A comparative analysis of renewable energy policy in Spain and the United Kingdom – a focus on innovation outcomes

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Abstract

The 2020, 2030 and 2050 EU Energy Strategies propose targets for renewables, energy efficiency, and greenhouse gas emissions reductions. However, these documents do not specify how those targets should be met at a national level. In this paper, we characterize the national-level policies supporting renewable energy technologies in Spain and the United Kingdom between 1990 and 2016 and assess the different outcomes associated with such policies. In order to analyse and characterize the policy approaches used by both countries, we implement a typology of policy instruments that can play a role in a transition to a low-carbon economy developed as part of the H2020 INNOPATHS project. We find that while the U.K. government relied on a wide range of policy tools, including auctions, tradable green certificates (TGC), feed-in tariffs (FITs) and various new energy R&D funding institutions and mechanisms among others, the Spanish government relied almost entirely on production-based subsidy instruments. We characterise the UK approach to energy innovation policy as 'holistic and experimental' and the Spanish approach as 'deployment-focussed'. To analyse the outcomes in renewable energy in both countries, we use an indicator-based methodology that considers technology, environmental, competitiveness, and socio-economic issues, with a particular focus on technology innovation outcomes. We find that, the combination of differences in the policies used, associated to the different geographic and industrial contexts in both countries, have contributed to different outcomes in terms of installed capacity, mix generation and patent portfolio among others. Overall, our analysis suggests that learning from history in combination with an experimental approach to policy could shape the rate and direction of both, the development and diffusion of energy technologies to better deliver societal goals.

Keywords: Renewable energy; support systems; innovation.

1. INTRODUCTION

Catalysing a transition to an electricity sector with a greater reliance on renewable technologies in the European Union has become an important policy goal for environmental, security, and competitiveness reasons. In particular,

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ensuring that the EU becomes a fertile ground for technology innovation in energy industries and is able to capture a large share of a vast and expanding global market is seen as a paramount goal by policy makers and the public.

Addressing environmental goals related to climate change has become an important policy driver since the United Nations Framework Convention on Climate Change was launched in 1992. The European Union has been active in nudging and requiring Member States to take action. The EU has put in place binding legislation in the form of the '2020 Package' (EC, 2010), which consists of three key targets to meet by 2020: a 20% cut in greenhouse gas emissions, 20% of energy across all sectors from renewables, and at least 20% of energy savings when compared to 1990 levels. While some of the 2020 targets have already been reached (for example, in 2015, the EU greenhouse gas emissions were 22% below the 1990 level), the EU has proposed additional goals, this time to 2030: at least 40% cuts in greenhouse gas emissions (from 1990 levels), a 27% share for renewable energy (which is still under discussion), and an indicative energy savings target of 27% (EC, 2016). And very recently, in January 2018, the European Parliament approved by a large majority a more ambitious (although not yet binding) target to have 35% of final energy consumption in the EU in 2030 from renewable energy sources.

It is generally believed, however, that these 2030 goals will be harder to meet and there is widespread agreement that additional policies are needed to meet and exceed these 2030 goals (EC, 2016). Within the European Union, Member States differ in terms of their targets and/or of their policies to promote renewable energy. In this analysis, we compare Spain and the United Kingdom. As we will discuss in the article, the two countries differ in terms of their targets for renewable energy and 'renewable electricity': while Spain's government targets are aligned with those mandated by the EC, the UK government targets are generally lower.[1]

A second driver to decarbonize EU electricity and transportation systems is the perceived benefits of reducing energy dependence. According to Eurostat, in 2016 the European Union (EU-28) had an energy dependence of 53.6%. This average value masks very significant differences among countries: *e.g.,* Spain's energy dependence

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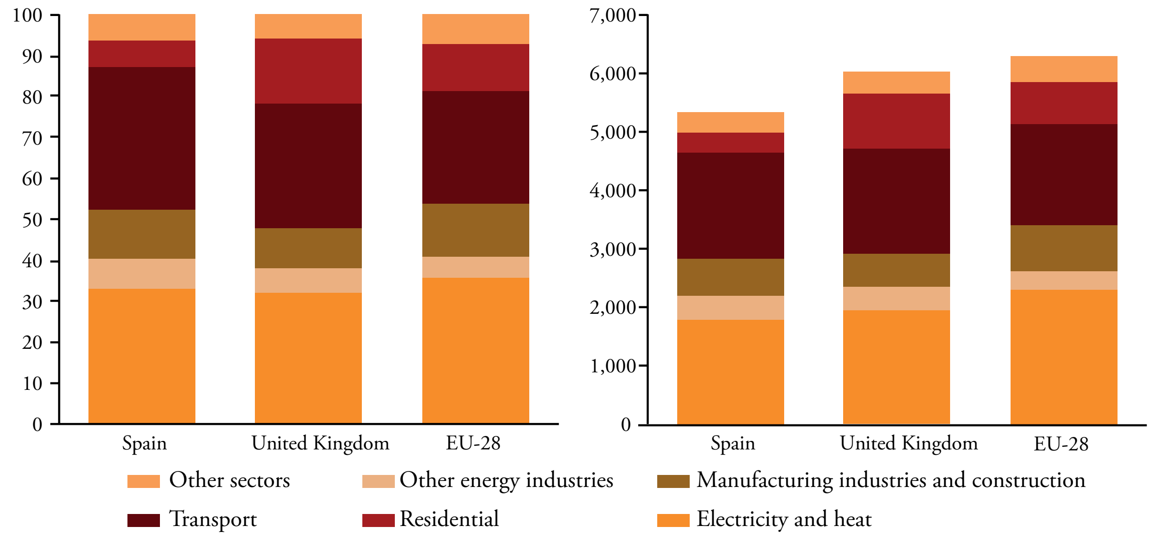
[1] There are not yet bidding official targets by country regarding RE consumption by 2030.

is approximately twice that of the UK (with 71.9% and 35.5%, respectively), with this difference being mainly driven by the UK's domestic primary energy production of natural gas (although these resources are running out) (Exhibit 1).

A third and increasingly important driver of policies with the objective of supporting a transition to a low-carbon economy, one relying much more significantly on renewable electricity technologies, is economic competitiveness. This focus of competitiveness in the energy sector is easy to understand given that estimates from the International Energy Agency (IEA) expect that investment in low-carbon energy technologies (including renewable power technologies) under the Remap scenario may reach USD 29 trillions by 2050 (IEA, 2017), on top of the USD 116 trillion under the reference (or business as usual) scenario. Countries all over the world (including the Member States of the European Union) are increasingly convinced that capturing part of this growing market is crucial for the sustained growth of their economies.

Exhibit 1



a) 2015 CO2 emissions by sector* in (%) over total emissions

b) 2015 CO2 emissions by sector in KgCO2/per capita 2015

Note: Total CO2 emissions from Fuel Combustion are 247, 389.8 and 3201.2 million tonnes of CO2 in Spain, United Kingdom and the European Union respectively in 2015 (IEA data).

Source: Own elaboration from IEA data.

In this paper we focus on how both countries have tried to enable a transition to a low-carbon electricity system. The focus on electrify comes because, at the European level (EU-28), out of the total CO2 emissions coming from fossil fuel combustion in 2015, 38.3% corresponded to electricity and heat production. This sector represents 31.5% of total CO2 emissions in the UK and 32.9% in Spain (see Exhibit 1).

Achieving the goals for the electricity system set by the EU and implicit in international commitments, such as the 2015 Paris Agreement (United Nations, 2016), will require a future electricity system with a greater reliance on renewable energy sources; on technologies that facilitate the efficient use of energy in buildings, industry and transport; and on intelligent networks, a greater use of hybrid and electric cars and enabling infrastructure. Other technologies that allow reductions in CO2 emissions in the electricity generation, such as carbon capture and storage are also likely to be necessary. In this review, we focus on the policies shaping our ability to improve the contribution of renewable power, including solar PV, concentrated solar power, onshore and offshore wind, bioelectricity, hydro and ocean energy. Importantly, we exclude from the analysis policies aimed at promoting other sources of low-carbon power generation, most prominently, nuclear power, given that the technical and political characteristics of this technology are significantly different from others (including differences in public perception across countries).

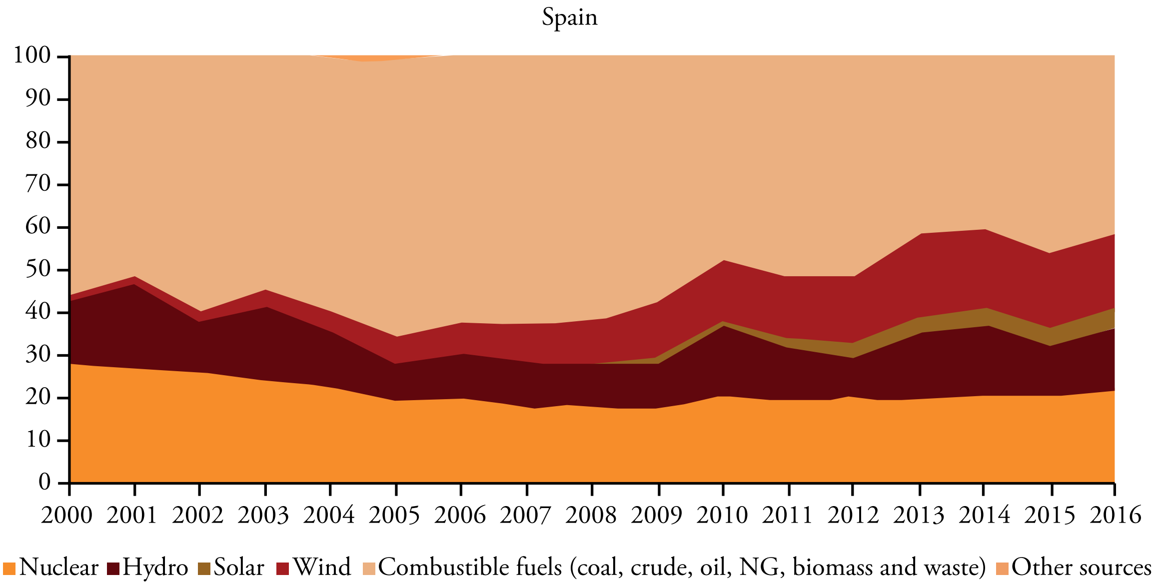
Exhibit 2 shows that between 2000 and 2016, Spain and the United Kingdom made some progress towards reducing the fraction of net electricity generation from combustion fuels (in light orange) from 63% in 2005 to 41% in 2016 in the case of Spain and from 77% to 63% in the case of the UK for the same period. In addition, as previously mentioned, although some progress has been made, it is time to take stock of what was learnt and what additional efforts may bring about a larger increase in the contribution of renewables to electricity generation (a faster rate of change).

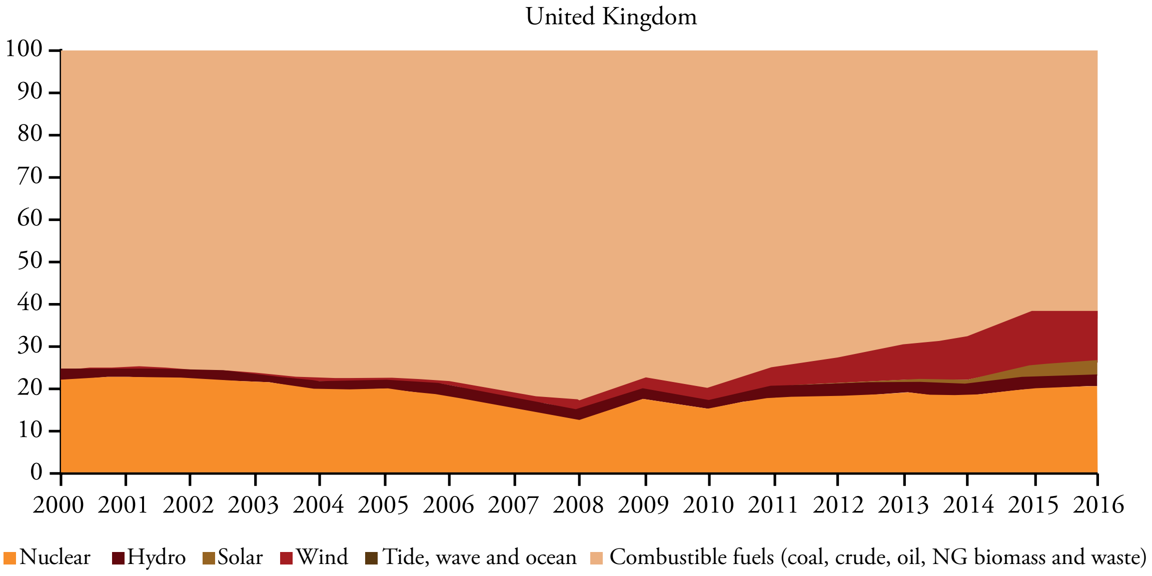
In spite of the impressive cost reductions in the price of some renewable power technologies over the past 5 years, particularly in solar PV and concentrated solar

Exhibit 2

Net electricity generation 2016 by source Spain vs. United Kingdom*

(Percentage)





Note: Total net electricity generation from Spain and from the UK reaches 264,351 GWh and 303,902 GWh respectively (Eurostat database).

Source: Own elaboration from Eurostat data.

power but also (to a lesser extent) on onshore and offshore wind power (IRENA, 2018); policy makers at the national level are facing the challenge of providing cost-effective support for renewable electricity to meet the various societal objectives previously discussed, without locking-in prematurely particular technologies and unfairly burdening those with the lowest incomes.

Generally, different countries have applied different types of policy instruments, and, even when two countries use the same type of policy instrument, details in its design and implementation can result in a wide range of financial incentives for renewable power and a range of different outcomes across countries. To stimulate demand for renewable power technologies, countries have used different 'market pull' or demand-side policies in the form of feed-in-tariffs, tradable green certificates or auctions (Bunn *et al.,* 2014). Such market pull policies can spur cost reductions through learning by doing or by using, enabling economies of scale, induced research and development efforts, and the development of new business models and the creation of feedbacks to technology developers (Menanteau *et al.,* 2003; Butler and Neuhoff, 2008; Del Río, 2009). Often countries have combined market pull policies with technology push support incentives such as R&D tax credits or direct R&D support (Uyterlinde *et al.*, 2003; Del Río and Gual, 2004; among others). Popp (2010), Del Río *et al.,* (2018), Jaffe *et al.,* (2005) and Anadon *et al.* (2014) argue that market pull policies and technology push policies are complementary.

In addition to improving our understanding of the relationship between different policies and innovation, technological, environmental, and socioeconomic outcomes; the literature on the economics of innovation, innovation systems, economic geography and entrepreneurial ecosystems has shed light on: (a) the extent to which different demand-pull policies have locked in early generations of renewable technologies (Hoppmann *et al.,* 2013; Doblinger *et al.,* 2016; Nemet, 2009), (b) the extent to which policies have induced increases in private sector investment in renewables R&D (Johnstone *et al.*, 2010; Lee *et al.,* 2009; among others), and (c) the fact that technological and domestic characteristics shape a country's or region's ability to develop an internationally competitive industry (Binz and Anadon, 2018; Surana and Anadon, 2015; Choi and Anadon, 2014; Huenteler *et al.*, 2016).

In this paper, we draw on recent research, new data collection and analysis to identify and categorize the set of policies that Spain and the United Kingdom have put in place to promote a low-carbon transformation in the electricity sector to meet the environment, security and competitiveness goals. This analysis is timely and important for two reasons. First, as previously mentioned, there is agreement that existing policies are not sufficient to meet EU and national goals (Robiou *et al.* (2017), and states have discretion in terms of the policies they put in place (Anadon, 2012). And second, governments in countries that hope to stimulate renewable power, at least partly, to drive innovation and competitiveness, now need to consider first, whether domestic industry formation is possible, and (if so), how much of a head start it could achieve before others (such as China) either organically (like in the case of solar PV) (Binz and Anadon, 2018) or by design (in the case of wind—(Surana and Anadon, 2015)) catch up.

The goals of the paper are thus three-fold. First, to provide an overview of the policies and measures established in the demand and supply sides in Spain and the UK to promote renewable energy generation. We do this implementing a typology of policy instruments developed within the H2020 INNOPATHS project, thereby providing a landscape of the policies and strategies followed by the different governments since the early nineties. Second, to assess the relationship between key outcomes of success and the policies by analysing a wide-range of criteria and indicators, with a particular focus on the evolution of innovation and economic competitiveness metrics. Third, we summarize the broader academic literature on the impact of key policies to illuminate a discussion on how policy goals may evolve and what additional policies may be necessary to meet and exceed domestic and EU goals.

The rest of the paper is structured as follows. Section 2 includes a classification of policy instruments for the promotion of renewable electricity. Section 3 explains important contextual details of the countries selected for the comparative case study analysis. Section 4 outlines the methodology, including the classification of policies to stimulate renewable energy development and deployment, the criteria and indicators used for the evaluation, and the data sources. Section 5 presents the main findings grouping results according to the following dimensions: a) environmental effectiveness, b) technological effectiveness, c) cost-saving impacts, d) innovation incentives, c) socio-economic aspects. In section 6 we discuss limitations, policy implications, and future research needs.

2. CLASSIFICATION OF POLICY INSTRUMENTS PROMOTING RENEWABLE ELECTRICITY

Achieving reductions in GHG emissions requires the combination of technological, behavioural and infrastructural changes with impacts in the short-, medium- and long-term. It has been argued that policy instruments may be able to facilitate some of those changes. Although there are some alternatives in the literature (see, Hood and Margetts, 2007; Linder and Peters, 1998), public policy instruments beyond the energy space have traditionally been classified primarily in the following three categories according to the design of the instrument (Borrás and Edquist, 2013; Bruijn and Hufen, 1998; John, 2010; Rogge and Reichardt, 2016): regulatory instruments, economic instruments and soft instruments. Applied to the electricity sector, this high-level classification adapted from work in the H2020 INNOPATHS project[2] allows us to categorize a range of policy instruments according to their design, as shown in Table 1. This classification complements the market pull vs. technology push classification introduced above, which focusses on the primary goal of the policy. In section 6, we discuss how this analysis of instrument design intersects with the analysis of the main focus of the instrument.

Table 1

Classification of policy instruments to spur renewable power generation

Policy instruments	Examples of instruments included in that category
Regulation	Codes, standard and mandates Obligation schemes or quotas: RE obligation schemes and carbon emission reduction targets Other regulation: *e.g.* net metering
Economic and financial instruments	Direct investment: R&D funding Fiscal and financial incentives: Instruments for the promotion of renewable energy diffusion and cogeneration (FITs, Auctions, Grants and Subsidies), carbon taxes or exemptions, loans or user charges Market based instruments: GHG emissions allowances system, Green certificates
Informational (or soft) instruments	Information campaigns Voluntary approaches (*e.g.*, industry pledges)

Source: Own elaboration drawing from the literature cited in the text.

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[2] http://www.innopaths.eu/

The promotion of renewable electricity has traditionally relied on economic and financial instruments, specifically three main instruments: feed-in tariffs (FITs), quotas with tradable green certificates (TGCs) and auctions or tendering schemes since the early nineties in Europe (See among others Del Río and Gual, 2007; IEA, 2008). In the United States, production and investment tax credits (other types of economic incentives) have been the main policy of choice at the federal level (Aldy *et al.*, 2018).

Economic instruments in the form of direct investments in R&D have been used by both countries at different level and with different results.

For completeness, the supplementary information (Table A.1) includes a brief description of each of the different policy instruments included in Table 1.

3. ANALYSIS OF RENEWABLE ELECTRICITY POLICY INSTRUMENTS IN SPAIN AND THE UK (1990-2016)

3.1. Case selection

We now describe the policy framework and instruments used by Spain and the UK since the early 1990s to promote renewable energy generation to meet environmental, competitiveness and security goals by applying the typology introduced in section 2. We choose these two countries because they are the only two major economies in Europe[3] that are expected to remain below the 10% electricity interconnection target in 2020 (EC, 2017). This situation will be specially challenging for the UK in the following years. The Commons' Energy and Climate Change Committee (2016) has warned that a hard Brexit may leave the UK in an exposed gas situation and has urged to find proper alternatives for electricity generation.

In addition, governments in both countries have stated publicly that they are crucially interested in promoting domestic innovation and competitiveness,

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[3] The UK are in the second position and Spain in the sixth in terms of nominal GDP in billion USD.

with different levels of activity, with the UK recently releasing a major Industrial Strategy initiative, which has energy at its core, partly spurred by concerns about the impact of Brexit (Pye *et al.,* 2017; Pollit, 2017; EPTT, 2017).

As we will show in our analysis in section 5.2., in spite of the various similarities between the countries regarding the gradual progress in the diffusion of renewables, the low level of interconnection, the relatively similar size of their economies (when compared to other much smaller EU countries), and their current focus on limiting the negative impacts of the low-carbon electricity transition for the poorest in society; the two countries have followed very different approaches to the promotion of renewable power. We will show that Spain's approach until 2012 can be characterized as a "deployment driven" approach, with an almost single reliance on very generous Feed-in-tariffs (FITs), while the UK relied on a more "holistic and experimental" approach focused on different parts of the innovation system. Having said this, over the past few years (since 2010), the UK has initiated a convergence towards production subsidisation moving closer to the Spanish approach for deployment but using a different instrument (auctions), while maintaining a lot of activity on various models for supporting energy R&D directly.

3.2. Renewable electricity policy landscape in Spain

Since the publication of the Law of the Electricity Sector and up to the implementation of the Royal Decree (RD) 661/2007, the regulation of the Spanish Electricity system has been limited to adjusting the levels of support in feed-in-tariffs for different types of renewables to provide certainty to investors interested in the electricity system. Until 2008, Spain was considered one of the most successful countries in terms of its ability to spur the deployment of renewable power technologies without considerations of cost-effectiveness (Del Río, 2008). After 2008, the combination of the high levels of support of Royal Decree RD 661/2007, solar PV prices falling faster than expected, and the availability of land after the construction sector collapse (Del Río and Mir-Artigues, 2012) caused an exponential increase in the installed capacity of photovoltaic solar energy. This fast increase in solar power installation contributed to an escalation in electricity system costs that have been reflected in the electricity bill of consumers and firms (De la Hoz *et al.*, 2014).

The 2009-2010 financial crisis and the overcapacity of the power generation system[4] combined with decreasing demand, have led the Spanish government to make relatively frequent legislative amendments to the feed-in-tariff system that held back the deployment of renewable technologies when compared to previous years. The regulatory risk creates uncertainty and volatility for investors and it can jeopardize the achievement of Spanish objectives for renewable generation established for 2020, including the goal to deploy 7250 MW of solar PV installed capacity (current installed capacity does not reach 4900 MW) (REN21, 2017).

The publication of the RD 1578/2008 in 2008 marked a shift in Spain towards designing policy instruments for renewable power generation to control public expenditure moving to different types of economic instruments from FiTs to the current scheme based in Auctions.

A new shift took place on June 6, 2014, when the RD 413/2014 framework established a new remuneration system by which, in addition to the wholesale market price, the renewable generator (the one with the right to receive a FIT on July 14, 2013) receives a payment called "Specific Remuneration Regime", based on the reasonable economic profitability[5] of a reference installation, and no longer for each kWh of electricity produced[6].

The last policy shift was to establish a new support scheme for renewable sources based on auctions (More detail can be found in the supplementary information-Appendix 2).

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[4] The power installed at the peninsular level as of December 2016 was 100,059 MW, -0.9% lower than in 2015. The maximum instantaneous power for the same year was 40,489 MW (REE, 2016).

[5] Royal Decree 413/2014 establishes that reasonable profitability in the level to the profitability before taxes of the average return on investment of the State Bonds to ten years in the secondary market of the 24 months prior to the month of May of the previous year plus a differential.

[6] Some organisations and companies (Enel Green Power, APPA, among others) are taking the RD413/2014 to trial the aforementioned Royal Decree 413/2014 because they consider it violates the principle of non-retroactivity.

In summary, since 1990, Spain has relied on feed-in-tariffs as the main instrument to promote the use of renewable energy sources for electricity generation until 2012. Indeed, although the FIT/FIPs framework has been amended several times, the same type of economic instrument (see Table 1) remained in place for fifteen years. The change, driven by the financial crisis, overcapacity, falling demand, and the falling costs of renewables, has led to the introduction of policies that could lead to limiting cost for consumers. Incidentally, limiting the cost to consumers, and particularly those with less ability to pay, has also become a focus of UK renewable power policy, as outlined by the Helm (2017) review.

In section 5 we describe the evolution of various outcomes related to renewable power in Spain.

3.3. Renewable energy policy landscape in the United Kingdom

The UK has followed a very different pathway to promote renewable power generation. While FITs or FITPs were the only instrument used in Spain for the promotion of all types of renewable energy sources for most of the period between 1990 and 2016, the UK government has relied on several schemes to provide financial support to different sources of renewable power. Currently, the UK support system includes a combination of FITs, Contracts for Differences (FIPs), quota systems with obligations and tradable green certificates and tax mechanisms[7].

Before the privatization of the British electricity sector in 1989, the UK renewable energy policy consisted of R&D programmes and in demonstration projects since 1970 (Mitchell, 1995). In contrast to the Spanish approach from the late 1990s relying on FITs and Feed in Premiums (FIPs), since the early 1990s the UK designed a tendering scheme called the Non-Fossil Fuel Obligation (NFFO) established as part of the 1989 Electricity Act. Under this scheme, electricity

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[7] It is worth mentioned that in April 2013, the UK adopted a tax on fossil fuels used to generate electricity. This tax modified the previous Climate Change Levy (CCL). The renew tax applies carbon price support (CPS) rates of CCL to gas, solid fuels, and liquefied petroleum gas (LPG) used in electricity. The tax amounts USD 15.75 per tCO2e (2014). There are no carbon taxes applied in the Spanish territory (World Bank, 2016).

supply companies had to generate a specific amount of new capacity from non-fossil sources, so the policy falls in the category of regulatory instrument in Table 1. This support mechanism consisted of competitive orders to cover specific technologies[8] for which renewable power developers concurred to an auction specifying the energy price to develop a project (Butler and Neuhoff, 2008). Successful bidders received a premium price per kilowatt-hour of generation as a result of the obligation of the regional electricity companies (RECs) of buying specific amounts of electricity generated from non-fossil sources (nuclear and renewable source), so it combined a regulatory and an economic instrument. The cost of the policy was assumed by electricity consumers who paid the difference between the premium price and the average monthly pool-purchasing price through their bills under the Non-Fossil Fuel Levy (Mitchell, 1995), effectively in place from April 2001. The NFFO policy went through five NFFO orders that resulted in 794 NFFO contracted projects with a capacity of 3271.106 MW, although as we will see in section 5, little of this capacity was actually built (NFFO FS11, 2005).

The NFFO scheme based on tenders was effectively replaced by the Renewable Obligation scheme (RO) in 2002.[9] As part of the Utilities Act 2000, the RO was proposed as a key policy for the UK to meet the targets for renewable electricity supply. The RO scheme became one of the main mechanisms supporting the deployment of large renewable electricity projects in the UK until 2013. Under the RO scheme, electricity suppliers had to prove that a specific percentage of the electricity sold to final consumers had been generated using renewable sources. The accreditation took place with the acquisition of Renewable Obligation Certificates (ROCs), which were green certificates that could be traded among the utilities to comply with their obligations. The corresponding obligation was set at 3% of the generation in 2002/2003 increasing up to 15.4 % by 2015 (Butler and Neuhoff, 2008). There was a buy-out penalty system for those companies that would not comply with the obligation. The RO obligation system was born with the main goal of reaching a 10% of renewable generation out of all electricity by 2010 (Anandarajah and Strachan, 2010). In 2009, the Renewable Obligation Order

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[8] Capacity level for different technology bands was established by the Department of Trade and Industry (Butler and Neuhoff, 2008).

[9] In 2005 in Northern Ireland.

2009 No. 785 revoked and replaced the previous Renewable Obligation Order with more generous economic incentives with the main goal of generating a greater and faster deployment of renewable in the UK. The RO framework has been amended several times; however, the type of instrument used remained in place during more than a decade until 2013.

However, neither the NFFO nor the RO delivered deployment at the projected levels. Indeed, in 2010 the share of renewable energy in total electricity generation[10] was a 4.7% far from the initial 10% target[11]. The Department of Energy and Climate Change (DECC) (which was merged into the Department of Business, Energy Innovation and Skills, BEIS, in 2016) acknowledged that UK policy goals had not been met (DECC, 2009).

In 2009 (before the RO scheme was discontinued, under the mandatory EU Directive 2009/28/EC) the UK, as well as the other Member States submitted to the European Commission its National Renewable Action Plan establishing internal renewable energy country targets. As previously indicated, the UK committed to a share of 15% of final energy coming from renewable sources by 2020s. Among the projected policy measures that would allow the UK to achieve the targets, the British Government supported a range of economic policy instruments spanning the market pull, technology push spectrum of goals, including: the continuation of the RO policy, the establishment of a FIT system for smaller scale generators, and increased cooperation with the European Investment Bank and the Green Investment Bank for capital funding provision, and growing and more stable support to R&D in key sectors (IEA, 2014).

It is interesting to compare the policy approaches used by Spain and the United Kingdom over time. While in 2005, Spain and the UK invested both 0.053 monetary units per 1000 units of GDP in energy research development and demonstration, according to data collected by the IEA, over time the UK has relied more significantly both in terms of funding and institutional innovation on technology push policies. The largest difference

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[10] Without taking biomass nor waste into consideration.

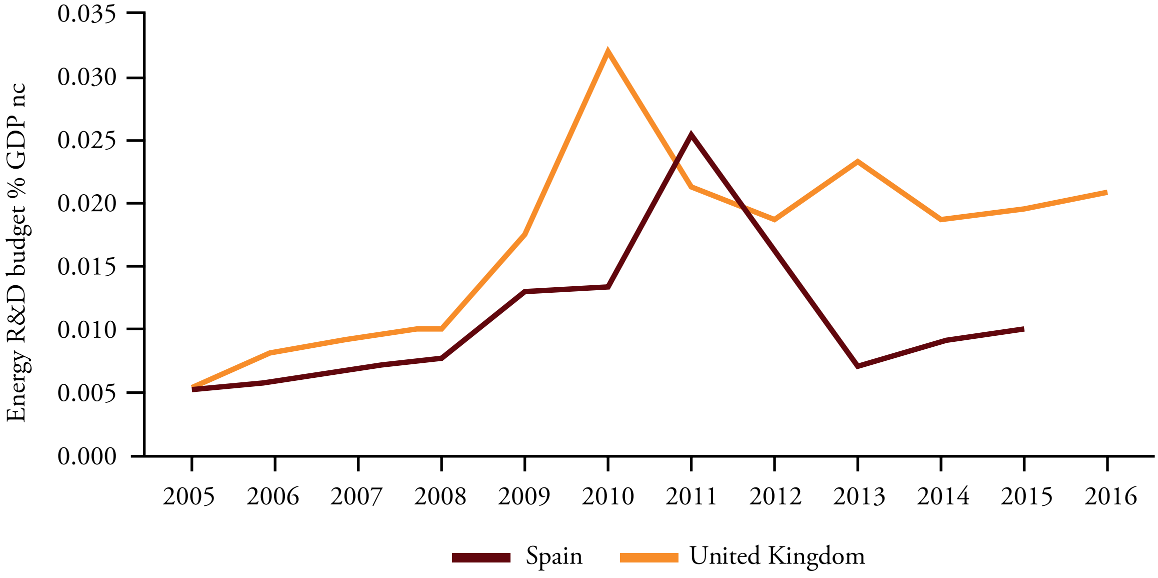
[11] Data have been extracted from Eurostat databases.

in terms of funding for direct R&D as a fraction of GDP was observed in 2010, when the UK had a public energy research and development budget twice as large as that of the Spanish one when normalizing by the size of the economy. Although the economic crisis affected both economies and it resulted in lower funding (Chan *et al.*, 2017), the UK tried to keep more or less stable a certain level of investment, while the public energy research and development budget in Spain fell dramatically from 2011 to 2013 by a factor of four (Exhibit 3).

Unlike the UK, which has created a plethora of technology push institutions to fund and support energy research, development and demonstration since 2000 (see the exhibit 5 for an overview of the new public institutions in the space, which are mainly, but not only, focussed on renewable electricity), funding from the Spanish government has fallen and, to the best of our knowledge, there have been no new public institutions created to advance energy R&D either by conducting it or funding it in different ways except for a small and slightly different R&D funding effort.

Exhibit 3

Public energy research and development budget % GDP national currency

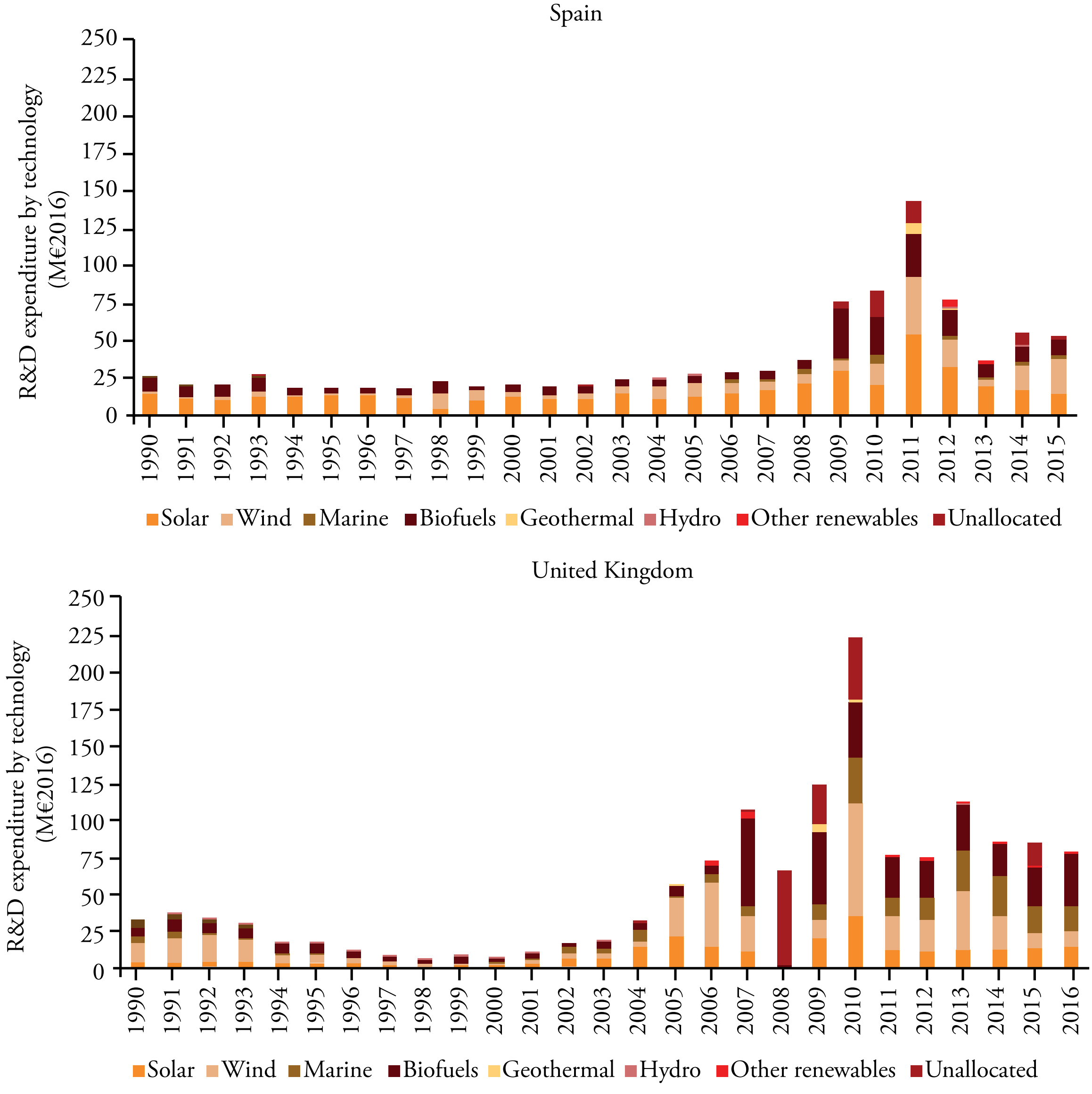


Source: Own elaboration with data from the IEA.

Energy R&D expenditures in both countries have increased their focus largely on renewable technologies over time. However, as previously mentioned, in Spain, in particular energy R&D investments plummeted after 2011 due to the crisis (See exhibits 3 and 4). In the UK the drop happened in 2010. In addition to

Exhibit 4

Evolution of energy R&D expenditure by technology (M€2016) in Spain and in UK



Source: Own elaboration from IEA database.

higher levels of investment, there has been a focus on the development of new institutions to harness innovation, as shown in Exhibit 5.

The year 2013 marked the shift away from the RO policy in the UK, with the Energy Act of 2013. This Act replaced the RO policy by a Contract for difference (CfD). The CfD, effective from October 2014, provides a premium payment for renewable electricity generated by large-scale projects not covered by the FIT system, paid on top of the wholesale market price up to a limit called "strike price". If the market price is higher, the generator must pay back the difference. Lastly, although we have previously mentioned the existence of a carbon tax in UK, it is worth noting that the UK Electricity Market Reform introduced with the Energy Act 2013 expects an increase in the carbon price floor to 30£ per CO2 tonne by 2020[12].

As we will show in section 5.2, the changes in the policy in the last few years have spurred an exponential increase in the UK renewable energy installed capacity. However, as we will see in section 5.5, consumers are seeing significant increases in their electricity bills, with policy makers and researchers putting most of the blame on renewable energy support schemes (Johnstone *et al.,* 2017).

Exhibit 5 summarizes the chronology of support mechanisms and research institutions for renewable electricity generation in both countries. The top of the exhibit includes renewable electricity policies in the UK, while the bottom includes the instruments in Spain. The common (EU level) carbon tax instrument separates policy instruments by goal, into technology push (at the top, above the section for EU ETS) and pull (below the section on EU ETS), while the coloring of the boxes indicate the type of instrument used using the Typology in Table 1.

In the next section we lay out the criteria used to determine the extent to which the policy mixes (Rogge and Reichardt, 2016; Rogge *et al.,* 2017) used in the UK and Spain are helping them achieve their various policy objectives. In order to do this, in section 4.1 we lay out the range of criteria used to determine the impact of the policy mixes in both countries.

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[12] However, in Budget 2016 the price floor was frozen in 18/tCO2 from 2016 to 2021 to limit potential competitive disadvantage by business and to reduce energy bills for consumers (Hirst, 2018).

Exhibit 5

Chronology of national-level support mechanisms for renewable energy generation in the United Kingdom (top) and Spain (bottom)

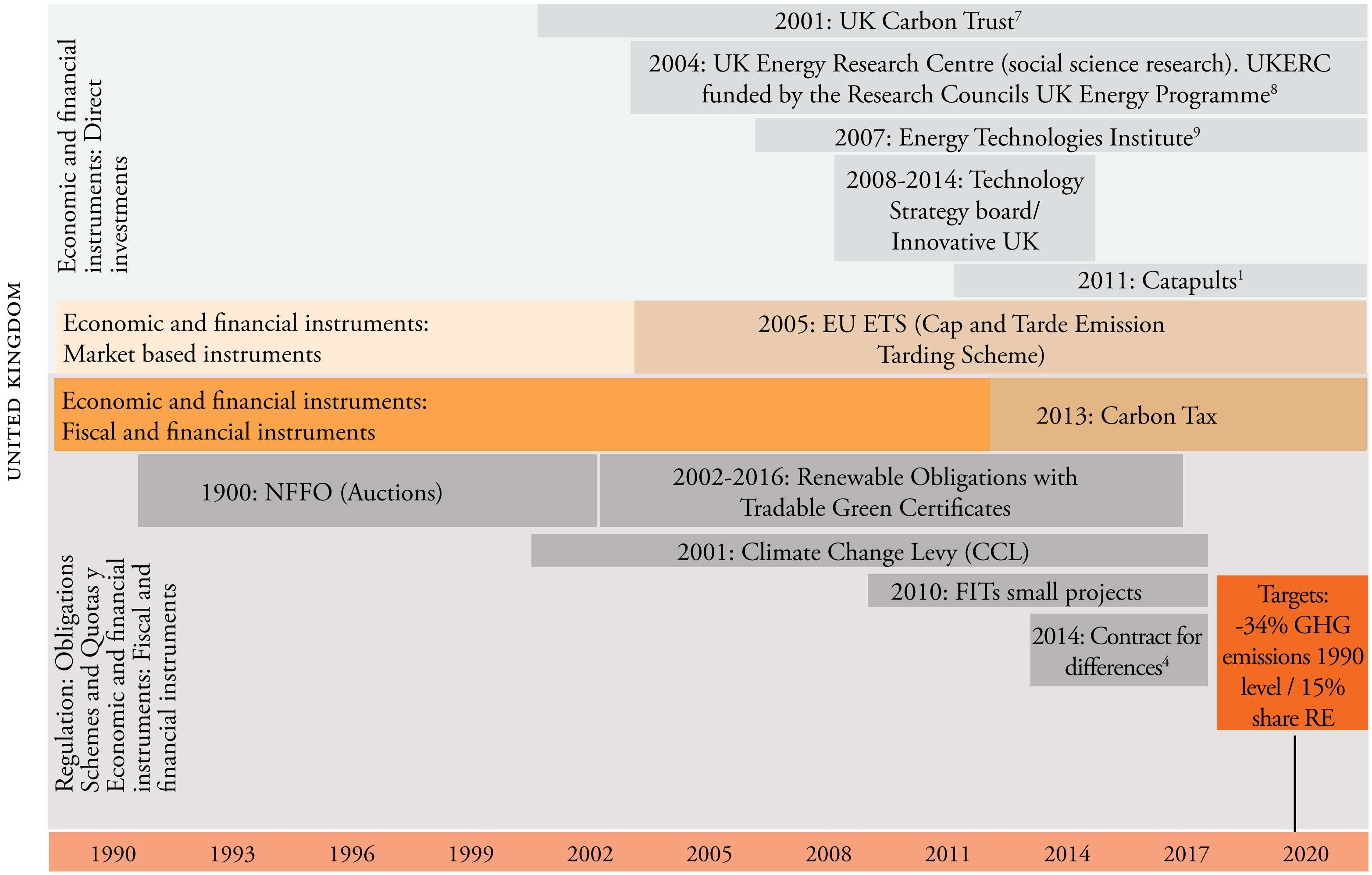
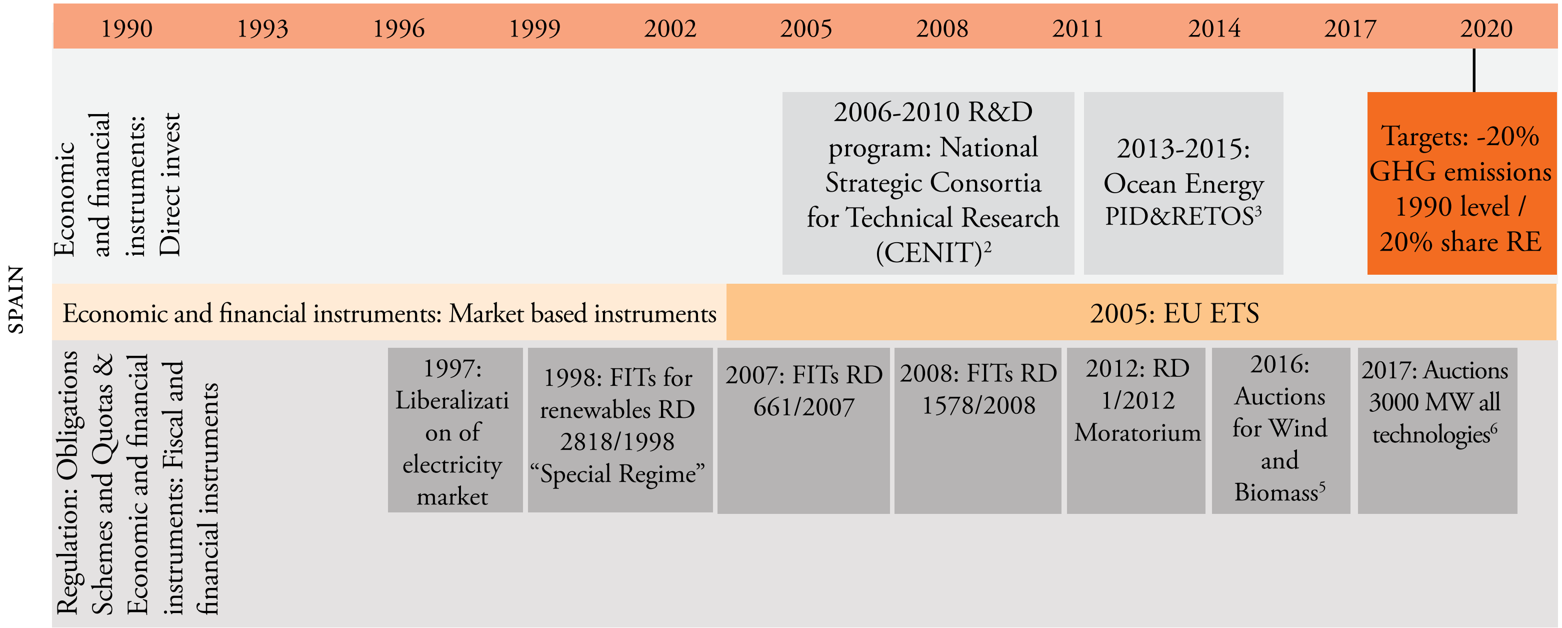


Exhibit 5 (Continued)

Chronology of national-level support mechanisms for renewable energy generation in the United Kingdom (top) and Spain (bottom)



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[1] The TSB also oversees a number of strategic Technology Innovation Centres (TICs), also known as Catapult Centres. 10 Catapult centers designed to transform the UK´s capability for innovation. In theory they were modelled following the german Fraunhofer Institute organisation scheme after a recommendation of entrepreneur Dr. Herman Hauser.

[2] CENIT includes energy researcha though topics such as design and production technologies; environment, sustainable development and renewable energies; new materials and nanotechnology; aerospace; and sustainable mobility (cars and railways). Between 2006 and 2010, 91 projects received 1071 million euros in grants, for a total investment of 2.298 million euros. The budget related to energy was 386.8 million euros.

[3] Programe budget: 550,000,000.00 & 700,000,000.00 euros respectively. Areas: Low-carbon heat and power, alternative fuels and energy sources for transport, Smart cities, Smart grids, EE industry, Energy innovation among others.

[4] Contract for differences for big projects.

[5] 700 MW RD 947/2015 and OM IET/2212/2015.

[6] RD 359/2017. OM ETU/315/2017.

[7] Specialist support to help businnes and public sector boots bussines returns by cutting carbon emissions, saving energy and commercialising low-carbon technologies.

[8] UKERC carries out research into sustainable future energy systems.

[9] The ETI is a public-private partnership between global energy and engineering companies and the UK Government.

Source: Own elaboration.

4. METHODS AND DATA TO EVALUATE NATIONAL LEVEL OUTCOMES

Having analysed the renewable electricity policy instruments deployed by both countries over time, we now explain the data we use for measuring outcomes.

4.1. Methods

As discussed in the introduction, governments have many overlapping societal goals with their renewable energy policies. Improving cost-effectiveness, including the internalization of social costs (*e.g.,* the health costs from air pollution or the harms induced by GHG emissions), and having policies that do not disproportionately harm the worst off are important goals. But there are additional policy goals that are relevant to the transition to a low-carbon economy that go beyond internalizing environmental externalities, cost-effectiveness, and fairness. For example, public policy could also have as a goal mitigating the uncertainty about both costs and benefits in economic and environmental terms of energy technologies, and incentivizing international industrial competitiveness and new employment opportunities.

To reflect the range of outcomes and indicators that are being used to both motivate policies and evaluate their impact, we develop an indicator-based approach, which has as a side benefit the fact that indicator approaches are widely used by international organisations (Mundaca *et al.,* 2016) to understand the country-level landscape in particular areas. Of course, evaluating renewable power policies based on a range of criteria and indicators is not new in the literature. Previous attempts to create a set of indicators include Gallagher *et al.* (2006), Gallagher *et al.* (2011), Wilson *et al.* (2012), Konidari and Mavrakis (2007) or Sonnenschein (2017) among others. We build on previous efforts by creating a short list of indicators along a set of policy goals and implement this short list of indicators in our country case studies to provide a comparison of the evolution in the indicators since 2000.

The EU Commission has provided a set of guidelines for assessing different regulations that can be summarized in five criteria: effectiveness, efficiency, coherence, relevance and EU-added value[13], and different authors have used a variety of different terms to refer to similar criteria (*e.g.,* Konidari and Mavrakis, 2007). We combine the EU's high-level criteria, with work on innovation systems (which states that the evaluation of policy instruments for catalysing a transition to a low-carbon economy needs to consider that policies affect the whole socio-technical system (Neij and Astrand, 2006)) and the public management and policy literatures, which further evaluate policies based on more granular indicators that are in turn classified into inputs, outputs and/or outcome-impact indicators. The analysis of renewable power outcomes in both countries draws on research from the H2020 INNOPATHS project by selecting a sample of outcome indicators. Although the focus is on outcome indicators and on innovation, in some selected cases (*e.g.,* technology impacts), we include an analysis of output indicators (*e.g.* patents) due to the lack of availability of data on broader outcomes.

Table 2 groups indicators into a modified version of the EU criteria for evaluating policies resulting in six high-level criteria that also reflect insights from the innovation systems and the public management literature. These six high-level criteria are environmental effectiveness, technological effectiveness, cost-saving impacts, innovation, competitiveness and socio-economic impacts. While innovation and competitiveness are clearly related, we separate these two criteria since the former is usually measured with output indicators and the latter with outcome indicators. We also separate innovation since that is an area of focus for this analysis. The supplementary information includes a definition of the different criteria (Appendix 3).

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[13] The EU has designed a set of guidelines or 'high level criteria' for assessing policy interventions: Effectiveness, efficiency, coherence, relevance and EU-added value. However, because these are high level criteria different authors have used a variety of terms to refer to the same criteria (Konidari and Mavrakis, 2007). An overview of the types of criteria used to evaluate policy instruments in both policy documents and academic papers is collected in Appendix.

Table 2

Criteria and outcomes (or outputs in some cases) used to compare the performance of renewable power policies in the UK and Spain between 1999 and 2016

Criteria	Outcome/Output	Specification	Data Source
Environmental effectiveness	1. GHG emission reduction and distance to targets	MtonnesCO2eq-Index (1990=100)	Eurostat database
		GHG emission intensity of energy consumption, gCO2eq/KWh- Index (2000=100)	
	2. CO2 intensity of the power sector	Carbon intensities of electricity (gCO2eq/Kwh)	Wigand *et al.* 2016
Technological effectiveness	1. Installed capacity of RE and distance to targets	Cumulative installed capacity MW and (%)	IRENA database
	2. Electricity generated with RE	Generation EC effectiveness indicator	Own elaboration from IRENA database and NREAPs
Cost-saving impacts	1. Support costs of generation RE	Cost in €/MWh of supported electricity	Council of European Regulators (CEER)
	2. Differences in the financing schemes of installed capacity	Type of financing scheme and entity (projects, loans, equity)	IRENA database
Innovation	1. Cost reductions and learning rates	€/MW	IRENA database
	2. R&D investments	Mill € 2016 and R&D expenditures by each 1000 monetary units of GDP	IEA database
	3. Patents	Patent applications to the EPO by applicant country and priority date by technology in RE	OECD database
Competitiveness	1. Net job creation	Number of jobs	IRENA database and Ortega *et al.* (2015)
Socio-economic impacts	1. Variation in the price paid for electricity (households)	€/Kwh	Eurostat database

Sources: Own elaboration informed by previous categorisation (EC, 2015; GGKP, 2013; IPCC, 2007; IRENA, 2014; Konidari and Mavrakis, 2007).

4.2. Data sources

The data used to evaluate the extent to which the policy mixes used in the two countries were moving them closer to their policy goals were collected from a variety of sources. We obtained indicators from Eurostat, the OECD statistic databases, the International Energy Agency, IRENA data and statistics, and the Council of European Energy Regulators. We also reviewed the academic literature and reports from international and national organisations on energy and green economy indicators. See table 2 for more detailed information about the data sources.

5. MAIN FINDINGS

5.1. Environmental effectiveness

Environmental effectiveness is defined as the extent to which a policy instrument meets its proposed environmental objective or realizes positive environmental outcomes (IPCC, 2007). There is scarce literature analysing the environmental effectiveness of the instruments for the promotion of renewable energy deployment (Thapar *et al.*, 2016). The literature available generally mentions that, in Europe, renewable support policies do not achieve further CO2 emissions reductions, but they generate higher compliance with the CO2 targets than would be the case in their absence (Frondel *et al.*, 2010; Del Río and Cerdá, 2017).

In 2015, the last year for which data is available, Spain emitted 335.56 MTonnes CO2 eq[14], 19% more than in 1990. However, using 2005 as the starting point Spain reduced its GHG emissions by 24%. In the case of the UK, total GHG emissions in 2015 were predictably higher (given the larger population and economy), 503.50 MTonnes CO2eq. However, compared to 1990 emissions

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[14] Data come from Eurostat database. They represent GHG emissions from all sectors excluding LULUCF and memo items.

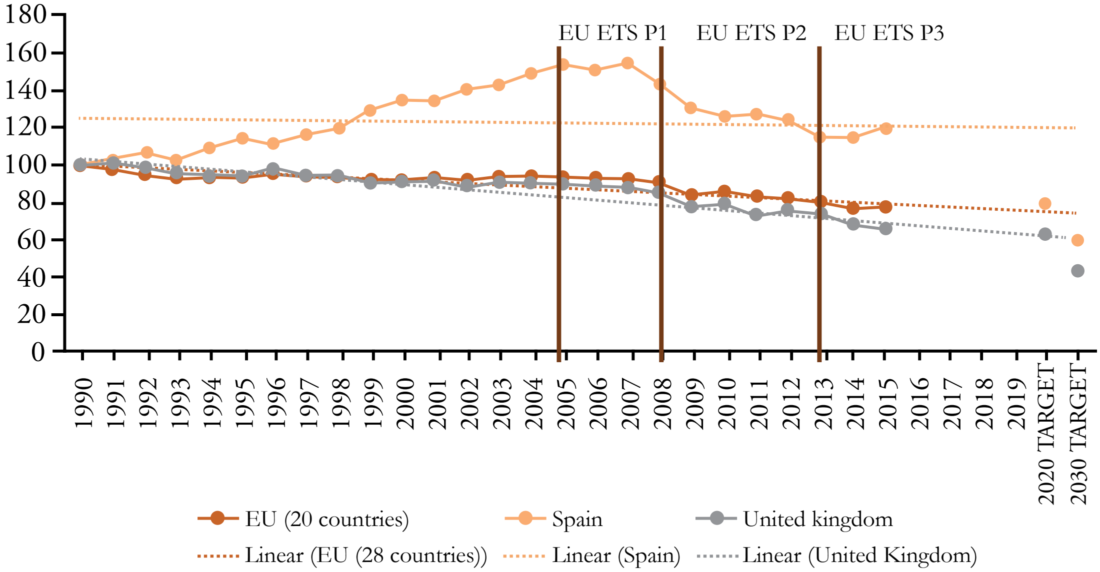
fell by more than 30% (Exhibit 6) due, to a large extent, to a shift from coal to natural gas (Wilson and Staffel, 2018).

5.1.1. GHG emission reductions and ability to meet targets

Exhibit 6 suggests that, unlike the UK, which is on track to meet its 2020 goal, Spain is not likely to meet its 2020 targets through domestic emissions reductions. According to the Committee on Climate Change in the UK (CCC), the country was 42% below 1990 levels in 2016. However, in spite of recent successes to meet the 2020 goals, the UK's ability to meet the carbon budgets in the period from 2023 to 2027 is under question.

Exhibit 6

GHG emission reduction (1990=100) and distance to the targets (shown in orange dots for Spain and grey dots for the UK)



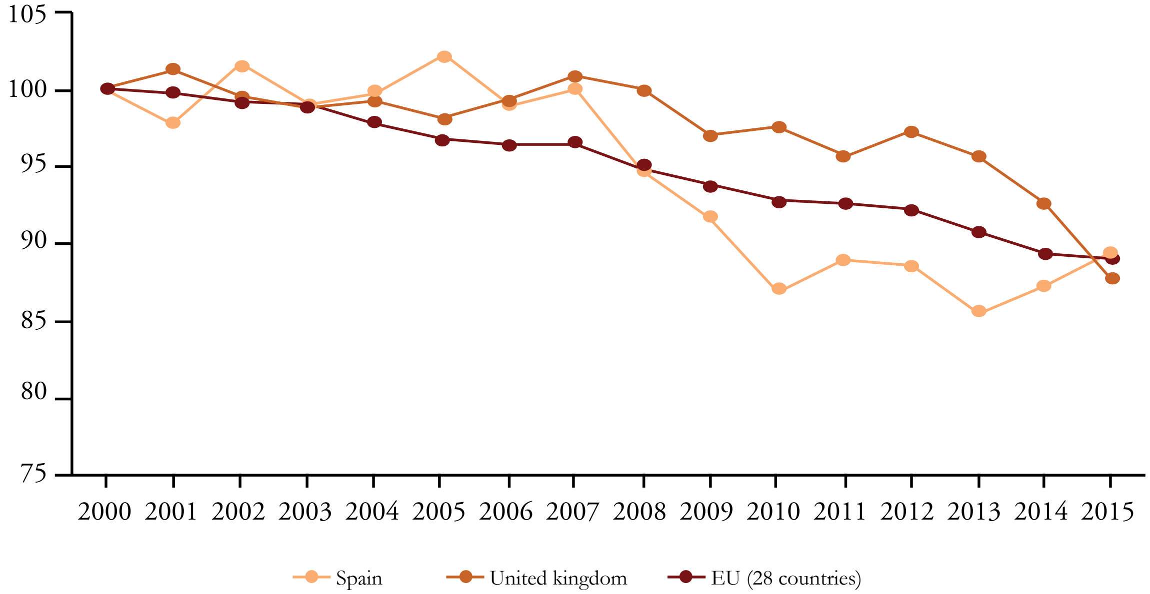
Source: Own elaboration with data from Eurostat.

5.1.2. Carbon intensity of the power sector

The carbon intensity of electricity can be defined as the GHG emissions generated in the production of a certain amount of electricity. Exhibit 7 indicates

Exhibit 7

Change in GHG emission intensity of energy consumption (2000=100)



Note: The exhibit shows the ratio between energy-related GHG emissions and gross inland consumption of energy, i.e. how many tonnes CO2 equivalents of energy-related GHGs are being emitted per unit of energy consumed.

Source: Own elaboration from Eurostat data.

that in the EU, starting in 2000, there has been quite a bit of convergence in terms of the evolution (relative change) of the carbon intensity of the power sector. The Exhibit also shows that the impact of the economic crisis was higher in Spain.

In addition to the convergence in the rate of decrease of the carbon intensity of power generation since the year 2000, in 2015 the carbon intensity of power in Spain was similar to that in the UK (between 290 and 310 g CO2eq/kWh). Last available data from Spain in 2015 show on average a carbon intensity of the power sector of 294 g CO2eq/kWh. Note that the UK carbon intensity of power generation experience a rapid decline of 47% in 5 years to 2016, largely due to carbon pricing in 2015, which enabled a rapid fuel switch from coal to natural gas. Having said that, some of the previous policies provided the enabling conditions and investment in generation and infrastructure to allow the switch, including the Climate Change Act of 2008 and the Electricity Market Report 2013 (Wilson and Staffel, 2018). Additional information about the evolution of environmental effectiveness using other metrics can be found in the Supplementary Information (Appendix 4).

5.2. Technological effectiveness

Technological effectiveness is understood in the IPCC (2007) as the extent to which policies are resulting in actual increases in the amount of renewable electricity generated or share of renewable energy over the total supply (IRENA, 2014). Perhaps more than any other indicator, the literature on renewable power policy instruments has focused on measuring technological effectiveness (Menanteau *et al.,* 2003; Butler and Neuhoff, 2008; Popp *et al.,* 2011; Del Río and Linares, 2014; Choi and Anadon, 2014; Schallenberg-Rodriguez, 2017; among others). There is consensus in this research that deployment subsidies have been effective from a technological (deployment) point of view. Moreover, these papers indicate that FITs, as implemented since the late 1990s and early 2000s, have been the most effective instrument in promoting RE deployment.

For the particular case of the UK, several articles have compared the British TGC and ROC system with FITs in Germany, showing that the British policy instruments have not stimulated the expected level of deployment and have thus been less effective in stimulating technology deployment when compared to FITs (Lipp, 2007; Butler and Neuhoff, 2008; Mitchel *et al.,* 2006; Wood and Dow, 2011).

5.2.1. Installed capacity from renewable energy sources

One of the most common indicators used to measure technological effectiveness is installed renewable power capacity, even though the indicator has important limitations[15]. One reason for its popularity is that it is the simplest indicator and

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[15] For a full explanation of the limitations see IRENA (2014).

data on installed capacity is readily available. The other two common indicators in the technological effectiveness category are renewable electricity generated, or the share of renewable electricity generated (IRENA, 2014). It is important to note that these three indicators do not indicate the cost or cost-effectiveness of achieving such RE deployment.

Exhibit 8 shows the evolution of the installed capacity of renewable energy by technology as well as the evolution of the shares of electricity capacity by technology in Spain and the UK between 2000 and 2016. The main differences between the countries are that bioelectricity and offshore wind play more important roles in the UK, while wind has been, to date, is the most significant non-hydro renewable in Spain. In addition, while renewable energy capacity in Spain installed after the crisis was stagnant because of the removal of support from FITs, it continued increasing in the UK. Additional exhibits can be found in the Supplementary Information-Appendix 5.

Exhibit 8

Cumulative renewable power capacity in MW (left) and in % over total capacity (right) by technology and country between 2000 and 2016

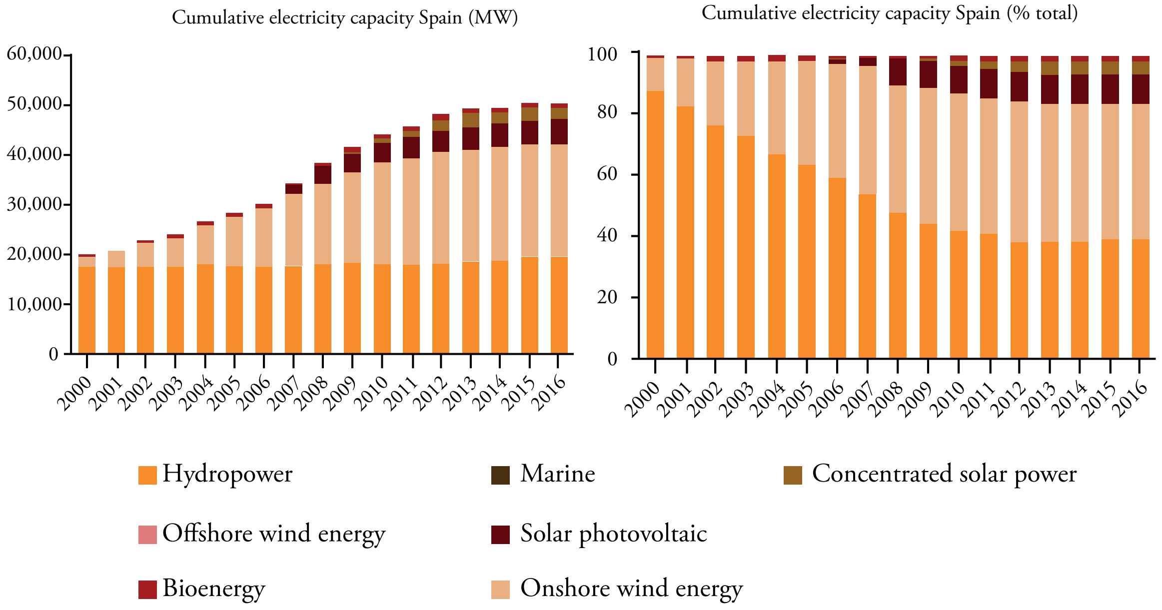
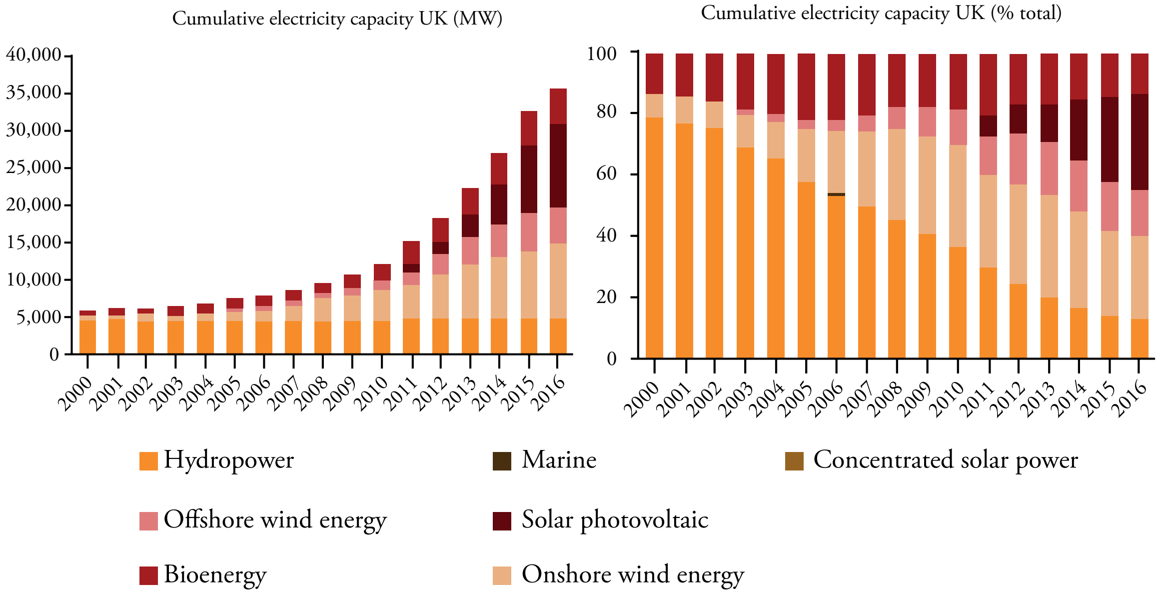


Exhibit 8 (continued)

Cumulative renewable power capacity in MW (left) and in % over total capacity (right) by technology and country between 2000 and 2016



Cumulative electricity capacity UK (MW)

Cumulative electricity capacity UK (% total)

Source: Own elaboration with data from IRENA.

5.2.2. Generation of electricity with RE compared with estimates of 'potential'

The European Commission (EC) has a more elaborate technology effectiveness indicator defined as the electricity delivered by a specific renewable energy technology in GWh compared to the potential of the country for each technology (EC, 2005). This indicator measures de additional generation achieved by a technology in a given year as a percentage of the total additional realisable potential by 2020.

We have calculated the EC effectiveness indicators for key technologies in UK and in Spain using the binding 2020 targets provided by the British and Spanish Government in their National Renewable Energy Action Plans (NREAPs)[16]. The calculation of the EC effectiveness indicator by policy scheme, technology and

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[16] See https://ec.europa.eu/energy/en/topics/renewable-energy/national-action-plans

country shows that effectiveness, measured in this way, has varied widely under different schemes (See the analysis in the supplementary information-Appendix 5). In general, our analysis of this metric confirms that neither auctions under the NFFO scheme nor TGC were able to trigger installed capacity, and it was not until the introduction of FITs in the UK in 2010 that the policy instruments to support renewable energy deployment have been effective. The only exception was the Utilities Act 2000, which included renewable obligations and TGC and resulted in significant increases in technology deployment for bioenergy.

5.3. Cost-saving impacts

In this section, we assess the expenditures dedicated to promoting renewable energy through the national support schemes by technology and in an aggregate way for the UK and Spain, on a comparable basis. Information and analysis are based on data from the Council of European Energy Regulators.

5.3.1. Deployment incentive costs for RE generation

Although the policy approaches in both countries have been historically very different (as discussed in Section 2), the UK and Spain have relied on economic and financial instruments funded through non-tax levies and passing down the RES costs to the end users through the electricity bills. In 2015, Spain produced 54 714 GWh under support schemes and the UK 73 316 GWh. In 2014, the percentage of electricity generated that received RES support represented 20.9% of the gross electricity generation in Spain and 16.8% in the UK (CEER, 2017). Given the large share of electricity that is supported by different incentives, these costs are not negligible.

Exhibit 9 shows the evolution of unitary support levels (cost per MWh of supported electricity) by the main renewable technologies from 2009 to 2015 in Spain and the UK[17]. There are significant differences across technologies and between both countries. We also see that the level of support in euros per MWh has been relatively volatile over time.

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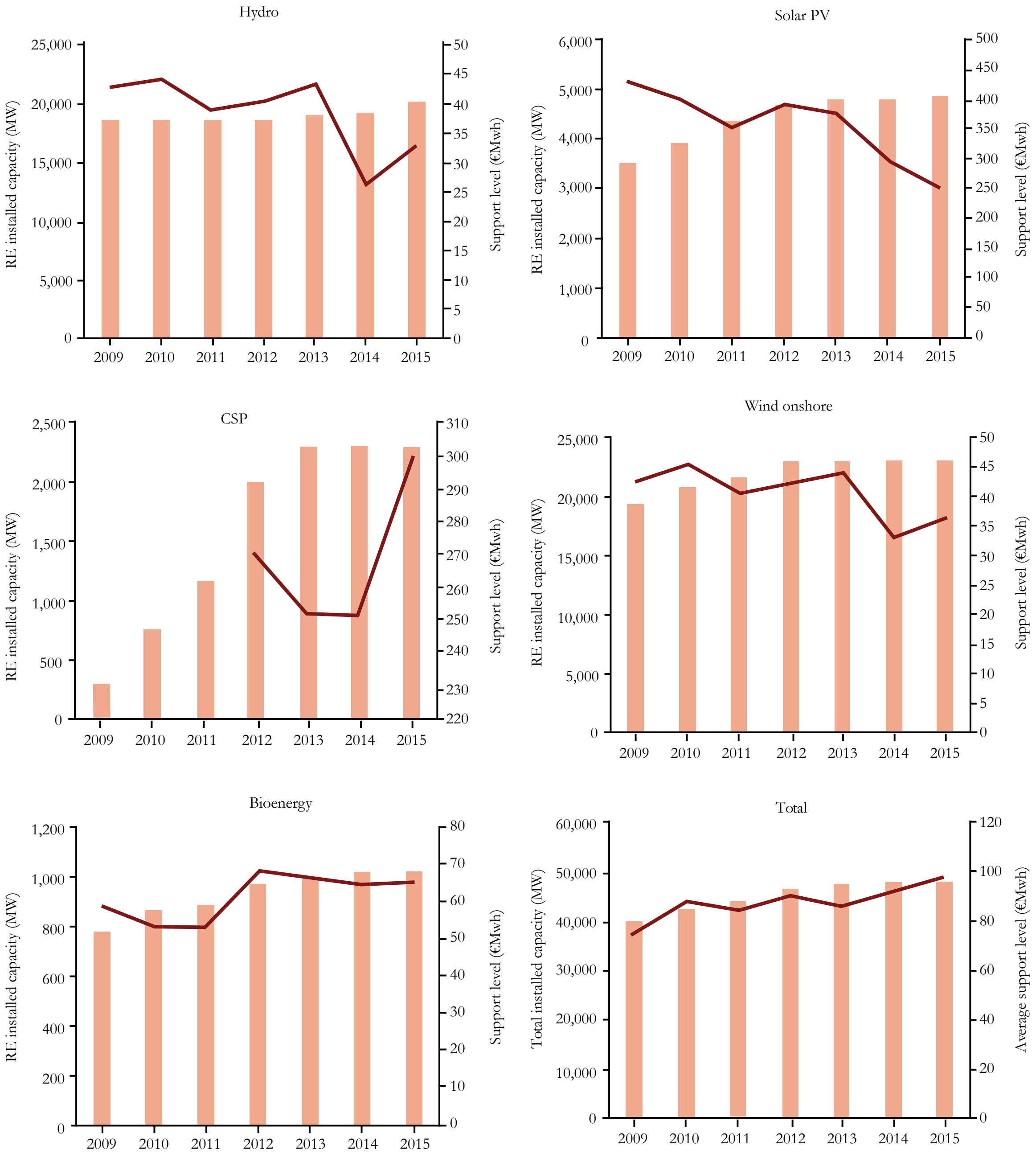
[17] We remit the reader to the previous sections to see which instruments were in place in the UK and in Spain from 2009 to 2015.

Exhibit 9

Comparison between cumulative installed capacity (MW) and Unitary support level (€/MWh) by technology in Spain



Sources: Own elaboration with data form CEER and IRENA.

With the exception of the support for hydropower, in Spain there has been a gradual decrease of support since the publication of the RD 1/2012 that suppressed the support for new capacity (Exhibit 9). A completely different pattern emerges when analysing the UK case. The UK has intensified its level of support in the last few years (Exhibit 10). This may be the main reason why, from 2009, there are no statistically significant differences in the unitary level of support between Spain and the UK. However, it must be highlighted that this analysis only includes relatively recent changes in the support. Previous research indicates that, in the past, differences in the level of support across the two countries were significant.

Exhibit 10

Comparison between cumulative installed capacity (MW) (light orange bars) and Unitary support level (€/MWh) (in a red line) by technology in UK

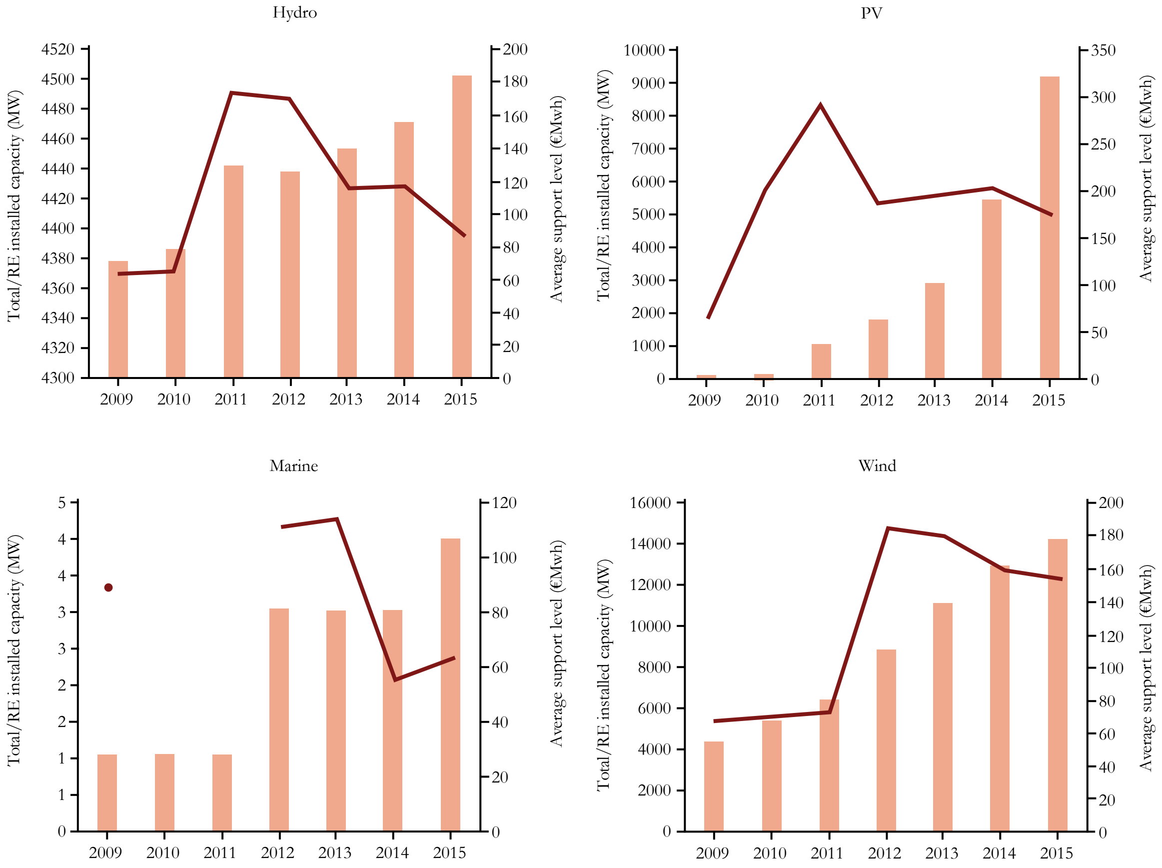
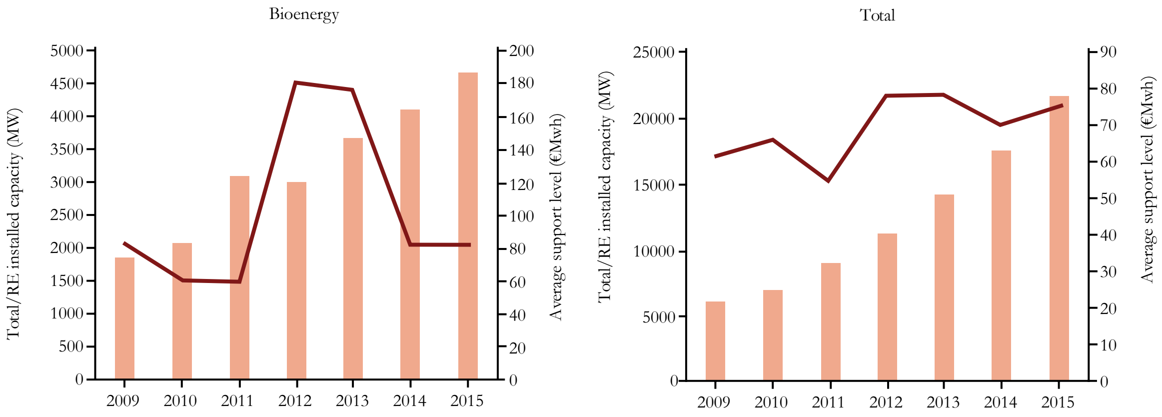


Exhibit 10 (continued)

Comparison between cumulative installed capacity (MW) (in colored bars) and Unitary support level (€/MWh) (in a red line) by technology in UK

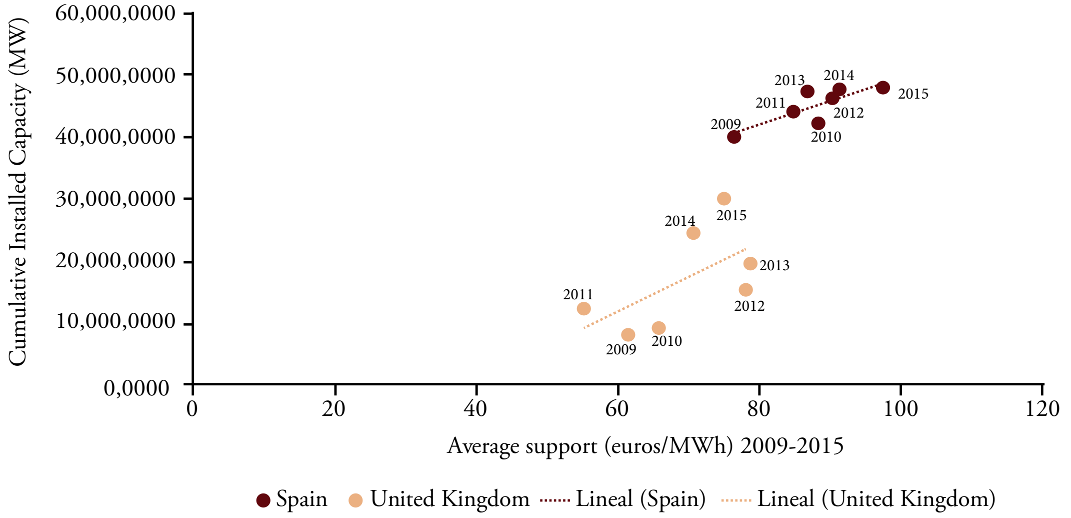


Sources: Own elaboration with data form CEER and IRENA.

Exhibit 11 shows the relationship between total cumulative capacity in MW and the level of support in €/MWh from 2009 to 2015 comparing both countries, *i.e.* the UK and Spain. As expected, there is a positive correlation between the level of deployment

Exhibit 11

Correlation patterns between installed capacity and support levels (2009-2015) in the UK and Spain



Sources: Own elaboration with data from CEER and IRENA.

and the unitary level of support to renewable technologies: the greater deployment in Spain was mainly due to the much larger size of the financial deployment incentive, on average, 32% greater in 2010 and 17% greater in 2015 in comparison to the United Kingdom.

From these graphs, we can extract as well that the increase in the installed capacity in the UK has experienced a steeper slope than the Spanish one. This increase may be partly due to a higher increase as well in the level of support in the last years.

5.3.2. Differences in the financing schemes for installed RE capacity

REN21 (2017) reports a total investment in renewable power capacity in Europe of approximately USD 60 billion in 2016. This represents an increase of 3% when compared to 2015. Interestingly, this increase is mainly attributable to important investments in offshore wind energy, where the UK has become a leader in terms of attracting funds for deployment. In 2015 and 2016 United Kingdom has seen the largest amount of finance for renewable power within the EU-28, with around USD 24 billion funded mainly through asset finance.

Of the total investment in renewables in Spain in 2015 and 2016, some projects were funded by loans from the European Investment Bank (EIB). According to the IRENA database[18] in Spain there were 13 projects from 2009 up to 2016 (2 built in 2015 and another 2 2016), and all of them were financed by EIB loans. Out of the 13 projects, 7 of them are solar plants, 2 are wind plants, and there is one for bionenergy, one for hydropower and two for other renewables. In total 2.3 USD billion have been financed through these instruments in Spain. The UK has its own public green bank and has relied to a lesser extent on the EIB. Additional information can be found in Appendix 7 of the Supplementary Information.

5.4. Innovation outcomes

Grubler and Wilson (2014) define energy technology innovation, as innovation in material and knowledge combined in some novel application, involving

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[18] http://resourceirena.irena.org/gateway/dashboard/?topic=6&subTopic=8

energy conversion and/or the provision of a useful energy service. The analysis of innovation effects of RES-E support schemes is a very relevant topic, as innovation is expected to play an important role in lowering the cost of renewable energy sources (Fischer and Newell, 2008) and some countries make explicit the fact that one of the main objectives of their RES-E support schemes is to effectively improve and reduce the cost of the technologies (BMU, 2008).

However, the importance of different policy instruments may vary across the innovation process, as technologies become more mature and cost competitive. The literature suggests that FITs may be more appropriate to incentivize innovation in the form of cost reductions for more immature technologies and TGC for mature ones (Del Río and Peñasco, 2014; IEA, 2008; Midtum and Gautesen, 2007). Del Rio and Peñasco (2014), based on a review of the empirical literature, compared innovation effects of different RES-E support instruments taking into account a range of innovation dimensions including technological diversity; research, development and demonstration (RD&D) investments; learning effects and technological competition. The authors conclude that more research is needed to attribute any causal relationships between deployment policies and those metrics.

Here we focus innovation outcomes on learning effects (outcomes), R&D investments (inputs) and on the impact that support can generate over patent applications (outputs) in renewable energy technologies.

5.4.1. Cost reductions and learning rates

Research has found large and statistically significant correlations between deployment and decreases in costs through a range of processes that are sometimes aggregated under the term of learning by doing. Since, as we have mentioned previously, FITs are considered to be generally effective at increasing renewable capacity in the European context (Menanteau *et al.,* 2003; Meyer, 2003; Gan *et al.,* 2007; Lipp, 2007; IEA, 2008, Ragwitz *et al.,* 2007, among others), there is consensus that they induce some cost reductions through learning by doing and other simultaneous processes, such as economies of scale and feedbacks to R&D. Most of this research has studied the evolution of wind and solar technologies in countries with FITs like Germany or Denmark (Papineau, 2006; Soderholm and

Klassen, 2007), but there is also some research specific on Spain: using learning curves, Del Rio and Gual (2007) found a positive and large relationship between FITs and cost reductions through learning by doing.

There has also been work comparing different deployment instruments. Menanteau *et al.* (2003) compared the innovation incentives generated by different instruments, *i.e.* FITs in Germany vs. Auctions (NFFO) in the UK and found that technological learning effects for manufacturing are greater in countries with FITs that in countries with bid systems because the reduced margins in bidding systems limits the R&D investment capability of manufacturers and suppliers. However, they attribute the reductions not to learning by doing in manufacturing, but to improved economies of scale and wind site selection. Although research on learning rates has emphasized that FITs have been more effective in Europe than TGCs (IEA, 2008), the last CfD auction in the UK got the second contract for awarded over 3GW of wind offshore at the low price of £57.50/MWh to be delivered in 2022-2023 undercutting 2015 prices by half, suggesting that the auction had facilitated learning by doing and economies of scale in offshore generation.

Wigand *et al.* (2016), from a complete case study analysis from twelve countries do not find conclusive results regarding the role played by auctions neither in terms of innovation incentives nor dynamic efficiency understood as the long-term reduction of costs.

While the extent to which deployment incentives have contributed to the cost reductions we have seen over time in wind onshore and residential solar PV is not settled, there is some agreement that deployment incentives have contributed to some of the cost reductions in the most mature renewable energy technologies.

Onshore wind costs have come down significantly in recent years (See Supplementary Information- Appendix 6 for more information). Spain presents the highest reduction in onshore wind installed costs (€/MW) between 1990 and 2016 out of the EU-28 countries, according to IRENA (2018), with a 52% reduction in installed costs, when compared to a 30% reduction in the UK during the same period. Regarding the levelized cost of electricity (LCOE) (See exhibits in the supplementary information- Appendix 6), from 2010 to 2016, onshore wind LCOE has decreased by 48%, while LCOE in the UK only went down by 10% during the same period. Capacity factors, another proxy for technology improvement, went up in both countries to 16% in Spain and 11% in the UK during the same period (IRENA, 2018). The extent to which the differences in capacity factors can be explained by better resources, better operations and maintenance, better siting, or turbine choice could be determined using an approach such as the one developed by Huenteler *et al* (2018).

5.4.2. R&D investments

So far we have discussed R&D investments as an input (as a policy) created to spur innovation and competitiveness in renewable power. In this section we focus on what we know regarding the extent to which R&D investments, particularly in the private sector, can be induced as a result of both deployment policies and (to a lesser extent) public R&D funding. Rogge *et al.* (2011) showed for Germany that the greater effectiveness of FITs in increasing the diffusion of the technology might positively influence R&D investments in firms.

Literature on technological change in green technologies agree that market-based policy instruments tend to be more effective than command and control policies. There is agreement in regards that there are other factors which may influence the aforementioned effect, *i.e* technology type, market structure and policy stringency (Groba and Breitschopf, 2013). In this line, Nesta *et al.* (2018) find that previous technological capabilities of the countries have an influence on green innovation. The role of R&D investment in important in this real. The authors conclude that in those countries with a level of competencies below the median, "neither market-based nor command-and-control policies" are effective in promoting greener technology options. Increasing specialisation in green technologies favours the positive effect of environmental policies. In this situation, market-based instruments are discreetly effective in promoting green innovation while command and control policies would decrease brown innovation. When the country is already a leader in renewable energy technologies, market-based instruments are the ones allowing to consolidate comparative advantage (Nesta *et al.,* 2018)

R&D expenditures seems relevant to promote green competencies. Wangler (2012) finds that that public R&D expenditures are important for innovative activities in orange technologies. We lead the reader to exhibit 13 to see the correlation between R&D in Renewable Energy and the total number of patent applications in RE and Non-Fossil Fuel sources in Spain and UK.

Additional information can be found in Appendix 8.

5.4.3. Patents

Patent analysis by Johnstone *et al.* (2010) concluded that FITs encouraged to a larger extent RD&D investments in more immature, high cost technologies like solar PV while TGCs encouraged to a greater extent RD&D investments in more mature technologies like wind onshore. The same conclusion is reached by other authors (see Verbruggen *et al.,* 2009; Bergek and Jacobsson, 2010 or Jacobsson *et al.,* 2009) who show that producer surpluses from TGC schemes are reinvested in mature technologies in those contexts where they are the main support scheme for renewable energy diffusion like in Sweden, Flanders or the UK. During the NFFO auctions in the UK, the fierce competition kept surpluses to the minimum and therefore there were limited availability of funds to reinvest in R&D (Lewis and Wiser, 2007). Lee *et al.,* 2009 concluded that countries with tendering have not been those with greater or lower patents.

A summary of relevant literature of the relationship between different policies and different innovation outcomes (mainly patenting) on different technologies can be found in Table 3.

In Exhibit 12 we show differences in total patents of patent applications to the EPO in climate change mitigation technologies (CCMT), between the UK and Spain, but also differences in the rate of increase. The reduction in both deployment and R&D incentives in Spain can be seen with relatively sharp declines in renewable patenting in Spain, a shift that did not take place in the UK. Given that the UK presents increases in patenting even during a time

Table 3

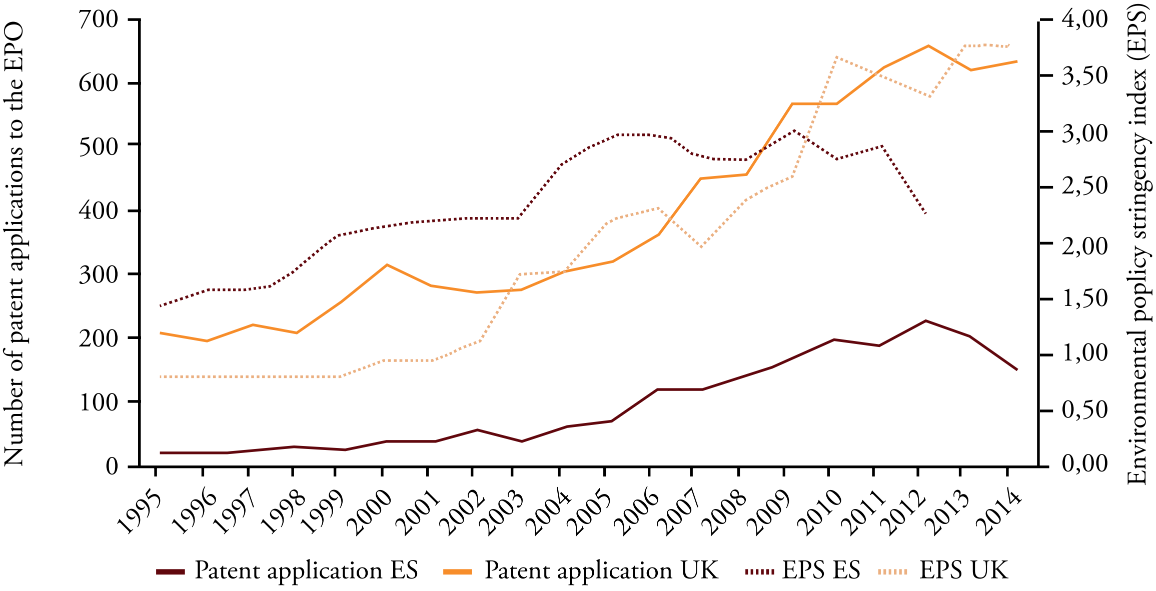
Summary of the impacts of different policies on various innovation outcomes from the literature

Paper	Policy	Outcome	Impact	Scope
Johnstone *et al.* (2010)	FITs TGC RO Taxes Voluntary programmes	R&D investments Patents	FITs: (+) on R&D investments and patents in immature, high cost techs, *e.g.* PV. TGC: (+) on R&D investments and patents in more mature technologies, *e.g.* wind onshore. Tax measures and voluntary programs are not significant for any technology. Obligations are only significant for wind	28 countries (AT, AU, BE, CA, CH, CZ, DE, DK, ES FI, FR, GB, GR, HU, IE, IT, JP, KR, LU, NL, NO, NZ, PL, PT, SE, SK, TR, US) [1978-2003]
Choi and Anadon (2014)	FITs RPS	Patents	FITs: (+) for PV, contingent on the prior existence of semiconductors manufacturing sector, with the exception of China. No effects of RPS	14 countries (AU, AT, CA, CH, FR, DE, IT, JP, KO, NE, ES, SW, UK, US) [2001-2009] Final database 13 countries excluding China
Lindman and Soderholm (2016)	FITs Public R&D support	Patents	Both: (+) on patent applications in wind power sector. Impact of public R&D greater if established with FITs. The impact of FITs become deeper as the technologies are more mature. R&D programs should not be designed in isolation. 10% increase in FIT levels is associated with a 3-4% increase in wind power patents	4 Western European countries [1977-2009]: DK, ES, SE, DE
Bergek & Jacobsson (2010)	TGC	Incentives to innovation	No Technological change incentives: it cannot be expected to contribute to technical change and cost reduction more than in a marginal way	Sweden [2003-2008]
Jacobsson *et al.* (2009)	TGC	Qualitative analysis innovation incentives	No impact. The TGC system is throwing money at investors, rewarding them with excess profits. These have been associated with investment in mature technologies, but little money on real RES-E innovations	Results for the EU with a focus on previous studies in Flanders [2002-2010, analysis: 2002-2007], UK [2002-2020, analysis: 2002-2006] and Sweden [2003-2030, analysis: 2003-2007]

Source: Own elaboration from literature review.

Exhibit 12

Joint evolution of patent applications and environmental policy stringency in Spain and in the UK



Source: Own elaboration with data from OECD.

in which there were 'weak' deployment policies, we can hypothesize that the domestic institutions created in the UK from a technology push perspective may have helped drive UK competitiveness in research, in spite of lower incentives for deployment and in spite of cuts to R&D budgets. Spain's laissez faire approach on the technology push side, as well as larger cuts in funding amounts for R&D meant that, once deployment incentives and R&D were cut, patenting suffered.

Mapping the stringency of environmental policies[19] against the number of Climate Change Mitigation Technology (CCMT) patents, we show a positive relationship between the two developments for both countries Spain and UK from the period

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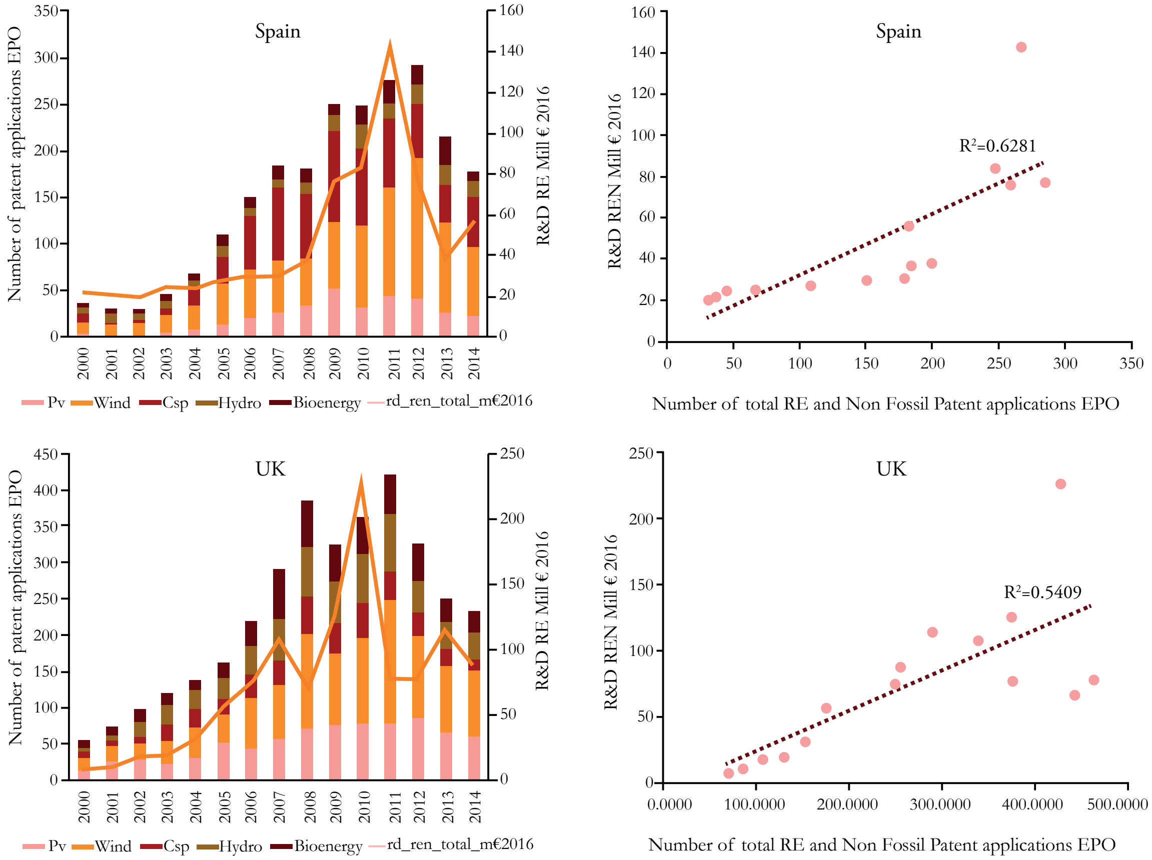
[19] The OECD Environmental Policy Stringency Index (EPS) is a country-specific measure of the stringency of environmental policy defined as the degree to which environmental policies put an explicit or implicit price on polluting or environmentally harmful behaviour. The index ranges from 0 to 6 (lowest to highest stringency). The index evaluates degree of stringency of 14 environmental policy instruments related to climate and air pollution among these the existence of FITs and/or TGCs (Botta and Kozluk, 2014).

1995 until the last year with available data[20] countries. As has been observed more broadly in a set of OECD countries (IRENA/EPO, 2017), the introduction of more stringent environmental policies is associated with a larger focus on innovation activities, at least as measured by patents in GHG mitigation technologies.

Although correlation does not imply causality, we could say that both regulation and the amount of R&D expenditure are associated with increased innovation activity measured by patent applications (Exhibit 13).

Exhibit 13

Correlation between R&D in Renewable Energy (Mill€2016) and the total number of applications in RE and Non-Fossil Fuel sources in Spain and UK



Source: Own elaboration with data from OECD and IEA.

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[20] 2014 for patent applications to the EPO by application date and applicant country of residence, 2015 for the EPS of the United Kingdom and 2012 for the EPS of Spain.

5.5. Competitiveness

5.5.1. Net job creation

Supranational Organisations like the UNEP or the International Labour Organisation (ILO) have stated that a green economy has positive effects on labour markets and enhances social equity (UNEP, 2011; ILO, 2011). It has been argued that promoting renewable energy can have positive effects on reducing energy security, addressing climate change, and promoting job creation (Lambert and Pereira-Silva, 2012). While the literature broadly suggests there is some evidence linking renewable energy promotion to benefits related to the two first challenges, the evidence is not conclusive with regard to employment effects of the promotion of renewable energy sources when considering the full economy and not just the renewable energy sector.

Although in the Impact Assessment on the Renewable Energy Roadmap, the European Commission concluded that meeting the 20% renewable energy target fix for 2020 would generate a net increase of 650,000 jobs in the EU (EC, 2006), other estimates suggest that reaching the same target would create 410,000 additional jobs (Ragwitz *et al.*, 2009). Cambridge Econometrics (2013) estimates that the 2050 Road Map and the CO2 emissions targets for that date would increase the net employment in the range of 0% to 1.5%.

Research suggests that the impacts on employment creation may depend on the technology and the country context. With a focus on the two countries analysed in this paper, Table 4 summarizes the results in literature. Most of the differences can be attributed to the scope of the analysis. As one would expect, when jobs in individual sectors in renewable were assessed, the results were more positive regarding job creation than when analysis aimed to understand general effects across the economy. This is the mirror image to research showing that imposing higher costs on energy intensive industries may result in local job losses in those industries with less negative effects (or in some cases positive) when considering the full economy.

Table 4

Summary of literature on employment effects of energy policy

Paper	Country	Impact	Results
Calzada-Alvarez *et al.* (2010)	Spain	Negative	Green programs in Spain destroyed 2.2. jobs for every green job created. Total of 110,500 destroyed jobs. Each MW of RE installed cacapcity destroys 5.28 jobs: 8.99 by PV, 4.27 by wind or 5.05 by mini-hydro mainly in metallurgy, non-metallic mining and food processing, beverage and tobacco industries
Moreno and Lopez (2008)	Spain (Asturias)	Positive	New employment in Asturias from 2005-2010. For the energy sector: creation of new 587 jobs in the baseline scenario varying from 782 jobs in the optimistic to 274 in the pesimistic scenario
Ortega *et al.* (2015)	European countries (Spain and UK)	Positive	The deployment of the wind-onshore, wind-offshore and PV led to the creation of 548,019 jobs (direct and indirect) in the EU28 in 2012. Five countries account for more than 75% of the generated jobs, among them Spain with a 9.5% of the total and the UK with a 5.7% of the total. See exhibit 13 for a detailed data
Markandya *et al.* (2016)	European countries (Spain and UK)	Positive	39,700 new jobs in Spain because of a shift to green economy. In the UK the generation of jobs had been around 13,300. In Spain the highest loss of jobs: basic metals and fabricated metal industry (-6,300), construction sector (-2,200) and financial intermediation (-6,400). The more positive effects in Spain: electricity, gas and water supply sector (+15,700), Renting of machinery and other business activities (+13,400) and retail trade and repair of household goods (+10,000). In the UK the highest loss of jobs: electricity, gas and water supply sector (-4,000), financial intermediation (-3,000) and real estate activity (-2,100). The more positive effects are: renting of machinery and other business activities (+12,000) and the whole sale trade and commission trade (+4,000)
Blanco and Rodrigues (2009)	European countries (Spain and UK). Wind sector	Positive	In 2007 Spain had 20,500 direct jobs in the wind sector. This situates the country as the third one after Germany and Denmark within the European context. In 2007 most of the people working in wind sector used to do it in the production of wind turbine components (32%) and in the provision of specialised services (31%). Wind turbine manufacturers represented 16% and development and operation workforce accounted for 21% (AEE, 2007). In the UK, the number of direct jobs reached 4500 people in 2007 with a high importance of offshore wind energy and small wind turbines

Table 4 (continued)

Summary of literature on employment effects of energy policy

Paper	Country	Impact	Results
Boettcher *et al.* (2008)	UK. Wind sector	Positive	Current and future jobs in the wind energy sector UK. The study provides direct employment exhibit s. Authors estimates that between 18,000 and 52,000 of additional full-time workers will be needed in the near future vs. the 2008 level of 5,000 people working directly in the wind energy industry.
Marsh and Miers (2011)	UK	Negative	Using an input-output model, the authors study the economic impacts of the renewable energy policy in Scotland and the UK in general. Loss in jobs in the UK economy in favor of green jobs. For 2009/2010 period and based on the direct employment for every job created in the renewable electricity sector 3.7 jobs were lost in the UK (-7,300 jobs of net impact) while 1.1 in Scotland (-100 jobs of net impact). Conclusion: the policy to promote renewable energy in the UK had an opportunity cost of 10,000 direct jobs in 2009/10 and 1,200 jobs in Scotland.

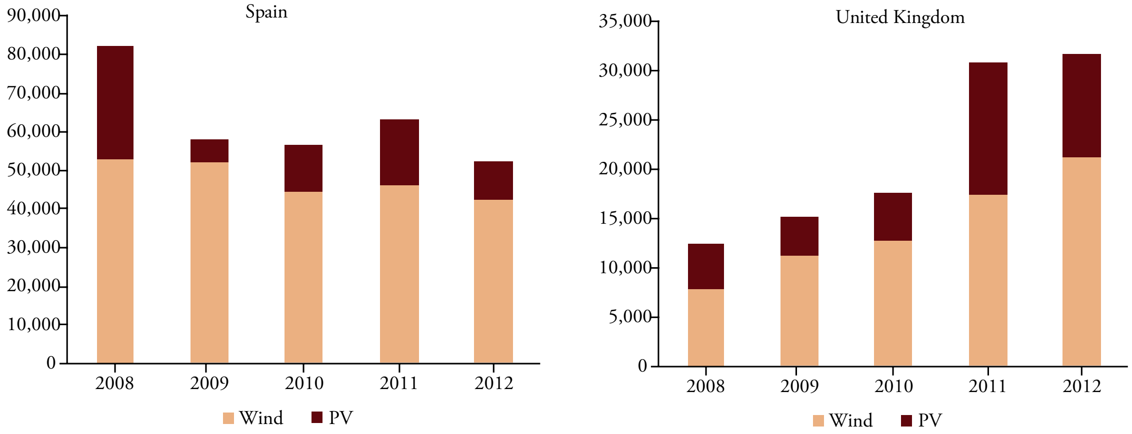
Source: Own elaboration from literature review.

Table 4 suggests that more work reconciling and deepening evidence regarding the overall ipmact of various policies on job creation is still needed.

Having said that, for completeness we include Exhibit 14 to show the extent to which the renewbale energey sector has grown in the two countries, drawing on wind and solar energy employment data presented by Ortega *et al.* (2015).

Exhibit 14

Total employment (direct and indirect) associated to wind energy and solar energy

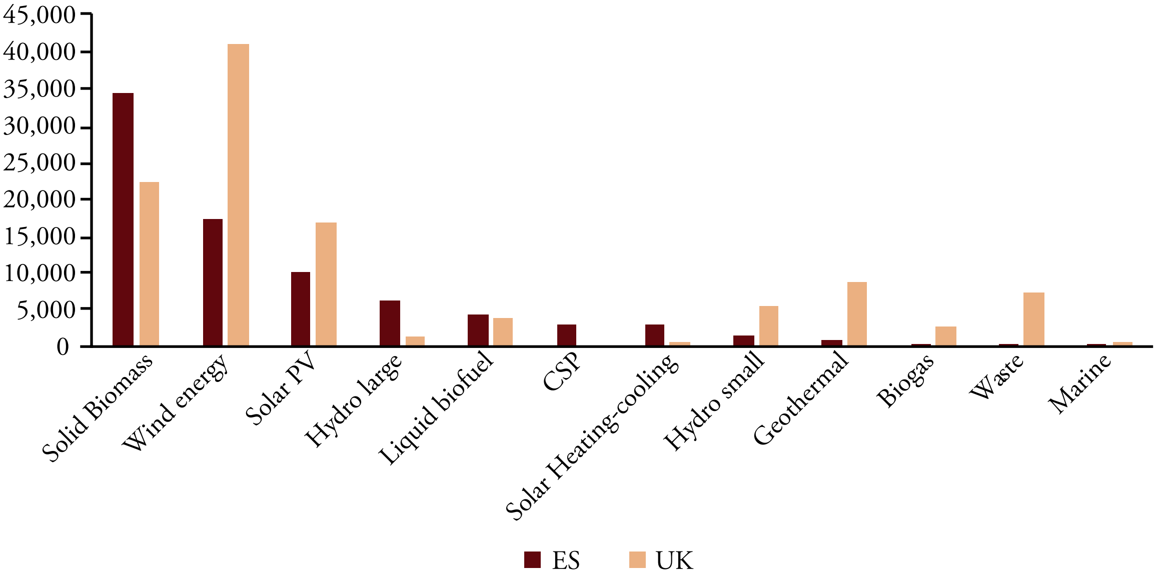


Source: Own elaboration with data from Ortega *et al.* 2015.

The last available data from IRENA (2017) from 2016, report that the total number of direct employment in renewable energy technologies reached 111,297 people in the UK vs. 82,363 in Spain (Exhibit 15), suggesting a very significant change between 2012 and 2016 in the UK.

Exhibit 15

Current level of employment by technology and country in 2016



Source: Own elaboration with data from IRENA data and resources.

5.6. Socio-economic impacts

Climate and energy policies and, particularly, renewable electricity support schemes are being financed in many EU countries through the electricity bill. Policy makers are increasingly concerned about the distributional and welfare impacts of those climate and energy policies and, particularly, on the effects on the poorest segment of the population. Low-income households are more likely to be negatively affected by the economic crisis and by higher electricity prices. Too large welfare costs from energy and climate policies for the poorest segment of the population may generate a social backlash against the policy, making it socially unacceptable and politically unfeasible (del Río *et al.*, 2012; Neuhoff *et al.*, 2013).

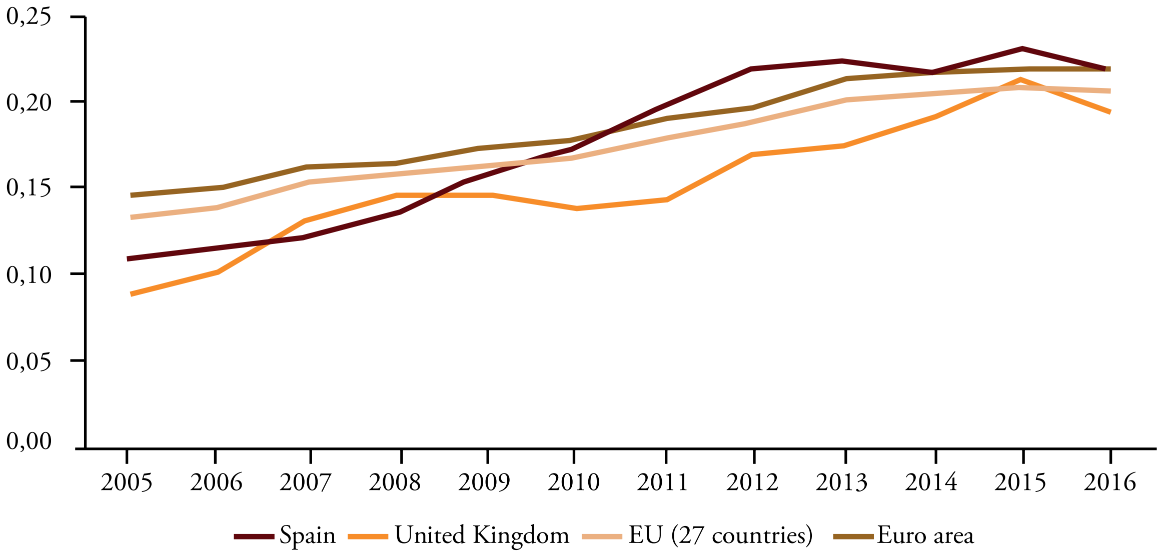
5.6.1. Variation in the electricity prices paid by consumers (domestic)

Literature has been quite critical about the effects of renewable energy support policies and the socio-economic impacts of this kind of instruments (del Río and Gual, 2007; Frondel *et al.,* 2010; Menanteau *et al.*, 2003; Jacobsson *et al.,* 2009, among others). Both the use of FITs and quantity instruments as TGCs have generate negative increases in the market price paid for electricity and it cost for consumers.

According to Eurostat (2017), the price of electricity for medium size households in Spain has doubled in a decade (from 0.11 €/kWh in 2006 to 0.22 €/kWh in 2016). A similar pattern can be found in the UK where the price escalated up to 0.19€/MWh in 2016, 90% higher than the 2006 price with 0.10 €/kWh. This growth has been more dramatic than the average increase in the EU where prices in the same period only upturned 50% (Exhibit 16). These marked patterns are raising the concerns of

Exhibit 16

Electricity price evolution for medium-size households (2500 and 5000 kWh consumption) (€Kwh)



Note: Average national price in Euro per kWh including taxes and levies applicable for the first semester of each year for medium size household consumers (Consumption Band Dc with annual consumption between 2500 and 5000 kWh). Until 2007 the prices are referring to the status on 1st January of each year for medium size consumers (Standard Consumer Dc with annual consumption of 3500 kWh).

Source: Own elaboration with data from Eurostat.

governments in both countries on the effects of the climate policy on electricity prices and therefore on the welfare of households, particularly the poorest ones.

In the Spanish case, the increase in the retail price may be attributed to the objective of the government to reduce the tariff-deficit, which reached its peak in 2013 with 30,000 M€, according to the European Commission (2014) and that has been reduced up to 23,070 M€ in 2016 according to the CNMC[21]. The tariff deficit has been the result of a fast increase in regulated costs from 2006 that were not covered by regulated prices for electricity. All the regulations established from 2012 onwards in Spain has had as their main goal to financially stabilised the electricity system through the significant reduction of regulated costs and the FITs and FIPs to support renewable energy generation (Costa-Campi, 2016; Dopazo and Rivero, 2014). Díaz-Mendoza *et al.* (2015) states that from 2006 to 2013 the cost of the electricity system increased 168% because of the subsidies to renewable generation, the regulated costs and the payment of the existing debt.

Indeed, the most recent information provided by the CCC (2017) reports an increase in electricity prices of 61% from 2004 to 2016 in UK households (31% due to an increase in wholesale and network costs, 7% due to the impact of non-climate policies and 25% due to the impact on climate policies on consumers). For the purpose of this paper, we are interested in the latter. Price support for low-carbon generation technologies added 1.6 p/kWh, the impact of EU ETS and UK Carbon price support on the wholesale electricity price added 0.8 p/kWh and 0.3p/kWh were added as a result of other climate policy costs as EE policies or upgrades in networks. These costs were counterbalance partly by a reduction in wholesale prices because of renewable generation of 0.6p/kWh. The CCC (2017) estimates that electricity prices will rise 33% from 2016 to 2030 due to rises in wholesale and network costs and climate policy costs.

6. DISCUSSION AND POLICY IMPLICATIONS

National governments and policy makers are facing the challenge of how to support the transition and transformation of a high-carbon electricity systems

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[21] The CNMC is the Spanish regulator called Comision Nacional de Mercados y Competencia.

to low-carbon ones, with the main objective of addressing the threat of climate change and complying with the objectives established at the supranational and national levels, in terms of GHG emissions, as well as meeting policy goals in terms of competitiveness, cost-effectiveness, security, and fairness.

We have compared the approaches towards promoting renewable energy, and their outcomes, in two large EU countries with similar low levels of interconnection, concern for energy poverty, and focus on competitiveness during the period between 1990 and 2017. In order to do this, we implement two typologies to characterize the approaches of both countries: a technology push / market pull typology that divides policies by their main impact, and a policy design typology that divides instruments into regulation, economic and financial instruments and informational (or soft) instruments. Using these typologies, we found that the Spanish approach can be characterized as 'deployment focused' and based on a single instrument, while the UK approach was more 'holistic and experimental'. Spanish energy policy has relied for more than 15 years on a single economic instrument to promote renewable energy capacity. Deployment subsidies, and specifically, feed-in tariffs/premiums payments to producers were the only policy instrument in the space until 2012. The most important difference between the Spanish and UK approaches were the efforts of UK policy makers on creating new policies and providing funds for energy R&D but also the variety of market pull instruments used by the UK over time.

We then evaluated the evolution of the renewable power sector in both countries over time by developing and implementing a set of criteria: environmental effectiveness, technological effectiveness, cost-saving impacts, innovation outcomes, competitiveness and socio-economic impacts.

Drawing on a range of indicators, we found that Spain was able to stimulate large amounts of deployment until it cancelled the support, because of its choice of tool and its incentive level. This deployment is associated with some cost reductions in the technologies and learning in terms of the integration of renewable electricity production into the system. However, from an economic and regulatory perspective the policy management does not seem to have been as efficient as it could have been. We showed that increased deployment also led to increases in electricity costs for consumers, and although the development of the wind and solar sectors (predominantly) was accompanied by jobs in installation; domestic activity in private sector R&D and patenting may not have developed.

The government has tried to control the costs of the system by publishing successive regulations that have progressively reduced public support for renewable generation, causing regulatory instability that harms and hinders investment. After the cancellation of any further monetary support in 2012 and the damage that the economic crisis caused in the budget allocated to renewable energy R&D, recently Spain has established an auction framework for the support of new installed capacity. These auctions are technology-specific and with a predetermined volume of capacity in order not to incur in unexpected high costs as in the past (Del Río, 2017). However, it is unclear and perhaps even unlikely that these auctions will result in increased innovation activities in the private sector and universities, measured by patents and private sector entrepreneurship. This is not necessarily a problem, but we argue that the literature does not support making a case for these policies in terms of private sector innovation or high-tech manufacturing.

A completely opposite approach has been followed by the United Kingdom. The UK relied for more than 10 years on an auction system to promote renewable generation capacity. However, as the country counted with natural gas reserves and a high generation from nuclear power, it was not until the early 2000 when government really tried to boost renewable generation. In view of the low success of the auction scheme to promote deployment, the UK government established a TGC system which was in place for more than 15 years. However, TGCs support in the UK has not been as effective as FITs in Spain in order to promote renewable energy capacity. It has not been until the introduction of FITs in 2010 for small projects and in 2014 with CfD that the UK has started to increase exponentially its electricity generation from renewable energy. It should be highlighted that the strategy followed by both countries has differed not only in terms of the type of demand-pull policy instruments used but as well in terms of the supply-push instruments. In view of the indicator-based assessment presented in previous sections, while the UK has relied on technology-push instruments, *e.g.* direct investment in the way of R&D funding in renewable energy in the last decades, Spain has not put in place any relevant institutional support to renewable energy R&D. Partly because of the economic crisis, Spain has not used neither direct funding, nor the creation of research organisations or the establishment of public private partnerships. We argue, however, that our analysis of policy approaches and outcomes in Spain and the UK makes a strong case that if the Spanish government is interested in innovation and competitiveness in the energy space, it will need to both invest more funds but also set up new institutions. A lot has been learnt from some of the approaches tried in the UK and we also have a growing body of evidence regarding the effectiveness of approaches in the United States, *e.g.* Howell (2017), Anadon *et al.* (2016), NAS (2017) or Doblinger *et al.* (2018). We believe that there is an opportunity to set up different mechanisms to both allocate and fund research and development in key energy technologies, where Spain may be able to compete with the right conditions.

Kitzing *et al.* (2012) state that there is a trend among European countries towards the use of policy mixes and the application of multiple support instruments in parallel. This convergence may be taking place because, after more than two decades trying to promote the use of renewable energy for electricity generation, policy makers have more information and ex-post evaluations of how different instruments have performed in different geographic and sectoral contexts. It may also be happening because the costs of some of the technologies have come down significantly and because their performance is better proven. This observation regarding the use of policy mixes is more reflective of the UK approach over time. While Spain is starting to test additional instruments on the market pull side (*e.g.,* it recently started to use auctions after several years of using FITs), providing additional support to the hypothesis about policy convergence, it has not yet devoted significant effort or resources for complementary programs promoting R&D.

The following table (Table 5) summarizes the main indicators and outcomes studied in this paper.

Table 5

Summary of indicators and outcomes for Spain and United Kingdom

Criteria	Outcome/Output	Specification	ES	UK
Environmental Effectiveness	1. GHG emission reduction and distance to targets	MtonnesCO2eq-Index (1990=100)	2000: 385.5877 MTonnesCO2eq (134.87, 1990=100) 2015: 335.6615 MTonnesCO2eq (119.41, 1990=100)	2000: 709.508 MTonnesCO2eq (91,43 1990=100) 2015: 503.4996 MTonnesCO2eq (66.33, 1990=100)
	2. CO2 intensity of the power sector	Carbon intensities of electricity (gCO2eq/kWh)	2016: 341gCO2/kwh	2016: 623gCO2/kwh
Technological effectiveness	3. Installed capacity of RE	Cumulative installed capacity MW	2000: 18,007 MW 2016: 48,021 MW	2000: 2,937 MW 2016: 35,505 MW18 007
	4. Distance to target	Distance to target (%)	%RE target 2005: 8.5 vs. 2016: 17.3 (Target 20%)	%RE target 2005: 1.3 vs. 2016: 9.3 (Target 15%)
Cost-saving impacts	5. Support costs of generation RE	Cost in €/MWh of supported electricity	On average financial deployment incentive 32% greater in 2010 and 17% greater in 2015 in comparison to the United Kingdom. Support costs (€/MWh) average: 2010: 144.37 vs. 2015: 143.17	Support costs (€/MWh) average: 2010: 98.33 vs. 2015: 118.04 While Spain has decreased the financial support, the UK has increased it in the last years.
	6. Differences in the financing schemes of installed capacity	Type of financing scheme and entity (projects, loans, equity)	Projects funded by loans from the European Investment Bank (EIB). 2.3 USD billion have been financed through these instruments in Spain.	USD 24 billion funded mainly through asset finance in 2015 and 2016

Table 5 (continued)

Summary of indicators and outcomes for Spain and United Kingdom

Criteria	Outcome/Output	Specification	ES	UK
Innovation	7. Cost reductions and learning rates	€/MW (%)	Installed costs reductions in commercial deployment for wind onshore from 1989 to 2017: 52% reduction in costs. For residencial PV 2013-2017: 48%	Installed costs reductions in commercial deployment for wind onshore from 1989 to 2017: 30% reduction in costs. For residencial PV 2013-2017: 44%
			LCOE OW from 2010 to 2016, Spain presents: 48%. For residential PV 2013-2017: 41%	LCOE OW from 2010 to 2016, UK presents: 10% decline. For residential PV 2013-2017: 38%
	8. R&D investments	Mill € 2016 and R&D expenditures by each 1000 monetary units of GDP	RE R&D expenditures: 2015 Mill USD ppp: 79.614	RE R&D expenditures: 2016 Mill USD ppp: 93.728
			Public energy R&D budget %GDP 2015: 0.0101%, 2016: n/a	Public energy R&D budget %GDP 2015: 0.0197%, 2016: 0.0208%
	9. Patents	Patent applications to the EPO by applicant country and priority date by technology in RE.	CCMT patent counts (EPO patents by inventor country of residence application date): 2000=36.6 vs. 2014= 151.6	CCMT patent counts (EPO patents by inventor country of residence application date): 2000=314.3 vs. 2014= 631.7
Competitiveness	10. Net job creation	Number of jobs	Total number of Jobs in RE: 82000 Net jobs: great variation depending on the source and indicator. No conclusive data	Total number of Jobs in RE: 111300 Net jobs: great variation depending on the source and indicator. No conclusive data
Distributional effects	11. Variation in the price paid for electricity (households)	€/Kwh	2000: 0.1097 €/kwh vs. 2016: 0.2185 €/kwh	2000: 0.0877 €/kwh vs. 2016: 0.1951 €/kwh

Source: Own elaboration from the literature review.

Although the analysis can help to draw conclusion on RES-E policy support in the UK and in Spain, there are some limitations to our analysis. First, as we have acknowledged throughout, it is impossible to isolate the impact of individual policies on the various outcomes used in the analysis. We draw on papers using observational studies and. in some cases (very few) quasi-experimental approaches to more clearly identify impacts, but none of the relationships between policies and changes in deployment, carbon intensity, patents, jobs, etc, are causal. But research undertaken over the past 20 years as well as data available regarding the evolution of the renewable power space do suggest some areas in which there is evidence that particular approaches fostered particular outcomes over others. The clearest example is the positive relationship between FITs and increasing deployment of renewable technologies, perhaps at the expense of costs. Evidence regarding the impact of domestic deployment on innovation activities and jobs beyond installation remains elusive.

The main reason for laying out the evidence (or lack thereof) on impacts is that different policy makers may assign more or less weight to different criteria, and an assessment of where two countries using different approaches ended up across a range of criteria may help make the policy debate more transparent. We take no view as to which approach was better, since that judgement would require valuing some outcomes over others.

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SUPPLEMENTARY INFORMATION

Appendix 1. Description of Policy Instruments

Table A.1

Brief description of policy instruments

Policy instrument	
1. Regulation	
1.1. Codes/standard/mandates	
Building codes and standards	Standards or obligations for building energy consumption which try to encourage an effective approach to capturing maximum energy savings (Definition from IEA-IRENA policy database). Building codes or obligations could require the installation of RE heat or power technologies, often combined with efficiency investments RE heating purchase mandates (IRENA 2012). For our purposes, only mandatory building codes and standards will be considered
Product standards (Minimum energy performance standards / energy efficiency standards)	A product standard is a specification, containing a number of performance requirements for an energy-using device that effectively limits the maximum amount of energy that may be consumed by a product. They are usually connected to programs for equipment renovation in buildings
Sectoral standards	Standards or obligations for sector energy consumption which try to encourage an effective approach to capturing maximum energy savings or maximum emission reductions (definition from IEA-IRENA policy database)
Vehicle fuel-economy and emission standards	Limit that sets thresholds above which a different type of emission control technology might be needed. While vehicle fuel-economy and emission performance standards have been used to dictate limits for conventional pollutants such as oxides of nitrogen and oxides of sulfur (NOx and SOx) in vehicles, this regulatory technique may be used to regulate greenhouse gases, particularly carbon dioxide (CO2)
Auditing (Energy audits)	Technical check of energy use, as in a home or factory, to monitor and evaluate consumption. For our purposes, only mandatory energy audits will be considered.
1.2. Obligation schemes/Quotas	Broad term that may include energy efficiency obligations on energy suppliers requiring them to deliver certain energy savings, as well as energy mix quotas requiring energy suppliers to include a certain amount of renewable energy in their generation capacity (IEA-IRENA database glossary)

Table A.1(continued)

Brief description of policy instruments

Policy instrument	
RE obligation schemes (Renewable portfolio standard / renewable electricity standard / renewable energy quota)	Obligates designated parties (generators, suppliers, consumers) to meet minimum (often gradually increasing) RE targets, generally expressed as percentages of total supplies or as an amount of RE capacity, with costs borne by consumers (IRENA, 2012) Minimum share of renewable energy sources (RES) in the energy mix of power utilities, electricity suppliers or sometimes large electricity consumers. Sub-quotas sub-quotas for individual RES in order to stimulate technology diversification could be defined. These quotas are established by national, regional or local governments and they usually increase over time in order to support the development of RES (https://energypedia.info/wiki/Renewable_Energy_Quota_and_Certificate_Schemes). Generally connected to tradable green certificates
Carbon emission reduction target (Energy Efficiency Obligations/ Energy saving obligations)	Target imposed on the energy transporters and suppliers to achieve combined energy savings by assisting customers to take energy-efficiency measures in their homes (OFGEM). Generally connected to White certificates
1.3. Other regulations	
Net metering	Net metering and Self-supply policies allow consumers to generate their own electricity from renewable energy sources and inject surplus generation into the grid, either to be balanced against future consumption or to be remunerated under contractual terms. Specific design elements include, among others, connection provisions, remuneration terms, banking, balancing periods, off-site generation, transmission costs and losses and fiscal regime (IRENA, 2015)
2. Economic and Financial Instruments	
2.1. Direct investment	
Funds to sub-national governments	

Table A.1 (continued)

Brief description of policy instruments

Policy instrument	
Government procurement	Public procurement refers to the process by which public authorities, such as government departments or local authorities, purchase work, goods or services from companies. In the context of this project Government procurement is directly connected to green and sustainable work, goods or services. A specific way of Government procurement is infrastructure investment in RE. Under infrastructure public investment renewable energy projects are directly developed by the governments (IRENA, 2015). Financing provided in return for an equity ownership interest in a RE company or project. Usually delivered as a government managed fund that directly invests equity in projects and companies, or as a funder of privately managed funds (fund of funds) (IRENA, 2012)
R&D funding	R&D funding
2.2. Fiscal/financial incentives	
FITs/FIPs	Price-driven instruments. Feed-in tariffs are regulatory instruments that provide guaranteed purchase at a (often above market price) tariff to eligible producers of electricity from renewable energy sources for a defined period of time (*e.g.* 20 years). Tariff design can account, among others, for technology, capacity installed, electricity prices and overall cost. As such, feed-in tariffs in some countries are designed with degression mechanisms to account for the reduction in generation costs (IRENA, 2014). FIP guarantees RE supplies an additional payment on top of their energy market price or end-use value (IRENA, 2012)
Auctions	Auctions refer to competitive bidding procurement processes for electricity from renewable energy or where renewable energy technologies are eligible. The auctioned product can be either capacity (MW) or energy (MWh). Project developers who participate in the auction submit a bid with a price per unit of electricity at which they are able to realise the project. The government evaluates the offers on the basis of the price and other criteria and signs a contract with the successful bidder, usually a long-term power purchase agreement (PPA) (IRENA, 2015)

Table A.1 (continued)

Brief description of policy instruments

Policy instrument	
Grants and subsidies	Monetary assistance that does not have to be repaid and that is bestowed by a government for specified purposes to an eligible recipient. Usually conditional upon certain qualifications as to the use, maintenance of specified standards, or a proportional contribution by the grantee or other grantor(s). Grants (and rebates) help reduce system investment costs associated with preparation, purchase or construction of renewable energy (RE) equipment or related infrastructure. In some cases, grants are used to create concessional financing instruments (*e.g.*, allowing banks to offer low-interest loans for RE systems) (IRENA, 2012)
Loan/soft loans	Provided by government, development bank or investment authority usually on concessional terms or below the market rates (*e.g.*, lower interest rates or with lower security requirements) (IRENA, 2015). Financing provided to a RE company or project in return for a debt (*i.e.*, repayment) obligation
Taxes & tax relief or exemptions (tax credits/tax rebates)	According to the OECD, Eurostat and other international organisms, Environmental taxes are those ones whose tax base is a physical unit (or a proxy of it) that has a proven specific negative impact on the environment Environmental taxes are divided into four categories: energy taxes (including CO2 taxes), transport taxes, pollution taxes and resource taxes (excluding taxes on oil and gas extraction) Environmental taxes can be allocated to the different tax payers: industry *i.e.* by economic activity according to the statistical classification of economic activities in the European Community (NACE), households as consumers, non-residents and not allocated. The most common in terms of low-carbon transitions are carbon taxes. Carbon taxes are a climate change mitigation policy that, by increasing the cost of fossil fuel technologies, arguably make low-carbon technologies such as renewable energy more competitive in that particular jurisdiction (IRENA, 2015). Other taxes with environmental purposes can be considered On the opposite site Tax reduction/exemption are found. Reduction in tax—including but not limited to sales, value-added, energy or carbon tax—applicable to the purchase (or production) of RE or RE technologies (IRENA, 2012)

Table A.1 (continued)

Brief description of policy instruments

Policy instrument	
User charges	A user charge is a charge for the use of a product or service. A user charge may apply per use of the good or service or for the use of the good or service. The first is a charge for each time while the second is a charge for bulk or time-limited use.
2.3. Market-based instruments	
GHG emissions allowance trading scheme	In GHG trading schemes, industries must hold permits to cover their GHG emissions; if they emit more than the amount of permits they hold, they must purchase permits to make up the shortfall. If they emit less, they may sell these (IEA-IRENA policy database glossary).
Green certificates	These systems are based on obligations to produce or purchase renewable energy-sourced power (generally electricity). Green certificates refer to renewable energy certificates which represent the certified generation of one unit of renewable energy, generally one megawatt-hour (MWh). Certificates can be traded and used to meet renewable energy obligations among consumers and/or producers (IEA-IRENA policy database glossary). The main objective of a system of tradable green certificates is to stimulate the penetration of green electricity into the electricity market. In a green certificate system, certification serves two purposes. It functions as an accounting system to verify whether the obligations have been met. Besides, it facilitates trade in electricity from renewable energy sources. Thus, through the establishment of a green certificate system (GC) a separate market for renewable electricity will originate besides the market for conventionally produced electricity (ECN, 1999)
White certificates (Energy efficiency certificates / energy saving certificates / energy efficiency credits / white tag)	These systems stem from energy efficiency or energy savings obligations; White certificate schemes create certificates for a certain quantity of energy saved, for example a MWh; regulated entities must submit enough certificates to show they have met energy saving obligations. Again, if they are short, this must be made-up through measures that reduce energy use, or through purchase of certificates (IEA-IRENA policy database glossary). Under such a system, producers, suppliers or distributors of electricity, gas and oil are required to undertake energy efficiency measures for the final user that are consistent with a pre-defined percentage of their annual energy deliverance. If energy producers do not meet the mandated target for energy consumption, they are required to pay a penalty.

Appendix 2. Last regulatory changes in Spain

The Law 24/2013 regulates four modalities of self-consumption and it was explicit that all these forms, provided they are connected to the system, must pay tolls for access to the network, the costs associated with the system and those generated by the backup service. In the case that those facilities wanted to sell the surplus of electricity production to the system, the Government would establish the conditions. Indeed, in 2015 the RD 900/2015 established the charges on existing and new self-consumption RES plants both on capacity and generation levels (RESLegal, 2017) which is hampering the recovery of the photovoltaic sector in Spain that had seen in self-consumption a way to regeneration (Mir-Artigues, 2013). On the other hand, and regarding the support mechanisms for renewable generation, in 2017 both the RD 359/2017 and 650/2017 included calls for the allocation of specific compensation for new renewable energy installations through auctions for specific technologies, PV plants and Wind plants, with a cap of 3000 MW (RESLegal, 2017).

Appendix 3. Explanation of criteria

Table A.3

Definition of criteria

Criteria	Definition
Environmental effectiveness	Extent to which a policy meets its proposed environmental objective or realizes positive environmental outcomes.
Technological effectiveness	Extent to which a policy meets its proposed objective in terms of deployment or realizes positive outcomes
Cost-saving impacts	Extent to which a policy has been economically efficient in terms of the resources expended (on financial terms or against social costs/impacts)
Innovation incentives	Potential for innovation (R&D investments and patent applications) and competition to reduce costs.
Competitiveness	Economics effects of the policy in terms of net job creation, industry creation or other macro magnitudes.
Socio-economic impacts	Fairness of the instrument in distributing compliance costs and benefits.

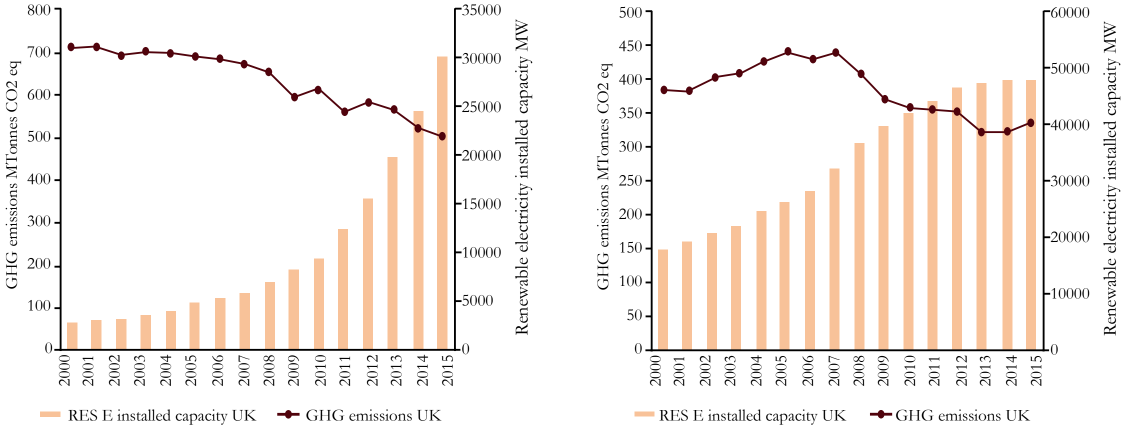
Source: Own elaboration informed by EC(2015), IPCC (2007), IRENA (2014), Konidari and Mavrakis (2007).

Appendix 4. Environmental effectiveness

Exhibits A.4.1 and A.4.2. show respectively the evolution and the correlation between the GHG emission reduction and the renewable installed capacity in the UK and in Spain.

Exhibit A.4.1

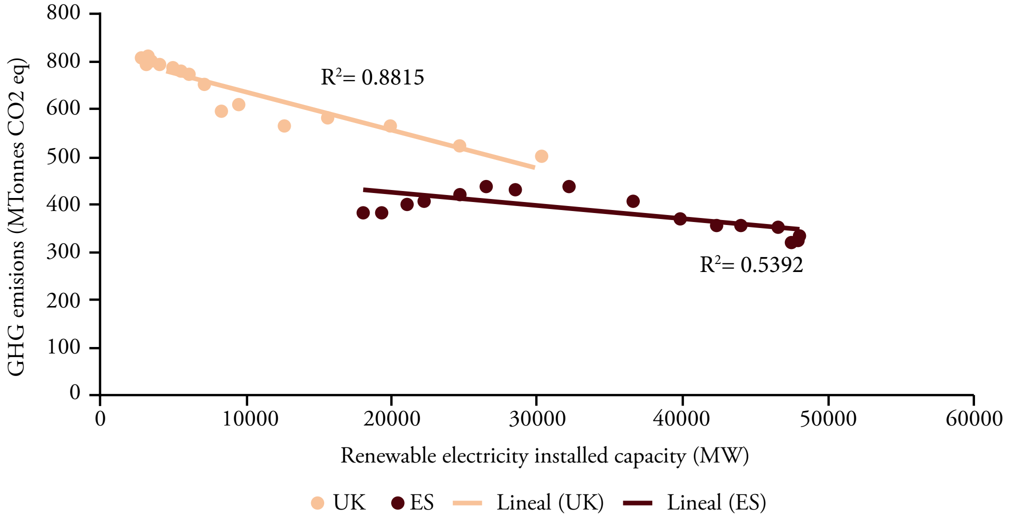
Joint evolution of GHG emissions and RE installed capacity UK and Spain (2000-2015)



Sources: Own elaboration from European Environment Agency (EEA) and IRENA data.

Exhibit A.4.2

Correlation between GHG emissions and RE installed capacity (2000-2015) (data shown in the SI)



Sources: Own elaboration with European Environment Agency (EEA) and IRENA data.

Appendix 5. Technological effectiveness

EC effectiveness indicator

$$E_n^i = \frac{G_n^i - G_{n-1}^i}{POT_{2020}^i - G_{n-1}^i}$$

$$E_n^i = \text{Effectivness indicator for RET } i \text{ for the year } n$$

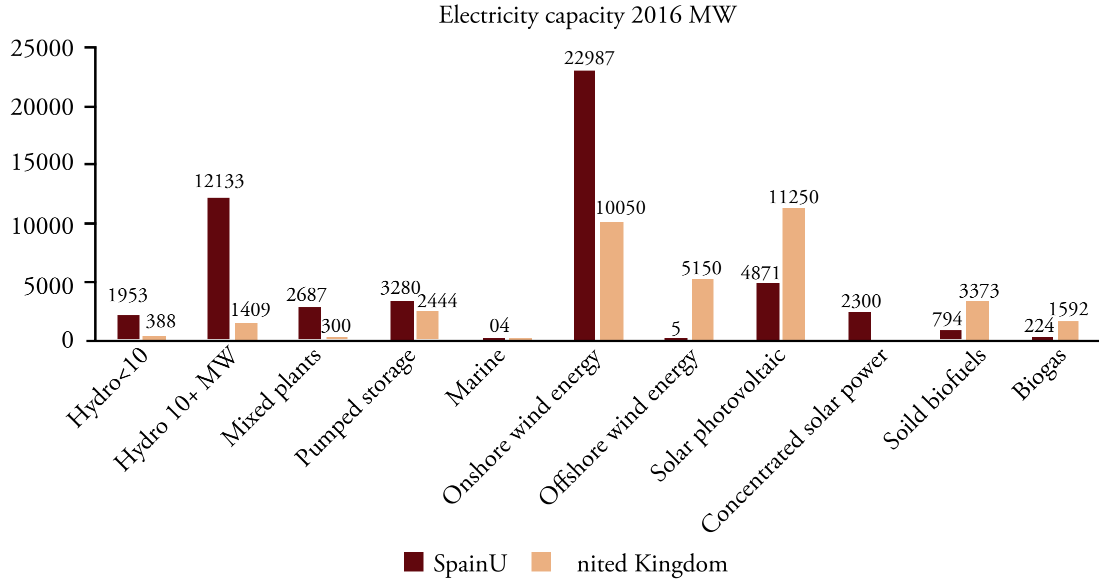
$$G_n^i = \text{Electricity generation by RET } i \text{ in year } n$$

$$POT_{2020}^i = \text{Total generation potential of RET } i \text{ until } 2020$$

The EC establishes as a score to consider an effective deployment above 7% for mature technologies as wind and above 3% for bioenergy and other moderate technologies and 0.5% for solar photovoltaic and immature technologies. These

Exhibit A.5.1

Electricity installed capacity MW by country and technology in 2016

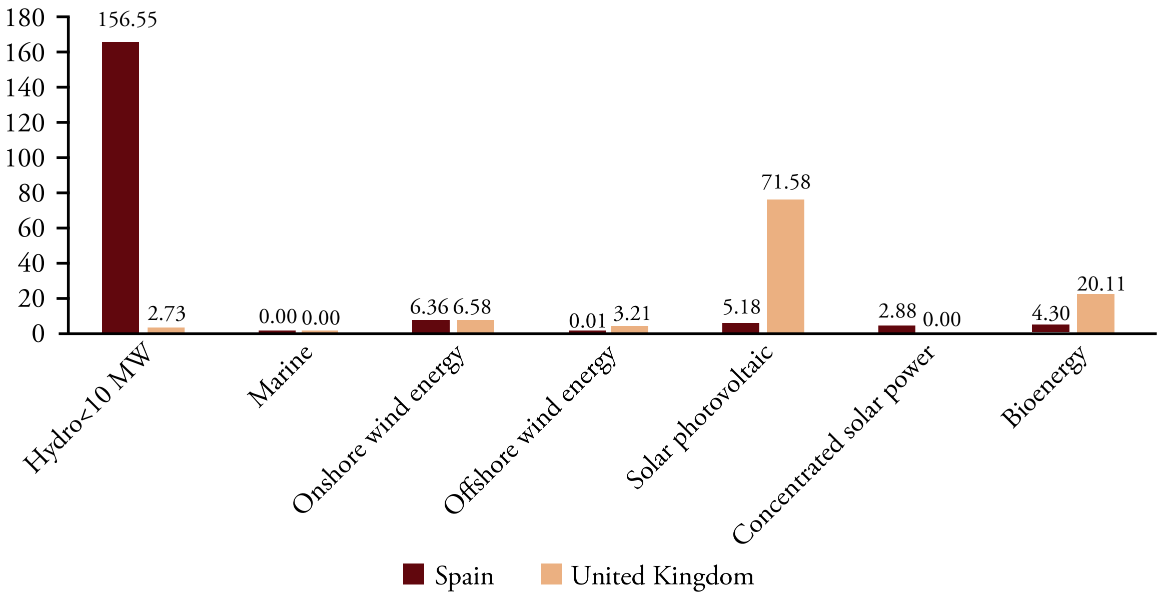


Source: Own elaboration with data from IRENA.

Exhibit A.5.2

EC Effectiveness indicator by technology in UK and Spain (2000-2015)

(Percentage)



Sources: Own calculations using IRENA data and UK and Spain NRPEAs.

thresholds were determined in 2013 so we should be careful when applying them to the different policies in more recent periods.

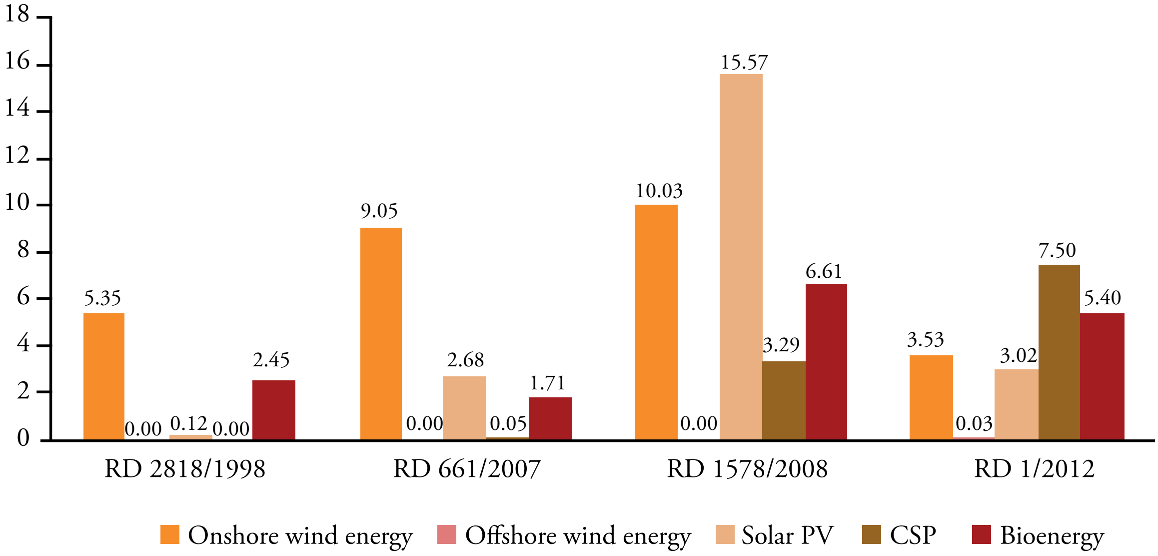
The following exhibits, *i.e.* Exhibit A5.3 and Exhibit A5.4 show an individual analysis of the effectiveness measured by the EC effectiveness indicator of the different schemes and instruments used in Spain and in the UK, respectively, differentiating by technology. The calculations have been made using IRENA data and the information provided by each country on their NRPEAs.

The share of RE in final energy consumption in 2016 and the distance to the 2020 target is another way in which we can measure the technological effectiveness of the different policy frameworks, the following exhibit shows this indicator for the European countries.

Exhibit A.5.3

EC effectiveness indicator by policy scheme and technology in Spain (2000-2015)

(Percentage)

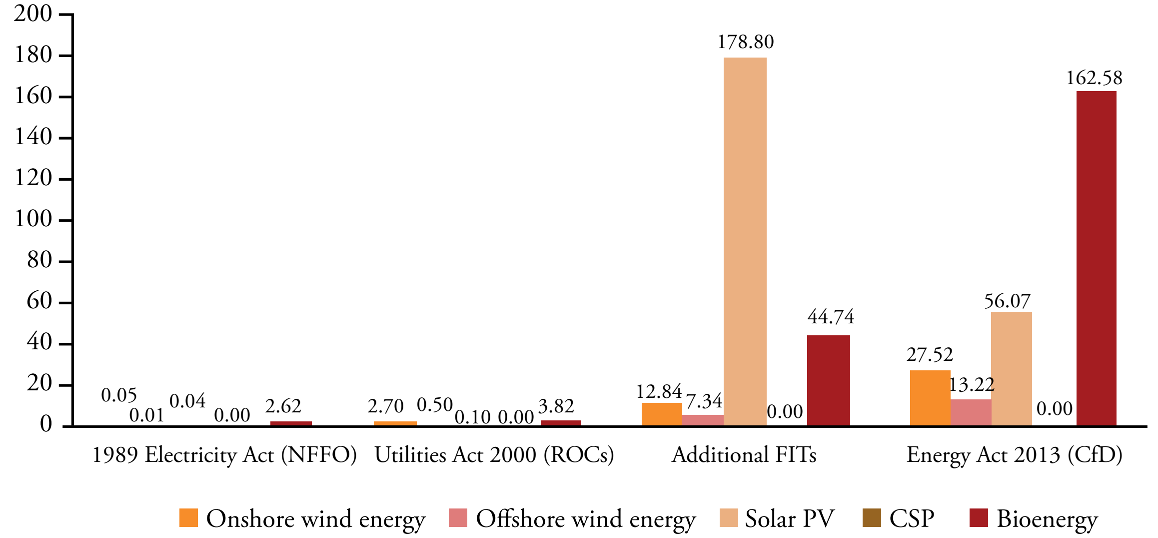


Sources: Own calculations based on IRENA and NRPEAs data.

Exhibit A.5.4

EC effectiveness indicator by policy scheme and technology in the UK (2000-2015)

(Percentage)

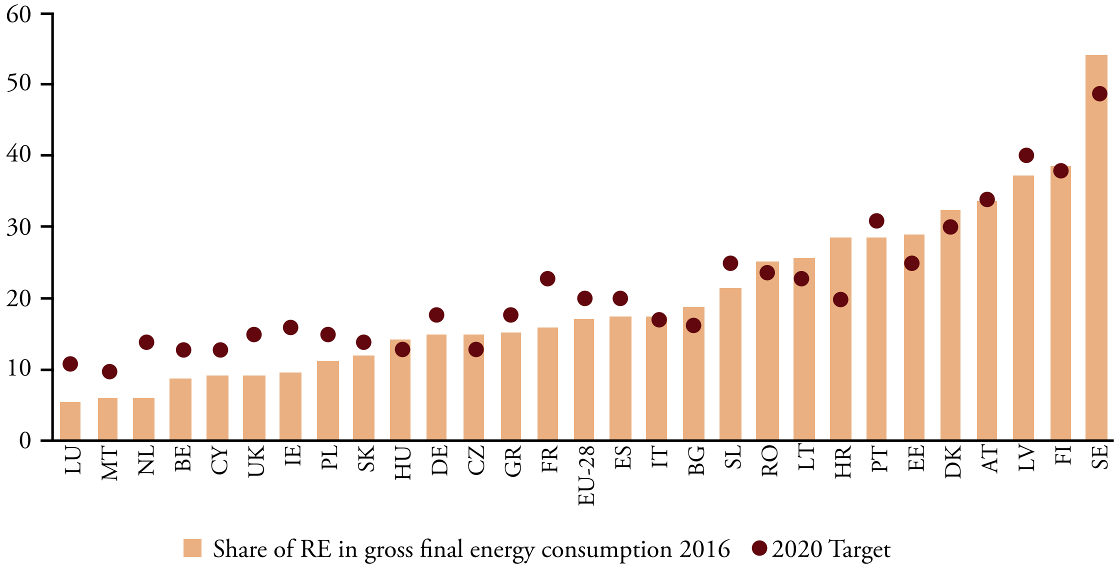


Sources: Own calculations based on IRENA and NRPEAs data.

Exhibit A.5.5

Share of RE in final energy consumption in 2016 and distance to the 2020 target

(Percentage)



Source: Own elaboration with data from Eurostat.

Appendix 6. Time series of cost reduction indicators (installed costs and LCOE)

Although there are some studies that analyse learning rates at the country level[22]; generally, information on learning rates is available by region but not by country (See Rubin *et al.* 2015 for a review of learning rates for electricity supply technologies). This is one of the reasons why we are going to focus on Wind onshore and residential PV in this section. Besides, highlighting the cost reductions in wind onshore as the most mature renewable energy technology and in residential PV as one of the technologies key for future sustainable cities is worth willing.

Installed costs reductions in commercial deployment for wind onshore varies widely from different countries. In the case of the United Kingdom and Spain, IRENA (2018) reports information from 1989, date that both countries started to

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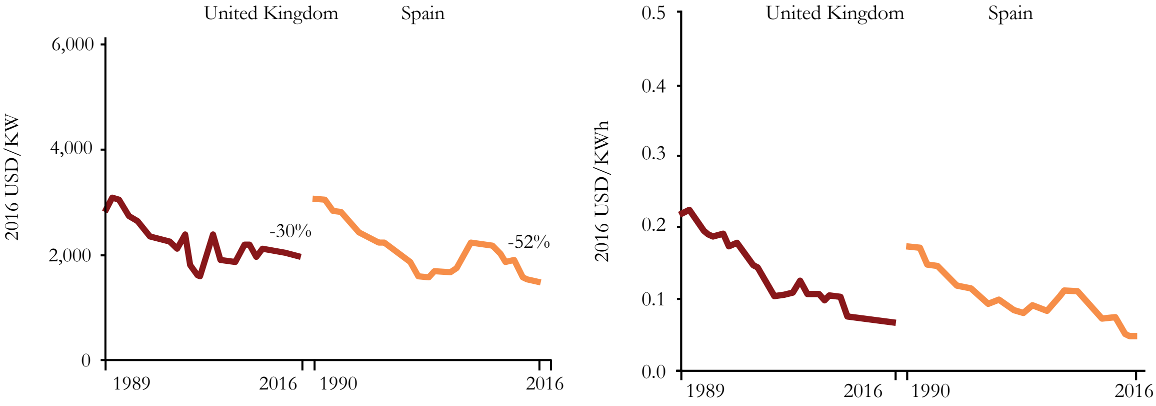
[22] See *e.g.* Neij *et al.* (2004) for turbine producers in Germany, Denmark and Spain; Ibenholt (2002) for UK and Denmark land-based turbines or Klassen *et al.* (2005) for Wind farms in Denmark, UK and Germany among other.

deploy wind onshore, to 2016. Among the countries in the same situation[23], Spain show the highest reduction with a 52% reduction in costs while UK only reaches a 30% reduction up to now. Anyway there is a wide range of individual project costs even withing a region mainly due to different maturity in local markets. Regarding the levelised cost of electricity (LCOE), Exhibit A.6.1. presents the evolution of the LCOE of onshore wind in Spain and in the UK. From 2010 to 2016, Spain presents the highest fall in LCOE, at 48% while the UK has experienced in the same period a decline in the LCOE of 10%. In the same period, capacity factors have increase 16% and 11% in Spain and in the UK respectively.

Exhibit A.6.1

Onshore wind weighted average total installed costs vs. LCOE 1989-2016



Source: IRENA (2018).

Regarding solar, in 2015 and 2016 only 49 MW and 55MW were respectively installed in Spain. Since, 2012 the solar industry in Spain has been stagnant because of all the changes and instability in the regulatory framework and support schemes. However, in 2017 135 MW of new installed capacity arose mainly driven by the combined effect of a reduction in PV equipment prices and the commitment of agents different from the central government, *e.g.* SMEs or regional administrations against climate change. Most of the new installed capacity comes from grid-connected PV systems for self-consumption and stand-alone systems (UNEF, 2018).

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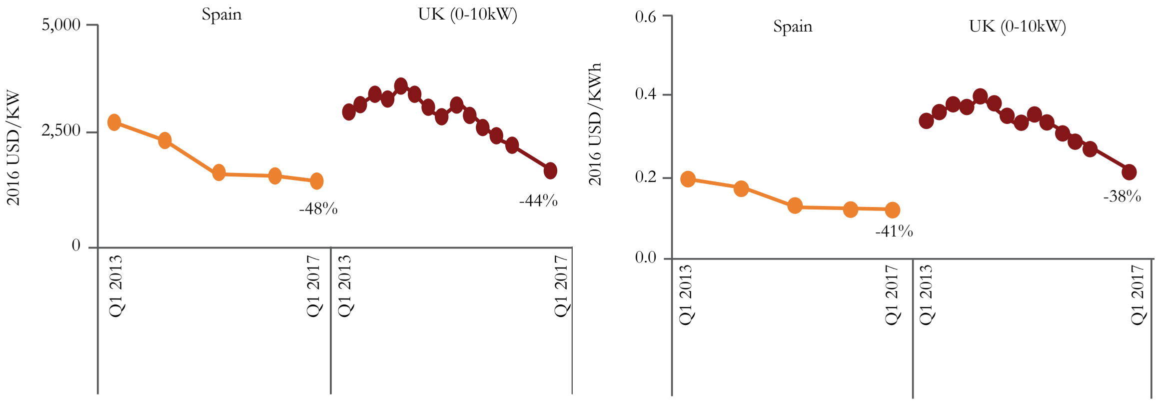
[23] Canada reports cost reduction of about 32% of totalled installed costs in wind onshore and Italy 44%.

The following exhibit (Exhibit A.6.2) show the evolution in the last years of both the average total installed costs and the LCOE for solar PV residential systems.

Exhibit A.6.2

Average total installed costs vs. LCOE from residential solar PV systems 2013-2017



Source: IRENA (2018).

Appendix 7. Differences in financing schemes

The British case is more interesting in terms of instruments and funders. From 2009 to 2016 the number of projects financed by development financial institutions have been much higher than in Spain. There have been 52 renewable energy projects assets from 2009 to 2016. The European Investment Bank through loans has financed 10 of them (8 for wind plants and 2 for other renewables) for 3213.6 USD Mill; while the Green Investment Bank has financed the other 42 (20 bioenergy projects, 10 wind projects and 2 projects for other renewables). The UK Green Investment Bank (now the Green Investment Group) was a non-departmental public body of BEIS, but is now an independent organisation owned by Macquarie Group Limited. This bank has used either loans (1038.8 USD Mill) or equity (3496.9 USD Mill) to finance renewable energy projects.

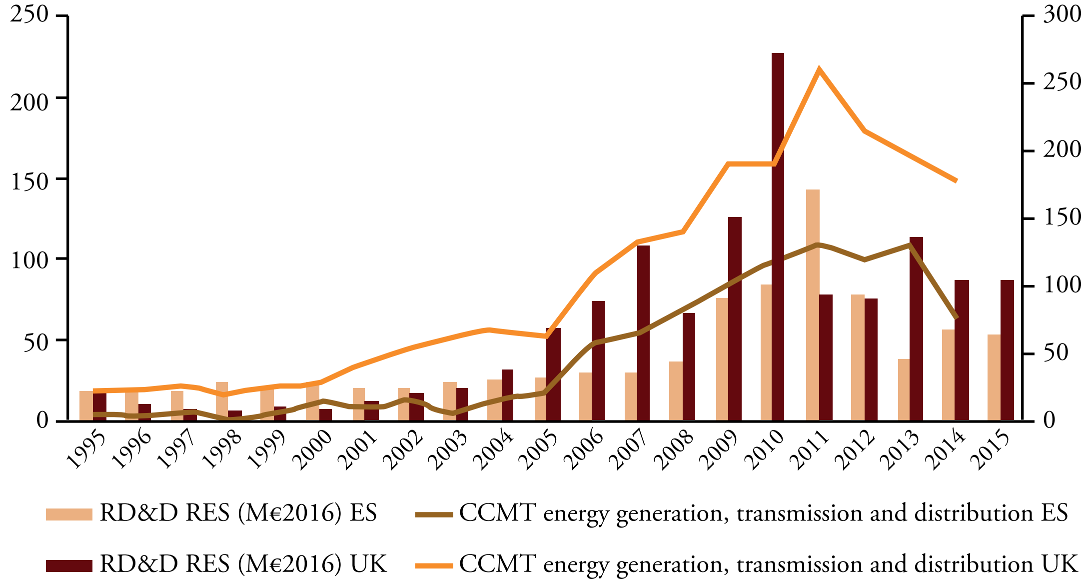
Appendix 8. R&D investment and patent applications

While the Pearson correlation coefficient is higher between the patent applications for the wide range of CCMT and the stringency of the policy for the UK (0.942) than for Spain (0.658), the opposite happens when considering the correlation between R&D expenditures in renewable energy sources and the patent application for such technologies with correlation coefficient for Spain (0.808) higher than for the UK (0.773).

Exhibit A.8.1

Joint evolution of R&D expenditures (M€2016) and number of patent application in Climate Change Mitigation Technologies

(M€2016)



Sources: Own elaboration with data from IEA and OECD.

Appendix 9. Jobs creation

There are more research on the implications of the renewable energy support policies and the green economy targets on labor markets in Spain (Moreno and Lopez, 2008; Caldes *et al.*, 2009; Llera *et al.*, 2013; Cansino *et al.* 2014; among others) than in the UK. Literature is scarce for the British case with few exemptions (Boettcher *et al.* 2008; Marse and Miers, 2011). The UK is generally analysed within the European or OECD contexts (Blanco and Rodrigues, 2009; EC, 2006; Markandya *et al.* 2016; Ortega *et al.*, 2015, among others).

Appendix 10. Socio-economic impacts

Opposite to the Spanish case, the Department of Energy and Climate Change (DECC) states that the average net impact of energy and climate change policies between 2010 and 2013 has been to reduce electricity bills. Increases in energy bills in recent years have been driven mainly by rising international prices for fossil fuels, particularly gas. The UK currently ranks well in Europe for household energy prices. UK households faced comparatively lower electricity prices in 2016 than the average of the European Union, and therefore than Spain which is above the average electricity price paid in the continent. Although in the last year, taxes and levies have increase, comparatively low levels of government policy costs and levies in the UK may contribute to this position. Taxes on energy in the UK are among the lowest in Europe while high prices in some countries are often the result of high levies generally driven by environmental policies (OFGEM, 2016). Anyway, Spain remains in 2016 as the 7th country with the highest electricity prices for households while the UK are in the 9th even being under the EU average.

Literature has been quite critical about the effects of renewable energy support policies and the socio-economic impacts of this kind of instruments (del Río and Gual, 2007; Frondel *et al.*, 2010; Menanteau *et al.*, 2003; among others). Del Río and Gual (2007) analysed the Spanish case for the period 1998 to 2003. The results show that costs of the RES-E support from 1998 to 2003 were almost entirely paid by consumers which may affect to the future acceptance of policies. The authors concluded that additional costs for RES-E support for the consumer increased by an annual average of 23% from 270M€ 1998 to 620M€ in 2003. The conclusion for other countries with FITs is similar. Menanteau *et al.*, 2003 stated that although FITs are simple to implement from an administrative point of view they are costly in terms of subsidies for customers. Frondel *et al.*, 2010 showed that the EEG's in Germany increased the consumer prices for electricity by 3%.

It could be the case the quantity instruments mainly used in the UK had generated different results. However, literature is even more unfavourable for TGC than for FITs. Jacobsson *et al.* (2009) in a comparative analysis of different type of instruments stated that, in the UK, the RO has been costly for the consumer.

Data published by the Non-Fossil Purchasing Agency (2008) suggests that the average price per MWh of wind power in 2006 was around £93.5/MWh, while the Department of Trade and Industry and Ofgem in the UK estimated the production cost at around £55/MWh (DTI, 2006). The profits amount to over 40% of the turnover. The TGC systems seems to have thrown money at investors, rewarding them with excess profits at consumer budget´s expenses. According to Marsh and Meirs (2011), Renewables Obligations as the main policy tool used to stimulate renewable energy generation raised the market price paid for electricity and it cost electricity consumer £1.1B in the UK and £100M in Scotland in 2009/2010.