plan	National R+D+I 1992-1995	RD 2366/1994	RDL 6/2009	
2005/2010 Energy Renewable Plan	National R+D+I 1988-1991	RD 615-1998	RD 1614/2010	
2005-07 & 2008-12 Action plans	PIE Energy Research Plan	Ley 54/97		
2011/2020 Energy Renewable Plan	R&D ESTELA Plan	RD 2818/1998		

Additional information sources
Yearbook Wind Energy Association (2003-2011)
OECD Reviews of Regional Innovation, Regional and Innovation Policy
Spanish Energy Regulator's Annual Report to the European Commission (2006-2010)
Annual report on energy purchases under the special, CNE (1999-2005)
Report on electrical energy demand in the Iberian Peninsula, CNE (2001-2011)
Report on the supply of electric power in the Iberian Peninsula (1999-2011)
Yearbook of activities of the Ministry of Science and Innovation (1996-2009)
Yearbook of activities Center for Industrial Technology Development(1978-2009)

Source: own elaboration

8.7 Annex 7: Tables on EU Policy – Chapter 3

Table 19 Performance of EU/OECD countries in the introduction of renewable[64]

Renewable energy																				
Country	1974-1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
Total	60	10	17	10	34	30	37	35	26	42	47	38	76	68	68	53	36	21	15	723
US	13	1	1		2		2	6		4	8	4	11	17	7	2				78
Australia	1		1	2	2	5	1	2	2	9	1	3	3	8	9	3	2	1		55
Germany	8	1	1	1	4	2	1	2		1	2	2	1	3	4	2	2	4		41
Canada	2	1	2	1	4		4	2	5		1	1	7	3	2					35
France	2	1			6	3	3	2	1		1	2	4	2	4	2	2			35
UK						3		7	3	4	1	3	2	4	4	2	2			35
Spain	4		1			1		1		1	1		4	2	4	3	6	3	1	32
Denmark	5		1	3	2	1	3			2				1	4	1	1	2		26
Japan	4	1	4	1		1				2			2	2	2	2	1	1	1	24
EU Dir.			1				2		1	1	2	2	6	2	1					18
Other EU	21	5	5	2	14	14	21	13	14	18	30	21	36	24	27	36	20	10	13	344
Wind energy																				
Country	1974-1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	
Total	9	2	5	0	1	3	3	3	2	5	5	3	9	9	14	3	4	3	4	87
Spain	2		1			1		1		1	1		1		2	1	1	1	1	14
UK						1		1				1	1	1	3	1				9
Luxembourg	2	1					1				1	1		1					1	8
Canada	1		1		1								2		1					6
Germany	1	1	1			1								1	1					6
Hungary							1			1			1	1	1					5
Italy										1				2			1	1		5
US	1						1						1		2					5
Other	2		2					1	2	2	3	1	3	3	4	1	2	1	2	29

Source: own elaboration based in IEA (2013)

[64] The data include policies, measures and various instruments. Updates are indicated as new events allowing more detailed tracking of policy performance. Spain's ranking is based on its main policy introductions, and is maintained if updates are included.

Table 20 Taxonomy of demand side policy and instruments by OECD

Policy type	Detail
Public procurement	Different types: - Buy ready-made products for which no R&D is required - Innovation-oriented procurement- Purchasing not-yet-existing product - Pre-commercial public procurement of R&D (PCP): no guarantee the public sector will buy the good or service) - Catalytic procurement. State buys to support private purchases in the decision to buy. Ice-breakers. Applied in energy efficient technologies
Innovation-oriented regulations and standards	Standards setting for technical specifications (e.g. energy efficiency-eco-labelling)
Regulations	Rules to influence behaviours (e.g. renewables policy based on tariff scheme and quotas for Germany and California)
Standards	Rules, practices, metrics or conventions used in technology trade and society (e.g. ICT-Internet and biometrics in the UK)
Lead markets	Aimed at diffusing innovation from one market to another (e.g. GMS telephone Europe, Combined supply-demand side policy for green innovation in Japan, EU LM initiative: eHealth, protective textiles, sustainable construction, recycling, bio-based products and renewable energies)
Consumer policies	Education and awareness (e.g. Generic and specific consumer skills UK)

Source: based on (OECD, 2011a)

8.8 Annex 8: output cluster analysis

8.8.1 Dendrogram Figure 53

Resumen del procesamiento de los casos[a]

Casos					
Válidos		Perdidos		Total	
N	Porcentaje	N	Porcentaje	N	Porcentaje
17	100,0	0	,0	17	100,0

Vinculación promedio (Inter-grupos)

Historial de conglomeración

	Conglomerado que se combina			Etapa en la que el conglomerado aparece por primera vez	
Etapa	Conglomerado 1	Conglomerado 2	Coeficientes	Conglomerado 1	Conglomerado 2
1	4	11	,033	0	0
2	2	10	,091	0	0
3	5	14	,157	0	0
4	2	17	,388	2	0
5	6	7	,409	0	0
6	8	16	,593	0	0
7	1	2	,774	0	4
8	13	15	1,179	0	0
9	8	12	1,466	6	0
10	3	6	1,476	0	5
11	1	9	2,087	7	0
12	5	8	3,429	3	9
13	4	13	3,986	1	8
14	1	5	5,278	11	12
15	1	3	6,203	14	10
16	1	4	15,624	15	13

8.8.2 Dendrogram Figure 54

Resumen del procesamiento de los casos[a]

Casos					
Válidos		Perdidos		Total	
N	Porcentaje	N	Porcentaje	N	Porcentaje
17	100,0	0	,0	17	100,0

Vinculación promedio (Inter-grupos)

Historial de conglomeración

Etapa	Conglomerado que se combina		Coeficientes	Etapa en la que el conglomerado aparece por primera vez	
	Conglomerado 1	Conglomerado 2		Conglomerado 1	Conglomerado 2
1	2	10	,150	0	0
2	8	16	,599	0	0
3	6	7	,724	0	0
4	2	17	,734	1	0
5	1	9	,914	0	0
6	4	11	1,015	0	0
7	3	6	1,571	0	3
8	4	13	2,257	6	0
9	1	2	2,454	5	4
10	8	12	2,519	2	0
11	3	15	3,591	7	0
12	1	8	4,314	9	10
13	1	5	7,103	12	0
14	1	3	8,624	13	11
15	1	14	10,469	14	0
16	1	4	20,183	15	8