Energy innovation in Spain

Analysis and recommendations

Policy Brief

Credits

This Policy Brief is based on the 2012 Annual Report by *Economics for Energy* "Energy innovation in Spain: Analysis and recommendations". The full report and the executive summary (both in Spanish) are available at www.eforenergy.org.

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1. Introduction

Energy remains essential for a country's economic development and social well being. In order to reach development levels similar to those of the more developed countries, many developing countries will need to increase their energy consumption, and many will definitely seek to do so in the coming years. Moreover, a large share of the world's population still lacks access to advanced forms of energy (according to IEA's estimates, more than 1,400 million people lack access to electricity and 2,700 million still cook with traditional biomass). If access to modern forms of energy increases, global energy consumption will be significantly affected.

Thus, more and more resources will be needed to meet this growing demand for energy services, a demand that will clash both with the finite nature of fossil fuels and other natural resources needed for producing, transporting and consuming energy. This scarcity has already led to significant increases in the prices of resources (with the exception of natural gas in the U.S., whose price has fallen since 2008 due to increased production of shale gas) and to the higher volatility of those prices, with the consequent negative effects on the economy, both global and of individual countries.

Moreover, fossil energy resources are also contributing to the creation of large-scale environmental problems. Both global warming, induced by increased concentrations of greenhouse gases in the atmosphere, and air pollution, caused by other regional or local pollutants (with their associated damage to health and ecosystems), are due largely to the production and consumption of energy. Indeed, the threat of global warming above tolerable levels is leading many countries, with the European Union as the most representative example, to consider large-scale decarbonization of energy systems.

In view of all this, it seems clear that we need a substantial transformation of the energy sector that allows for meeting our energy needs with moderate environmental impacts and affordable costs. In this situation, energy savings and energy efficiency are becoming more and more important. However, the potential of savings and efficiency, despite being large, is limited. For Spain, for instance, the *Economics for Energy* 2011 report considered feasible (technically and economically) savings of 40% by 2030, in line with the estimates of similar studies for other countries. But there is still a remaining demand that needs to be met.

Here is where innovation plays a key role: we need new technologies, or to make improvements to existing ones, that allow for maintaining the production of energy but in an affordable and environmentally friendly way. In fact, even energy savings and efficiency measures require new technologies to facilitate cost-effective reductions in consumption. Innovation is, in this sense, a fundamental tool for achieving a sustainable energy system, one that increases welfare and the knowledge capital in society.

All of the above is especially applicable to Spain's situation. Spain is a country heavily dependent on foreign energy (in 2011, the energy trade balance contributed 88% to the deficit of the Spanish trade balance[1]), with the consequent risks in the supply price and impact on the competitiveness of the Spanish economy. As regards environmental impacts, there has been a negative trend for greenhouse gas emissions in Spain since the early nineties. The use of advanced technologies could greatly contribute to alleviating these problems.

However, one may question the rationale of a medium-sized country like Spain to promote energy innovation. Indeed, it might make more sense for Spain to delegate this activity to the European Union or to other countries and then, in the context of a globalized world, benefit from their achievements.

In this regard, we need to consider that the development of new energy technologies can become a source of socioeconomic value and employment. Investing in knowledge, in innovation, can bring significant revenues and knowledge spillovers in the medium term by making the Spanish production system more robust and competitive. Moreover, Spain has a relatively developed industrial infrastructure in certain areas of the energy sector. Of course, in order to be able to capture the possible future benefits of expanding this infrastructure, an adequate design of innovation policies would be required.

Unfortunately, innovation processes face many obstacles, both market failures and institutional (or other) barriers, which make innovation productivity insufficient. In the case of the energy sector, liberalization processes have also contributed in this respect (since environmental and public considerations are typically less relevant in the decision-making of private companies than in the decision-making of public companies). These failures and barriers to the innovation process also mean that markets alone cannot produce the innovation that society needs. Thus, although the governments of many countries have worked for decades to enhance domestic innovation (with different degrees of consistency and success), their role seems to be increasingly necessary to achieve the required transformation in the energy sector, given the challenges it faces, and the more knowledge we have about the importance

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[1] Data from the Spanish Ministry of Economy and Competitiveness

of having an aligned, consistent, and efficient innovation system. Indeed, the importance to treat innovation as a system makes this strategy essential.

This policy brief summarizes the contents in the *Economics for Energy* 2012 annual report, whose aim was to assess the state of energy innovation in Spain and the barriers it faces, to evaluate the potential benefits that may result for the energy system from greater investment in energy R&D, and to provide a set of recommendations for the Spanish government to stimulate energy innovation. The policy brief is organized in the following sections: Section 2 presents a summary of the assessment of the state of innovation in Spain based on several indicators; Section 3 provides the main results of the evaluation of benefits of R&D investment in terms of cost reductions in the energy system; Section 4 provides some recommendations on how to encourage energy innovation in Spain from the public sector; finally, Section 5 closes this policy brief with some conclusions. The full report (available on the *Economics for Energy* website [2]) provides further details on both the assessment of the current state and the evaluation of benefits.

2. Energy innovation in Spain: an assessment

Beginning with good news, we can say that in some areas (mainly those related to renewable energies), Spain is developing some internationally competitive technology. However, in general terms, it is difficult to attribute this to the existence of good conditions for innovation, but rather it could be attributed to the individual efforts of some agents. In the case of renewables, the favorable environment that allowed some companies to invest in R&D part of the income derived from premiums to renewables can also have played an important role, together with the support of some regions to industrial development in this area.

In particular, R&D and deployment subsidies since the 1990s are likely to have contributed to a flourishing wind energy industry with relevant innovation activity. However, the support to other renewable technologies has not resulted in a similarly competitive industry: it is particularly paradigmatic the case of the solar photovoltaic industry, which has basically been dismantled even if relevant players existed in Spain before the introduction of premiums to renewables.

[2] Full report, in Spanish: *Economics for Energy, 2012*. Innovación en energía en España: Análisis y recomendaciones. Available from: http://www.eforenergy.org/en/publicaciones.php

This seemingly paradoxical situation is repeated in other fields: the regions that perform the best are not the ones that have the largest budget or the most researchers. Creating a productive innovation ecosystem depends not only on how much money is put on the table (for the PV industry, the size of the premium did not contribute to maintaining the manufacturing industry), but also on the set of measures implemented, on their design and coordination. The challenge for the Spanish energy sector is that no analytic framework currently exists that can guide decisions like how much is financed, in what is funded, and in how it is done.

First, the Spanish expenditure (both public and private) in energy R&D is low compared to other sectors. Part of the explanation for this lies in the liberalization of the energy sector that took place since the late eighties. Indeed, the expenditure in energy R&D was greatly reduced at that time and has remained at very low levels since then. However, not everything can be blamed on liberalization: the expenditure in energy R&D in Spain is also very low when compared to that in neighboring countries (including those in which the energy sector has also been liberalized), and even lower if compared to leading countries in energy R&D worldwide.

The per capita public investment in energy R&D is below the European Union average (even EU-27), and represents only about 10% of the Japanese and 20% of the United States figures[3]. This is the case even if Spain receives significant funds from the European Union for energy R&D (in the period 2007-2010 it was the second country that received the most funding for this purpose, only after Germany).

Moreover, a significant part of the Spanish public investment in R&D is of a financial nature, consisting of loans and repayable advances. While these instruments have some advantages, as the greater commitment they require from the companies involved, they also present some challenges. The first challenge is that they distort the statistics, which usually reflect the total funds and not actual expenditure (the differential of the subsidized interest rate). The second problem is that this type of support is not well received by the companies, due to the limited amount of the subsidy and to the greater responsibility that it involves. In Spain in recent years (2009-2011) a significant portion of the public budget for innovation has not been spent (43% in 2011). This may be due precisely to financial support instruments that get rejected by the potential recipients. The third challenge is that the type of projects that companies are willing to finance with loans instead of grants will be less risky, and therefore only incremental innovation is likely to be funded.

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[3] Data from IEA Data Services.

One reason for this lack of investment in innovation could be the lack of popularity of science and the lack of scientific knowledge among Spanish society in general, at least in comparison with other countries. In fact it is surprising that, given the importance attached to energy in many issues (e.g., impact of electricity tariff hikes in the media, how much energy costs mean in families' budgets, or its impact on the CPI), most of society remains unaware of the underlying reasons and the consequences that innovation could bring about in the energy field. The fact that Spain spends less than 1% of the total energy bill in energy R&D appears revealing.

Another notable aspect of energy innovation in Spain is the large participation of public investment, or alternatively, the low participation of private investment. Indeed, private investment, which is essential to stimulate technology transfer to markets and to society, and is in a better position to identify interesting opportunities for investment, is particularly low in Spain. This is not only harmful because of the untapped possible benefits of innovation mentioned above, but also because of the fact that excessive dependence on the public sector exposes investment in innovation to greater fluctuations, as has been the case in Spain in these recent years of economic crisis (we can see how Spanish public investment in R&D has decreased significantly in the period 20010-2012: in 2012 it was 34% lower than in 2009). In fact, the public sector should serve to stabilize this type of investment, particularly in times of crisis in which some companies may have greater difficulty investing in long-term projects.

In Spain, energy companies spend less in R&D than companies in other sectors (measured as the percentage of turnover invested in R&D). Even in the clean-tech sector, for which there is significant private contribution to R&D investment at the European level, the private contribution in Spain does not exceed 30%. It is interesting to contrast this with the hypothesis advanced by Menanteau et al. (2003)[4] that premiums to renewable technologies stimulate private investment in R&D. According to this hypothesis, Spain should have significant private R&D activity in wind and solar, and indeed there is greater patent activity in those renewable technologies supported by means of premiums. Besides, Spain exports wind technology, but imports more solar technology than it exports. However, the R&D intensity of wind and solar is between 2% and 4% (worldwide, data not available for Spain), higher than in the energy sector as a whole, but lower than in other innovative sectors such as biotechnology or ICT. This is possibly due to the fact that technologies in wind and solar sectors are gradually becoming "commodities", something that is clearly not

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[4] Menanteau, P., Finon, D., Lamy, M.-L., 2003. 'Prices versus quantities: choosing policies for promoting the development of renewable energy'. *Energy Policy* 31, pp. 799–812.

happening in distinctly innovative sectors, such as the sector of biotechnology applied to health, which deliver new functionalities.

In the electricity sector, Spanish companies do have a certain degree of investment in innovation, although again lower than that in other countries. **As expected, incumbent utilities, such as electricity and oil companies, are not the ones playing the dominant role, as they may lose from a disruptive innovation.** In this regard, it is worth noting that the available data only include the R&D carried out by traditional companies in the energy sector (electricity, oil and mining, and equipment manufacturers) and that other companies that can also be considered as part of the energy sector, such as those in the wind business or in biotechnology for biofuel production, probably invest more in R&D than the traditional companies do.

Despite the low levels of private investment, most of the R&D is performed in private firms. On the one hand, this is positive, because it means having innovation activity directly connected with the productive sector. In fact, a high percentage of Spanish companies (greater than in other sectors) has introduced innovative products and processes: up to 80% of Spanish energy companies report incorporating innovations on a continuous basis over time. Moreover, the regions that have more innovative companies are the ones in which innovation efforts and policies have been more linked to the production process. However, if the R&D conducted in companies does not translate into visible, transferrable and public results, the implication could be that public funds get transferred to the private sector under the guise of innovation. In this case, the risk of free-riding and of poor effectiveness in the use of public funds is evident.

A symptom or consequence of the lack of private investment is that, although there has been an improvement in the number of scientific publications in the energy field in recent years (2006-2010; especially in areas such as hydrogen, biomass and biofuels, or fuel cells), the number of patents is still very low compared to other countries: for example, even when patenting has increased in recent years (1999-2008), especially in renewables and biofuels, the number of patents produced per capita in Spain has only been 10% of the per capita patents in Denmark. It is true that even though patents themselves are not perfect measures of innovation (patents could in some cases hinder innovation), and in some cases they are only used as a weapon for trade war, but Spain's poor performance in the number of patents is likely to result in low income (in terms of GDP) derived from licenses and patents from abroad, and also in a low contribution of high technology to the trade balance.

Within this gloomy picture, and as has been already suggested above, some technologies are in a better position. **Thus, within the Spanish limited production of innovation, the clean-tech sector performs significantly well and constitutes a very**

relevant area in the Spanish innovation system. For example, Spain produces 3% of the world total patents related to renewable energy (a percentage beyond the contribution of the Spanish economy to global GDP, which is about 2%).

The reason for this may be that a large percentage of public investment in energy R&D is assigned to renewable technologies (even when total public investment in energy R&D is comparatively low in Spain, both in absolute and per capita terms, the fraction of that budget devoted to renewables is greater in Spain than in other countries): in relative terms, it represents more than twice that percentage in Germany, and six times more than that percentage in the United States. However, in order to be leaders in a technology, what matters most is the absolute level of public investment (assuming comparable efficacies in implementation) and here Spain is well below other countries. This fact is not likely to change given the relatively small size of the Spanish economy in the global context.

The very low levels of investment in innovation related to energy efficiency are particularly striking since this is an element that should have high priority in Spanish energy policy. [5] The high levels of investment on nuclear technology (only surpassed in recent years by the expenditure in all renewable technologies), even when the future prospects for this technology are not particularly bright in terms of social acceptance, is also worth noting [6].

Finally, Spain seems to be in an intermediate position regarding human resources for innovation. **Energy innovation requires human resources with technical knowledge, mostly, engineers and scientists. Spain has a significant number of graduates in engineering and sciences in per capita terms: less than Germany, but similar to Sweden and well above the United States**. The problem is that the number of graduates in these disciplines is not a good indicator of innovation capacity. First, because what matters is not only the quantity but also the quality: it may be the case that technical training in Spain focuses on solving problems with known techniques rather than on developing new techniques. On the one hand, the problem of the lack of engineering and science graduates can be solved by importing foreign trained personnel. On the other hand, Spain has, by far, fewer researchers than many other countries (in per capita terms). Obviously, this can be both a cause and a consequence of the problem (as there is little innovation activity, few people are hired to work on

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[5] See previous reports by *Economics for Energy* on energy intensity and economic assessment of energy efficiency measures for Spain, available at www.eforenergy.org/en/publicaciones.php

[6] See e.g. WWF, 2011. '*Renuévate: WWF desmonta mitos sobre las energías renovables en España*'. Available at http://awsassets.wwf.es/downloads/renuevate.pdf

it). Even so, it is noteworthy that Spain has highly qualified and internationally recognized teams in some fields of study, though they are generally limited to the academic sphere.

Spain also has a rather positive situation regarding the research infrastructure. **There are many publicly-owned energy research centers, although seemingly with poor coordination among them, as many of them respond only to their territorial interests, which limits their potential contribution to the overall Spanish innovation system. In addition, these centers often only give priority to incremental innovation, and do nothing to promote disruptive innovation.** Disruptive innovation projects are significantly risky, which makes them unsuitable for centers run by civil servants (unless incentives are designed to reward groundbreaking research that has the potential to contribute to the creation of new markets). Employees in private companies are usually neither in a good position to perform this type of innovation, since they are often under pressure to produce short-term results.

Another important fact worth mentioning is **the low entrepreneurial culture of Spanish society**. In Spain, few people engage in entrepreneurial opportunities[7], both inside and outside the workplace. Moreover, the social status of entrepreneurs is relatively low. As a consequence, the incentive to start new businesses is much lower in Spain than in neighboring countries.

In order to provide an overview of the performance of the Spanish energy innovation system in an international context, Table 1 shows a summary of indicators of different inputs and outputs of the energy innovation process for Spain, the European Union and the United States.

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[7] According to the Global Entrepreneurship Monitor for 2010, both the perceived opportunities for entrepreneurship and the intention of becoming an entrepreneur are considerably lower in Spain than in other countries like Germany, France, Sweden, the United States or Israel.

Table 1: Summary of energy innovation indicators; comparison Spain-EU-US

	Spain	EU	US	Source and time scope
Weight of energy area in public budget for R&D	3.4%	4.1%	1.7%	Eurostat Average 2007-2010
Public investment per capita per year in energy R&D	6.28 €	8.78 €	6.00 €	
Public investment per capita per year in energy R&D [8]	1.6 €	8.9 €	12.6 €	IEA Average 2005-2011
Weight of the energy area in total number of publications	1%	0.73%		(Fundación General CSIC, 2012)[9]
PCT patent applications per million inhabitants	2.5	6.5	6.2	OECD Year 2007
Weight of energy technologies for emissions reduction in total number of PCT patent applications	7.3%	6.4%	3.8%	
Patent and licensing revenues from abroad as % GDP (all areas, not just energy)	0.07%	0.21%	0.64%	European Commission - *Innovation Union Competitiveness report*. Year 2009
Contribution of high-tech to the trade balance (all areas, not just energy)	0.3%	5.1%	5.4%	

Source: Own elaboration with data from various sources

Figure 1 presents this comparison visually, transforming the values of the above indicators into percentages with respect to the maximum value among the three countries / regions considered.

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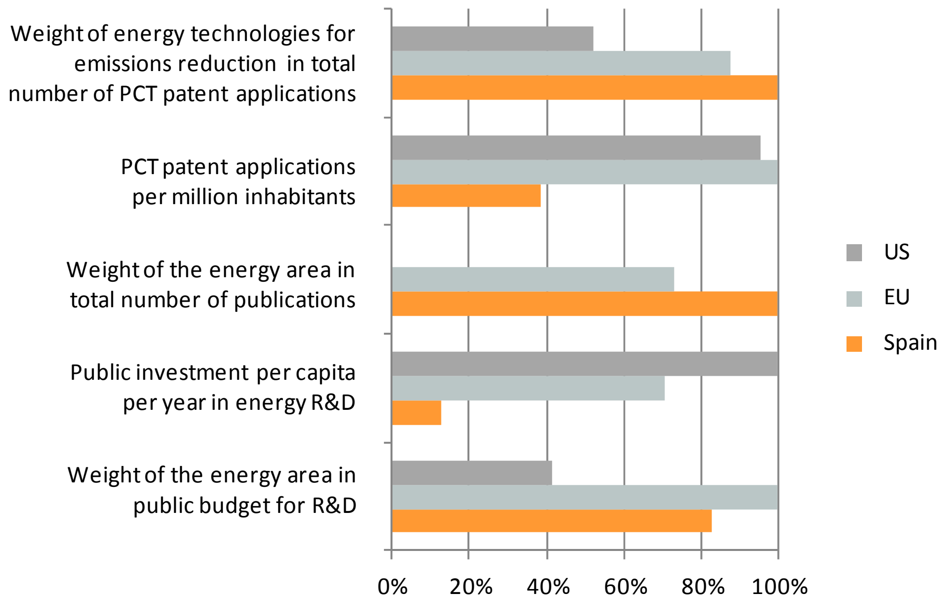
[8] This in indicator and the indicator in the previous row are equivalent, but they provide data from different sources. Note the large differences in the data for public R&D investment between IEA and Eurostat sources.

[9] Fundación General CSIC, 2012. '*Informe de la I+D en energía y automoción'*.

Figure 1: Summary of energy innovation indicators; comparison Spain-EU-US



Source: Own elaboration with data from various sources

The evidence presented in this section suggests that there is much room to improve the performance of Spain's energy innovation system. Furthermore, evidence from other countries indicates that, by failing to stimulate more innovation in the energy sector, Spain may be missing significant savings in the energy system, along with other benefits for the overall economy. Section 3 provides an evaluation of the returns of R&D investment in terms of cost reductions in the energy system for the Spanish case.

3. Benefits of investing in energy R&D: Potential savings for the Spanish energy system

The purpose of this section is to present the assessment of savings that could be achieved in the Spanish energy system if investment in energy R&D increased. The analysis does not include investment in other policies that could also contribute to innovation understood in a broader sense, such premiums, loans, standards, etc.

Before presenting the analysis, it is important to stress that only savings in terms of reduced cost of energy technologies are quantified here. Other benefits mentioned in previous sections, such as domestic value creation, increased competitiveness, environmental benefits, etc., require complex and rather speculative methodologies, and have not been studied for this report.

The study presented here considers scenarios of increased investment in R&D at the European level with respect to current levels of investment for different energy technologies. The technologies considered are solar photovoltaic (PV), concentrated solar power (CSP), wind, CO_2 capture and sequestration (CCS), nuclear, gas, batteries (for electric vehicles and plug-in hybrids) and biofuels.

When defining the R&D scenarios, we will consider annual public investment levels in R&D in energy in the European Union as a whole. However, it is important to note that, for the purpose of this study, both where the funds come from, and where they are executed is irrelevant. This is because, as already mentioned, we will estimate benefits for Spain as "taker" of technological improvements, whereas other potential benefits as "maker" will not be considered (e.g. improvements in the industrial infrastructure, income from exporting technology, etc.). Regardless of which countries invest in R&D, if reductions in the cost of energy technologies can be realized, then savings in the Spanish energy system can be realized as well.

Regarding forecasts for cost reductions of individual technologies through increased R&D, we use data provided by two projects, a European one[10] and an American one[11]. Both projects carried out expert elicitations on the future cost of energy technologies based on the level of public investment in R&D (experts came from various sectors: private, academic, and government). Both projects presented the experts' estimates of future costs of technologies and the uncertainty associated with these estimates (measured as percentiles 10 and 90) for a time horizon set in 2030. The exception to this approach will be wind technology, for which we had no available data from expert elicitation. Thus, we have used two-factor learning curves to estimate the cost savings associated with R&D investments[12].

To evaluate the savings that potential cost reductions of technologies could mean for the energy supply in Spain, we have used the model of the Spanish energy system developed by Lopez-Peña et al. (2011)[13]. This is a bottom-up partial-equilibrium model

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[10] The ICARUS Project: http://www.icarus-project.org

[11] Energy Research, Development, Demonstration & Deployment Project (ERD3): http://belfercenter.ksg.harvard.edu/project/10/energy_technology_innovation_policy.html?page_id=213 . The final report includes data: Anadon, L.D. Bunn, M., et al. (2011). *Transforming U.S. Energy Innovation*. Available at: http://belfercenter.ksg.harvard.edu/publication/21528/ .

[12] Note this approach has well-known limitations. See e.g. Qiu, Y., Anadon, L.D., 2012. 'The price of wind power in China during its expansion: Technology adoption, learning-by-doing, economies of scale, and manufacturing localization'. *Energy Economics* 34 (3), pp. 772-785.

[13] López-Peña, Á., Linares, P., Pérez-Arriaga, I., 2011. 'A policy-oriented energy optimization model with sustainability considerations'.

of the whole Spanish energy sector. The model describes all major energy processes, from primary energy production (domestic or imported), through conversion and transport of energy (oil refining, gasification, power generation, transmission and distribution, etc.), to final energy consumption in all sectors (residential, industrial, primary, services, and transportation).

With this model, we estimated the total cost of the Spanish energy system in 2030 given certain reductions in the cost of technologies in different scenarios of R&D investment. As a base case, we consider the scenario in which the annual investment in R&D is maintained at current levels until 2030. From the model results, calculating the difference between the cost of the system in different scenarios of investment in R&D and the base case, we can estimate the savings for the Spanish energy system that could be achieved thanks to R&D. We also estimate the returns by dividing the annual savings by the increase in annual investment in R&D required for achieving them.

In our analysis we also wanted to consider the uncertainty inherent in the innovation process. For this purpose, for each technology, we consider the most pessimistic estimate (or, in other words, the one of minimum cost reduction, which is included in the table as "min"), the most optimistic estimate (of maximum cost reduction, "max" in table), and an intermediate estimate (the median of the estimates of cost reduction, "med" in the table), among all the percentage savings calculated from the expert estimates for percentiles 10, 50 and 90. For improving the representation in the most probable range of cost reduction, we also consider the minimum, median and maximum savings among the experts' best guesses (percentile 50). Table 2 collects all these estimates for the different technologies and R&D scenarios considered.

Table 2: Scenarios of cost reductions in energy technologies depending on the level of public R&D investment in the European Union

		Percentiles 10, 50, 90			Percentile 50 ("Best guess")				
Technology	R&D investment scenario	min	med	max	min	med	max	Reference	Method, project
PV	current +50%	0%	16%	50%	0%	16%	37%	(Bosetti et al., 2012)[14]	Expert elicitation, ICARUS Project for EU
	+100%	0%	32%	83%	0%	31%	64%		
CSP	current +50%	0%	10%	17%	5%	13%	17%		
	+100%	2%	19%	57%	10%	19%	33%		
Biofuels	current +50%	0%	13%	38%	0%	13%	29%	(Fiorese et al., 2012)[15]	
	+100%	0%	25%	67%	0%	25%	57%		
Batteries > EV	current +50%	0%	10%	50%	0%	10%	33%	(Bosetti et al., 2011)[16]	
	+100%	0%	22%	75%	0%	17%	60%		
> PHEV	current +50%	0%	10%	50%	0%	9%	32%		
	+100%	0%	20%	67%	0%	16%	59%		
Nuclear	recom.x0,5	0%	0%	14%	0%	0%	8%	(Anadon et al., 2012)[17]	
	x1	0%	8%	21%	0%	8%	17%		
	x10	0%	17%	25%	5%	20%	25%		
Gas	recom.x0,5	0%	0%	40%	0%	0%	40%	(Chan et al., 2010)[18]	Expert elicitation; ERD3 Project for US
	x1	0%	0%	52%	0%	8%	52%		
	x10	0%	7%	66%	0%	16%	66%		
CCS > coal power plants	recom.x0,5	0%	0%	6%	0%	0%	0%		
	x1	0%	4%	20%	0%	9%	20%		
	x10	0%	18%	40%	3%	20%	40%		
> gas power plants	recom.x0,5	0%	0%	50%	0%	0%	50%		
	x1	0%	4%	60%	0%	10%	60%		
	x10	0%	18%	67%	5%	20%	67%		
Wind	current +50%					8%		(Klaassen et al., 2005)[19]	Learning rates, data from EU
	+100%					11%			

[14] Bosetti, V., Catenacci, M., Fiorese, G., Verdolini, E., 2012. 'The future prospect of PV and CSP solar technologies: An expert elicitation survey'. *Energy Policy*, 49, pp. 308-317.

[15] Fiorese, G., Catenacci, M., Verdolini, E., Bosetti, V., 2012. 'Advanced biofuels: Future perspectives from an expert elicitation survey'. *Energy Policy* , 56, pp. 293-311.

[16] Bosetti, V., Catenacci, M., Fiorese, G., Verdolini, E., 2011. 'Electric drive vehicles: short technical report from the ICARUS survey on the current state and future development'.

[17] Anadon, L.D., Bosetti, V., Bunn, M., Catenacci, M., Lee, A., 2012. 'Expert judgments about RD&D and the future of nuclear energy'. *Environmental Science & Technology* 46, pp. 11497–11504.

[18] Chan, G., Anadon, L.D., Chan, M., Lee, A., 2010. 'Expert elicitation of cost, performance, and RD&D budgets for coal power with CCS'. *Energy Procedia* 4, pp. 2685–2692.

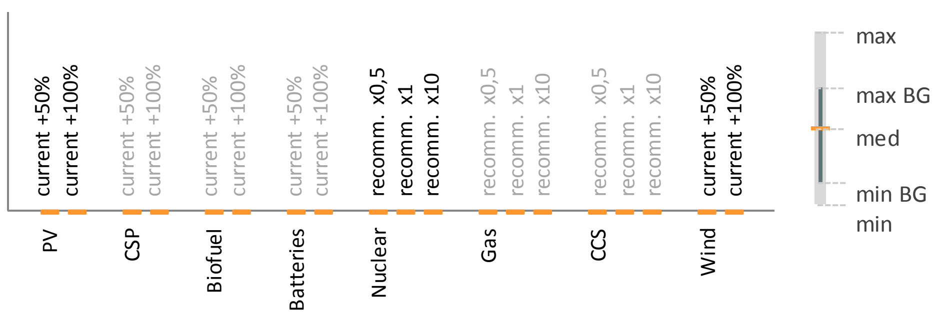
[19] Klaassen, G., Miketa, A., Larsen, K., Sundqvist, T., 2005. 'The impact of R&D on innovation for wind energy in Denmark, Germany and the United Kingdom'. *Ecological Economics* 54, pp. 227–240.

Source: Own elaboration

For the analysis, CO_2 emissions throughout the Spanish energy system will be limited to an annual maximum of 164 Mt in 2030, which would mean a reduction of 20% compared to 1990 emissions (in line with the objectives of the European Union for 2020). In our baseline scenario, we assume that no new nuclear plants will be installed, because their construction would have to begin in the coming years if they were to be operative in 2030, and this does not seem realistic in view of the current climate. However, in the sensitivity analysis, we will assess how much the results would vary if the installation of new nuclear power plants was allowed.

To present the results in a condensed form, we will include some graphs showing savings and returns for all technologies and R&D scenarios, which also reflect the range of uncertainty of the results. Figure 2 works as a legend for these graphs[20].

Figure 2: Legend to understand the figures presenting the results



Source: Own elaboration

[20] On the left side of the figure, we can see how technologies and scenarios will be organized in the graphs: the first four technologies have two columns of results each, corresponding to scenarios "current +50%" and "current +100%" respectively (this will be the case also for wind technology, placed separately as the last technology just to emphasize we have used different type of data, as data from expert elicitation was not available); the next three technologies have three columns of results each, corresponding to scenarios "recommended x0.5", "recommended x1" and "recommended x10".

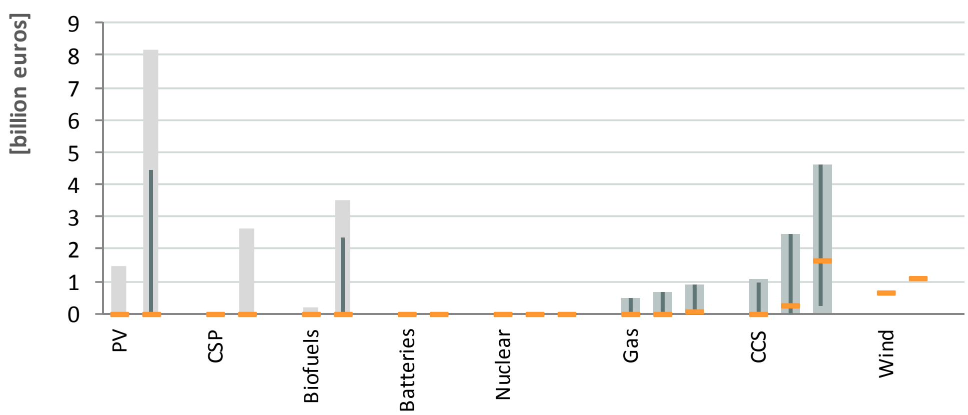
On the right side of the figure, we can see how uncertainty has been represented: the horizontal orange line indicates the result for the median estimate of percentage saving in the cost of technology; the wider light grey column represents the range between the result for the minimum estimate and the result for the maximum estimate; analogously, the vertical dark grey line represents the range between the result for minimum estimate and the result for maximum estimate but only among the best-guess estimates (BG, those in percentile 50), which allows for more detail in the most probable range of results.

Savings

As already mentioned, savings are calculated as the reduction in the cost of the Spanish energy system (electricity, transport, heating and industrial uses) in 2030 for a scenario in which R&D investments increase with respect to current levels, as compared to a business-as-usual (BAU) scenario in which R&D investments are maintained at current levels. Figure 3 represents savings in the baseline scenario for different technologies and scenarios of R&D investment.

It is noteworthy that, although the savings are presented by type of technology, they depend on the investment portfolio including other technologies, as some of these technologies would compete in the market. The total cost of the system, with respect to which the savings are calculated, is 113 billion euros (considering costs of investment in new capacity, operation and maintenance costs, transportation costs, etc. for the entire Spanish energy system in 2030).

Figure 3: Savings in the Spanish energy system in 2030 due to reductions in the cost of technologies thanks to R&D investment, baseline scenario



Source: Own elaboration

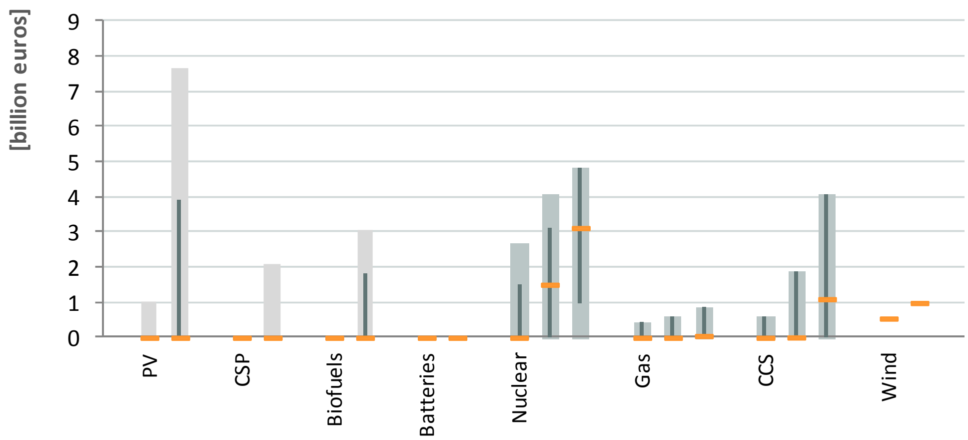
A first observation is that for most of the technologies and scenarios of R&D investment considered there are no savings for the median estimate of cost reduction (i.e. horizontal orange marks are at zero). What happens in these cases is that no new capacity of the corresponding technology is being installed, since it is less cost effective than other technologies. In particular, in the baseline scenario in which CO_2 emissions are limited to 80% of the emissions Spain had in 1990, the need for new installed capacity is being covered mostly with wind, gas turbines, and coal and gas power plants with CCS. Thus, we can observe how median estimates of cost reduction do lead to savings in the cases of wind and CCS. However, other technologies (PV, CSP and biofuels) need cost reductions over the median estimate in order to lead to savings for the system.

In terms of maximum achievable savings, photovoltaic technology stands out (with maximum potential savings of up to 8.000 million euros in the highest R&D investment scenario), followed by CCS (with maximum potential savings of 4.500 million euros in the highest R&D investment scenario). Biofuels and CSP only get significant savings in the highest R&D investment scenarios (reaching maximums of about 3.000 million euros). Gas power plants present moderate maximum potential savings compared to other technologies for all R&D scenarios (below 1.000 million euros). Savings for wind technology are in that same order of magnitude.

In the case of batteries, our results show no savings even for the maximum cost reduction estimates in the highest R&D investment scenario. The explanation for this is that, based on cost expectations of future vehicles, electric vehicles (including PHEVs) are less cost effective than biofuel vehicles to decarbonize the transport sector. We estimate that for electric vehicles to displace biofuel vehicles, the cost reduction of batteries needs to be over 75%. Given that the maximum cost reduction we have considered in our scenarios is 75% (see Table 2), electric vehicles do not get to penetrate the market in our results, and thus present zero savings or returns on R&D investment.

For nuclear technology, no savings are obtained in the baseline scenario because, as already mentioned, we are assuming no new nuclear power plants will be installed in Spain in the 2030 horizon. If we allow for the installation of new nuclear power plants, results are as shown in Figure 4. Savings for all the technologies but nuclear become slightly lower as compared to the baseline scenario (between 100 and 600 million euros less, depending on the technology and scenario, which represents in any case less than 0.5% of the total cost of the system). For nuclear technology, significant savings are achieved (in the order of 1.500 million euros for the most probable cost reduction at the level of R&D investment recommended by experts, and up to 5.000 million euros in the scenario of maximum investment in R&D and for the most optimistic cost reduction estimate).

Figure 4: Savings in the Spanish energy system in 2030 due to reductions in the cost of technologies thanks to R&D investment, case with new nuclear capacity



Source: Own elaboration

We have also assessed the sensitivity of these results to changes in the price of fuels and confirmed they are robust: if the price of gas and oil increases by 35%, savings barely vary (differences represent less than 1% of the total cost of the system).

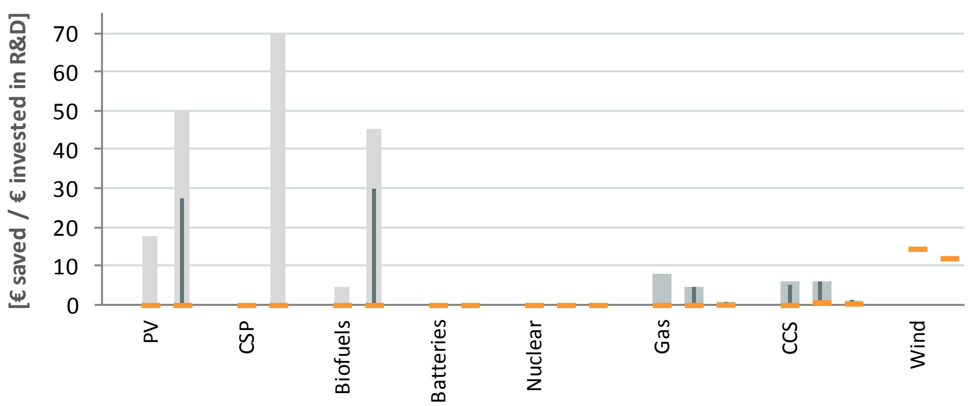
Returns on investment

Once savings have been estimated, we can now compare the potential savings with the level of R&D investment that they would involve. For this purpose, we calculate returns on R&D investment as the annual savings in the Spanish energy system for a given scenario of R&D investment (which correspond to the savings presented in Figure 3), divided by the increase in R&D investment that that scenario involves with respect to the baseline scenario.

It should be noted here that we are considering savings for Spain and investments at the European level. Despite the apparent inconsistency, the returns calculated in this scenario are meaningful in two ways. First, as we have already explained, the purpose here is to estimate the savings that the Spanish system could realize given certain reductions in the cost of technologies, regardless of where the investment in R&D takes place. Second, if we confirm that the savings that the Spanish system could realize are greater than the required levels of R&D investment at the European level, this would mean that the returns for Europe as a whole (the savings for all the Member States compared to their total investment in R&D) would be even higher, since we could expect other European countries to realize savings in their energy systems as well.

Figure 5 presents the returns on R&D investment obtained in the baseline scenario. The considerations that we made for savings (regarding zero savings for the median estimate of cost reduction, regarding nuclear and regarding batteries) apply for returns as well. Also the sensitivity analysis already mentioned applies to these results, since returns are obtained just by dividing savings by investments.

Figure 5: Returns to R&D investment, baseline scenario



Source: Own elaboration

Once more, we see how for many technologies and scenarios, there is a chance no returns will be realized, since the expected reductions in the cost of technologies (as predicted by experts from various sectors) are not sufficient to make those technologies competitive. However, when cost reductions become sufficient to make the technology cost-effective, then returns soar: potential savings can represent up to 70 times the investment. This is the case for CSP in the highest R&D investment and for the most optimistic cost reduction estimate (nevertheless, CSP presents zero returns in the lowest R&D investment scenario). Photovoltaics and biofuels can also achieve very significant returns, up to 50 or 45 times the investment respectively. Returns for wind technology are around 14 times the investment. Of course, here it should be noted that given the uncertainty about future costs, the expected return is lower than the highest possible returns.

Gas and CCS technologies showed returns in the order of 5 times the investment, although these returns become almost zero when R&D investment increases too much. This happens also for nuclear technology, when we allow for its installation (not represented in this figure): it achieves returns over 50 times the investment in the lowest R&D investment scenarios, but its returns plunge in the high investment scenarios. These results are consistent with those obtained in a similar study for the

U.S., in which increasing public investment in energy R&D by a factor greater than 20 has no beneficial result (Anadon et al., 2011) [21].

Then, we observe how for some technologies increasing R&D investment leads to higher returns (as in the case of PV, CSP and biofuels), whereas for other technologies increasing R&D investment actually leads to lower returns (as in the case of gas and CCS), simply due to the fact that the reduction in the cost of a technology saturates at a certain point beyond which any additional investment does not lead to significant additional reduction in the technology cost. Thus, for the first group of technologies (that provide increased returns when R&D investment increases), the levels of investment that we have considered seem to be below the saturation zone, whereas for the second group of technologies (that provide reduced returns when R&D investment increases), the levels of investment seem to be beyond the saturation zone. Indeed, this seems reasonable given that for this second group of technologies the highest investment scenario corresponds to ten times the investment recommended by experts. This saturation depends on the opinion of experts consulted in 2010 and 2011. Once the level of R&D increases and the scientific knowledge advances, this estimation can possibly change (in other words, the saturation point should not be considered permanent in time).

This effect can be observed clearly in Figure 6, which presents the returns obtained when considering together all the technologies for which we have investment scenarios based on current levels of R&D investment (FV, CSP, biofuels, batteries and wind), and all the technologies for which we have scenarios based on recommended levels of investment (nuclear, gas and CCS). We can observe how for the first group of technologies, the highest investment would yield the highest returns, whereas for the second group of technologies, the highest returns would be yielded by the lowest investment.

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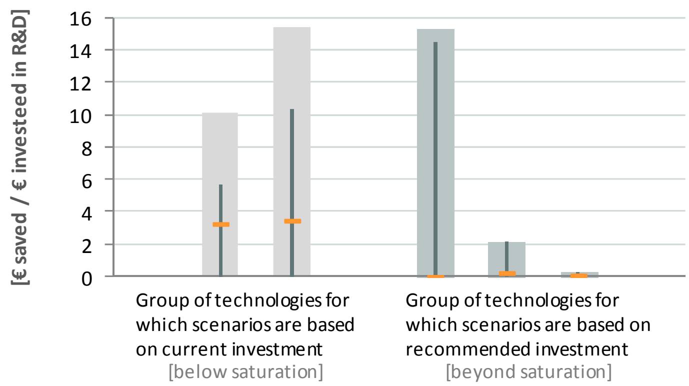
[21] Anadon, L.D., Bunn, M., Chan, G., Chan, M., Jones, C., Kempener, R., Lee, A., Logar, N., Narayanamurti, V., 2011. *Transforming U.S. Energy Innovation*. Energy Technology Innovation Policy research group, Belfer Center for Science and International Affairs, Harvard Kennedy School, Cambridge, MA.

Figure 6: Returns on investment in R&D for groups of technologies, baseline scenario



Source: Own elaboration

Considering this last figure, we could conclude that if we were to invest in the portfolio composed of FV, CSP, biofuels, batteries and wind (first group of technologies), the expected returns would be in the order of three times the investment (corresponding to the median estimates of cost reduction), although returns could be beyond ten times the investment in the most favorable scenarios. For the portfolio composed of nuclear, gas and CCS, the maximum returns could be in the same order of magnitude (up to fifteen times the investment in the most favorable scenario), but only for the lowest level of R&D investment.

These returns are in a similar order of magnitude, although slightly more conservative, of those estimated for the U.S., which were about twenty times the level of investment (in 2030, for recommended levels of R&D investment and median estimates of cost reductions) (Anadon et al., 2011).

From this analysis we can conclude that the savings that the Spanish energy system could realize due to reductions in the cost of energy technologies, thanks to R&D investment, are significant and sufficient to recuperate the investment in R&D in most cases (with a high degree of uncertainty, though). However, it is difficult to identify the most promising technologies due to the high degree of uncertainty involved. The recommendation would then be that Spain chooses the technologies in which to focus its R&D investment in the context of a European portfolio.

Given the background presented in Section 2 and Section 3 for the Spanish case, and given the interest in developing energy innovation effectively and efficiently, it seems essential to reconsider, reorient, and where appropriate strengthen public policies to support energy innovation. The following section is a brief overview of the policy options available.

4. Recommendations for an energy innovation policy in Spain

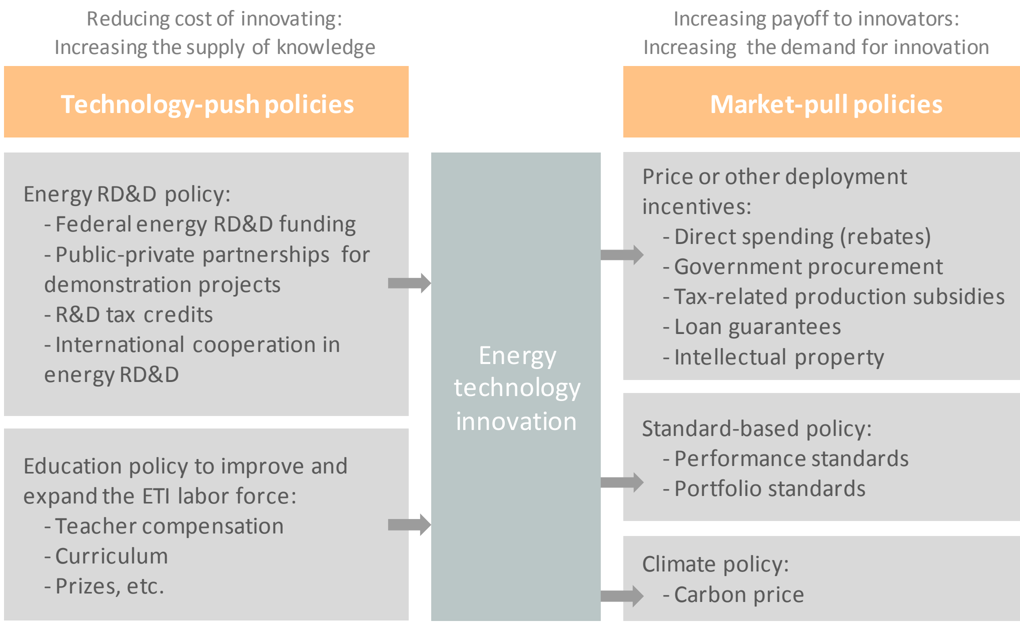
In view of the assessment presented in the previous sections, and of the available options, which should be the priorities of an energy innovation policy aiming to create national wealth?

These priorities should target various fronts. As has been argued previously, a successful innovation policy cannot rely only on subsidies and grants, but rather should also consider an appropriate institutional framework that covers all areas of knowledge, and that provides answers to the technological challenges of companies.

There are several instruments available for this, and they should be combined to achieve the proposed objectives. Public policies for innovation can be categorized into two groups as technology-push policies and market-pull policies. Figure 7 shows the most relevant types of policies under these categories.

It is important to remember that both approaches, technology-push and market-pull, should be aligned (indeed, focusing in just one of the approaches would rarely yield positive results).

Figure 7: Types of policies for energy innovation: technology-push and market-pull



Source: (Anadon and Holdren, 2009)[22], based on (Mowery and Rosenberg, 1979)[23]

In the Spanish case, the conclusions of the assessment of the current situation and the evaluation of potential savings suggest the following priority actions to promote energy innovation:

- **perform a strategic analysis of innovation priorities, of the areas in which Spain would better specialize,**
- **promote an increase in private investment, and also in more public-private partnerships in the execution of R&D,**
- **improve the institutional design and promote ecosystems for innovation and entrepreneurship,**
- **consider carefully the coordination between energy policies and innovation policies, and incorporate incentives for innovation into the regulatory design of the energy sector,**
- **and improve the communication to and the education of society on the importance of energy innovation.**

[22] Anadon, L.D., Holdren, J.P., 2009. 'Policy for energy technology innovation', in: Gallagher, K.S. (Ed.), *Acting in Time on Energy Policy*. Brookings Institution Press, Washington, D.C., pp. 89-127.

[23] Mowery, D., Rosenberg, N., 1979. 'The influence of market demand upon innovation: A critical review of some recent empirical studies'. *Research Policy* 8, pp. 102–153.

Below we develop some of these ideas. However, we should mention that the recommendations expressed herein are general in nature, due to the characteristics of this study. The implementation of specific measures should be preceded by a thorough analysis of their consequences for the Spanish innovation system, based on empirical data, not available during the preparation of this analysis. Only a thorough analysis would allow for adequately specifying the most appropriate measures.

Strategic analysis of priorities

First, **it is essential to perform a strategic analysis that would allow for establishing priorities in the promotion of energy innovation. Given the size of the Spanish economy, Spain cannot claim to be leader in all technologies.** Moreover, given the scarcity of public funds, investing effectively requires concentrating in a particular set of technologies. At the same time, because of the uncertainty inherent in innovation, focusing on only one or two productive sectors is not advisable either. It will be necessary to choose the technologies for which Spain has some comparative advantages, in the context of a joint exercise that also defines the desired energy model and the policies that need to be implemented in order to achieve it, as well as to consider the possible implications of innovation investments for the competitiveness of the country. This exercise should be advised by experts both from academia and the business world. It may be interesting in this respect to appoint a panel of experts, much like the Energy Innovation Council proposed in the U.S. to both analyze policies and propose new measures.

When choosing technologies or priority areas, we should take into account their potential for improvement, their niche market, Spain's comparative advantages and the benefits that can be derived from them. For instance, Spain has a better starting point in some clean technologies than other countries (in terms of publications and patents). Spain has also competitive technology for oil exploration.

The results provided in Section 3 show the potential savings offered by different technologies as well as their return on investment, these results are an important input when deciding how to prioritize technologies. Even though these results depend on the model and technology assumption, they are based on a transparent and consistent analysis. As shown above, PV is the technology with the most potential in terms of maximum achievable savings for the Spanish energy system (but with great uncertainty), followed by CCS (with less uncertainty). In terms of potential returns, PV stands out again, together with other technologies such as concentrated solar and biofuels, with similar levels of maximum return. CCS, however, presents more modest return levels, similar to those of gas technologies. Wind technology is in an intermediate position, ranking better in terms of potential returns than in terms of potential savings. Nuclear technology (when new nuclear plants are allowed) also shows significant potential savings (in volume terms, not per MW installed), and high returns in the lowest R&D investment scenario (but low returns in high R&D investment scenarios).

Promoting private investment

Correcting the imbalance between public investment and private investment is also essential for energy innovation in Spain. This involves both redesigning the support mechanisms and redesigning the related institutions and infrastructure. The goal should be to break the false dichotomy between public investment and private investment, in such a way that one is not used to replace the other, but rather that both act in parallel, complementing each other. Except for basic research, the role of public investment should not be just funding what private investment fails to fund, but instead public and private investment should act in concert to strengthen the prioritized areas of research and technologies, and thus be able to achieve the above-mentioned technological leadership with the corresponding value creation.

Of course, within this coordination between the public and the private sectors, the private sector should play a more active role, given the generally applied nature of energy technology. This does not mean that funding for basic science should be reduced. Instead, Spain could experiment with the creation of targeted institutions, such as the Energy Frontier Research Centers created in the U.S., in which some resources are focused in those areas of basic science that have the greatest potential to contribute to technological advances in areas such as energy, nanomaterials for energy efficiency applications, electrocatalysis for applications in biofuels and energy storage, systems far from equilibrium for conductivity applications, superconductivity, energy storage, to name just a few. These centers have more stable funding, promote multidisciplinarity and have a critical mass of researchers.

Another problem of many funding programs for applied research is that companies do not collect information on the short- and long-term results, therefore making it difficult to design programs that would benefit from previous mistakes or experiences. **Thus, support mechanisms should focus on evaluating the results of the projects and, in many cases, depending on the results of these assessments, focus on gradually adding new support mechanisms to the usual instruments in the form of grants** (direct or financial). For, although grants are recommended for basic research, they sometimes may be suitable for business and applied research because of the difficulty of ensuring their efficient use and their proper dissemination. In some cases it may be desirable to introduce other types of incentives, such as prizes, which are open and competitive, to reward results and not mere spending, and to attract different types of inventors and entrepreneurs, who may produce more disruptive inventions, and thus generate added value for society. Another instrument under the induced innovation framework would be to use price signals. In this case, it is essential to keep price signals stable in the long-term and to allow the participation of private investors.

In any case, the instruments used must be properly fitted to the characteristics of the technology or the desired innovation, mainly related to the position of the technology in the learning curve. Less developed technologies should rely more on direct support policies, while those technologies already in a commercial phase could benefit from induced innovation policies, and demonstration projects should be supported by public-private partnerships.

The creation of markets and business opportunities can also contribute to the mobilization of the private sector. Of course, these markets should have the appropriate level of competition to optimize innovation investments. It is generally considered that too low or too high competition discourages innovation. On the one hand, excessive competition forces companies to cut costs in the short term; on the other hand, the lack of competition, while it generates rents that could be invested in innovation, it removes the incentives to do so. A possible compromise (albeit with many complexities of design) is that the State provides such funds that would be available to a monopolist, but that companies compete for the funds in a real market. This is not without problems, of course: in a competitive environment, how can we ensure that the results of innovation provide benefits for society?

Institutional design, innovation ecosystem and entrepreneurship

Related to this last issue, and now moving into the realm of the third line of action we mentioned, **the promotion of innovation also requires establishing an inclusive institutional design (as defined by Acemoglu and Robinson) that provides enough reward for innovators and entrepreneurs, and prevents rent extractors from stifling innovation in which they do not have a stake**.

As already mentioned, the evaluation processes and the accountability of those agents participating in the innovation system and receiving public funding should be improved. This would create the opportunity to learn and improve the effectiveness of the funding system. Although obviously the innovation process is inherently uncertain, and some of the expected results may not get realized, it is possible to demand more accountability, traceability and transparency in the use of public resources. The aims would be to identify both new areas of interest and the most efficient funding mechanisms for different purposes and technologies.

The role of structures and facilities can also be the key to improve the environment for energy innovation. The creation of an agency like ARPA-E in the U.S., run by people with an entrepreneurial spirit, specializing in risky innovations, and supporting energy start-ups, could contribute much to the rather conservative current structure. It also seems appropriate to create virtual structures, centers of excellence, in line with the idea of prioritizing as already mentioned. These centers could operate similarly to the Energy Innovation Hubs in the U.S., focusing the efforts of individual research centers, universities, and of course private companies on the technology or innovation lines identified as priorities. The model followed by the Basque Country also provides an interesting reference, as does the newly created International Energy Research Centre (IERC), a research center led by industry, funded by government, and in direct collaboration with university, which aims to achieve commercial innovations in the energy field. These centers often engage in international collaboration with the technology leaders of the future (no matter where they are located -Europe, United States, China or Brazil).

Not only is it important to create leading centers in priority technologies, it is also important to create the right environment and relationships so that innovation can emerge from below, as the result of collaboration between various stakeholders. The case of wind technology in Denmark, where networks of cooperation and communication between industry and interest groups (largely motivated by a suitable design of incentives) played a key role in developing successful wind energy technology is also interesting. Industrial clusters (defined as a concentration of companies of a specific sector in a particular geographic area, interconnected collaboratively among them and with suppliers and local institutions, and generally characterized by strong social roots in their region) can also play a key role in the development of energy technologies, as the case of the wind energy cluster in the Basque Country demonstrates.

To complete the innovation ecosystem, we should also encourage entrepreneurship and promote the funding sources that make it possible. Entrepreneurs can play a key role in generating disruptive innovations and ideas that can really challenge the status quo. They also have the ability to enhance the productive industrial network, generate employment and add value. The case of Israel is particularly noticeable as a model of an entrepreneurial ecosystem. Israel is now one of the world leaders in clean-tech start-ups, despite not having an energy policy that promotes these technologies, and thanks to a large extent to the exceptional mobilization of private seed capital. It is important to note that investor capital in Israel, which nowadays is one of the highest in the world, was initially boosted by a government program (the Yozma program, introduced in the early 90s), and also that the defense activities of Israel have contributed to a very competitive technology sector.

Indeed, we should not forget that the government could play a key role as facilitator and promoter of all the ideas mentioned about the institutional design and the creation of productive innovation ecosystems: by establishing the right incentives, supporting with public funds the initiatives that require it, creating adequate and purposive institutions, encouraging collaboration among institutions, disseminating information and contacts, promoting a favorable investment climate, etc.

Coordination with energy policy and attention to regulatory design

Energy innovation policies should be aligned with more general energy policies. This idea

has already been advanced in part when we mentioned the need to combine and coordinate technology-push policies and demand-pull policies. Energy policies may serve to guide investments in energy innovation thereby serving as market pull policies. Incentives for renewable installation are a clear example of this: the decision to promote the installation of renewables spurs the market for renewable technologies, and promotes innovation in the sector. Another example is the introduction of a market for CO_2 emissions: if the price of CO_2 becomes sufficiently high, it will provide an incentive to invest in innovation in low carbon technologies.

The literature shows that both market pull and push polices are needed. For example, considering again the case of renewables, it is striking how the large subsidies that Spain has devoted to photovoltaics have not resulted in significant innovations in the sector inside the country. It is possible that if those subsidies had been complemented with policies that had directly supported innovation (technology-push), the results might have been more favorable. Some ideas that might have been considered then, and could be considered in the future are (many related to lines of action already mentioned): we could prioritize public investment in R&D on technologies that are being promoted in the general energy policy framework; we could create centers of excellence in these technologies to integrate and coordinate all the related R&D activities developed in the country; or we could open channels of communication and establish collaborative networks among research groups, investors, installers, operators and manufacturers of the technology in the country, so that the knowledge generated in the installation and operation phases can provide feedback to the research and development phases.

Finally, it is important to highlight the potential importance of regulation in the energy sector in limiting or promoting innovation, most notably in the electricity sector. While in most sectors the expectations of rewards from innovation depend directly on market conditions, in the electricity sector they depend significantly on regulatory conditions. The clearest example is perhaps the case of the regulated activities of transmission and distribution of electricity, whose remuneration depends on a regulated tariff. To encourage innovation in these activities, it would be necessary to introduce incentives for innovation in its remuneration scheme (as intended in the RIIO compensation scheme proposed in the U.K.). In order to promote innovation in power generation, besides improving market creation policies, regulation could facilitate the entry of new players, for instance, by removing barriers to the connection of distributed generation, which could be a fertile ground for innovation. On the demand side, there are entry barriers for new potentially innovative agents (ESCOs, aggregators, or start-ups for demand management), that regulation could help to overcome.

Education and communication

First, the lack of scientific knowledge about energy and its environmental and economic implications suggests the need to make **communication and education efforts convey the importance and possible benefits of investing in energy innovation to society**. We must take this message to the media, and also present related scientific analysis in the major social and political debates.

Second, it is essential to **promote an entrepreneurial culture** in schools and universities. An entrepreneurial culture is key to creating companies that innovate in the energy sector, and that will create value for the Spanish economy.

Finally, regarding communication, we must also try to strengthen the **dissemination of the innovation results, and to facilitate their transfer to the productive sector**, in such a way that the innovation results reach companies beyond those where publicly funded innovation takes place.

In a context where innovation is increasingly essential as part of the economic policy of a country, as a factor of competitiveness, the government should carefully consider those options that would allow moving towards a more secure, environmentally friendly and competitive energy model. However, as already mentioned, defining specific policies would require further analysis of these recommendations (using sufficient empirical data) so that the most appropriate design can be defined and its performance and expectations assessed.

5. Summary and conclusions

As noted in the introduction, energy innovation is an essential step toward achieving an energy system that respects the environment, involves low risk in prices, and remains affordable in cost. Moreover, for a country like Spain, innovation can help to create new economic activities and businesses, to generate socioeconomic value and employment, and to improve the competitiveness of the production sector. In times of crisis like the present, the need to create this added value, together with the need to use public resources as efficiently as possible, becomes even more pressing,

And yet, Spain does not innovate enough in energy technologies. This lack prevents the country from creating wealth based on technological development in this field, even when Spain could have an advantaged position arising in part from the large investments in recent years in the installation of clean technology. It also prevents the country from realizing potential cost savings in the energy system.

In the Spanish case, as shown by the results provided in Section 3, the savings for the energy system could reach more than fifty times the R&D investment for some technologies, although with a high degree of uncertainty (if cost reductions achieved thanks to R&D are not enough to make a technology competitive, the returns for that technology will be zero). It is also true that some technologies do not get significant returns in any of the scenarios (e.g. batteries, which according to our scenarios do not reach levels of cost reduction that make electric vehicles competitive with respect to biofuel vehicles for the decarbonization of the transport sector).

The conclusions from all the analysis about energy innovation in Spain reported here are not very positive. There are two main reasons: first, the low volume of investment, particularly of private investment; and second, the lack of a robust innovation ecosystem. More specifically, the main shortcomings of the Spanish energy innovation system are:

- low absolute level of investment in energy innovation (and a large part of it is channeled as loans, which does not seem appropriate),
- low contribution of private investment,
- low innovation production, particularly in terms of patents and exports (not that low in terms of publications),
- low popularity and scientific knowledge about energy in Spanish society,
- low entrepreneurial culture.

It then seems urgent to strengthen and redirect investment in energy innovation, and foster private investment, creating an environment that promotes innovation in an entrepreneurial environment. The priority actions identified in this report to achieve these objectives are:

- perform a strategic analysis of the innovation priorities, of the areas in which Spain should specialize,
- increase private investment, and promote public-private partnerships for executing R&D,
- improve the institutional framework and promote innovation and entrepreneurship ecosystems,
- coordinate innovation policy with energy policy, and consider how the regulatory design of the energy sector could facilitate innovation ,
- and raise public awareness of the importance of energy innovation through communication and education to society.

The challenge now is to translate these recommendations into specific policies. Although the full report develops the recommendations in more detail, more research will still be necessary to design and evaluate the most desirable actions.

It is important to bear in mind three important aspects about the conclusions presented here. First, that the innovation process is inherently uncertain. Therefore, it should not be assessed only for its concrete results in the short- to medium-term, which may depend to some extent on luck, but for its good design and robustness as well. In this sense, flexible support schemes, which control for the risk of failure but also allow betting on potentially disruptive technologies, are preferable to other conservative schemes that would hardly bring these improvements. In short, if new policies are implemented, a monitoring system should be created simultaneously so as to allow learning from the accumulated experience and adapting from the implemented measures to the new available information.

In this line, a natural extension of this report would be to build a robust portfolio of technologies in which to invest, with varying degrees of risk, and different support instruments, with the objective of maximizing the returns both in terms of cost savings for the energy system and in terms of improvement of the business and industrial fabric. This exercise should be raised in the context of a long-term strategic program, given the large volume of investment involved and the long lifespan of energy technologies.

Second, the report’s analysis suggests a significant change in the role of government, which should evolve from its traditional role as provider of R&D subsidies into a much more active role as catalyst of knowledge sharing, as promoter of innovation in businesses, and as facilitator of the strategic planning process already mentioned. The cases of the Basque Country, or of Israel, can provide interesting references in this regard.

Third, we must reiterate the exploratory nature of this report. A topic of such importance and complexity can not be resolved without further analysis. In this sense, the aim of the report was to draw attention to the major issues and actions that might be taken, but further development and implementation would require additional analysis. The work by Anadon et al (2011), cited repeatedly in this report, constitutes a good reference in this respect: it is necessary to study specific cases of innovation in Spain, perform quantitative analysis of the relationship between inputs and outputs, evaluate the perceptions and behavior of companies, etc. For this purpose, it would obviously be desirable to have more reliable or currently inexistent data. Moreover, policy decision-making should incorporate considerations arising from scientific analysis. The authors are already working on the proposed extensions to this work, and expect to offer updates to this report in the coming years.