









**Table 1: Number of green patents and total patents among top 20 green patenting companies (1990-2011).**

company_name	green patents	total patents	percentage of green
Shell	2318	6630	34
Evonik Industries	1867	22018(1)	8
PSA Peugeot Citroen	1332	9848(5)	13
OSRO GmbH	1219	3189	38
BMW	1098	8993(6)	12
VATTENFALL	1087	1614	67(4)
Renault	1069	7422(7)	14
BASF	1009	1660	60(6)
AIR LIQUIDE	952	3737	25
Emitec GmbH	901	1070	84(1)
AkzoNobel	854	11920(2)	7
Vestas Wind Systems	844	1087	77(2)
Bombardier	815	1161	70(3)
Novozymes	740	2111	35
Johnson Matthey	732	1284	57(7)
Polieri Group	719	5706	12
ZF Friedrichshafen	688	10841(3)	6
Continental	656	10791(4)	6
UPM-Kymmene	606	3193	18
Umicore	582	889	65(5)

**Note:** Top 7 share of green patents; Top 7 # of patents; Rank in brackets

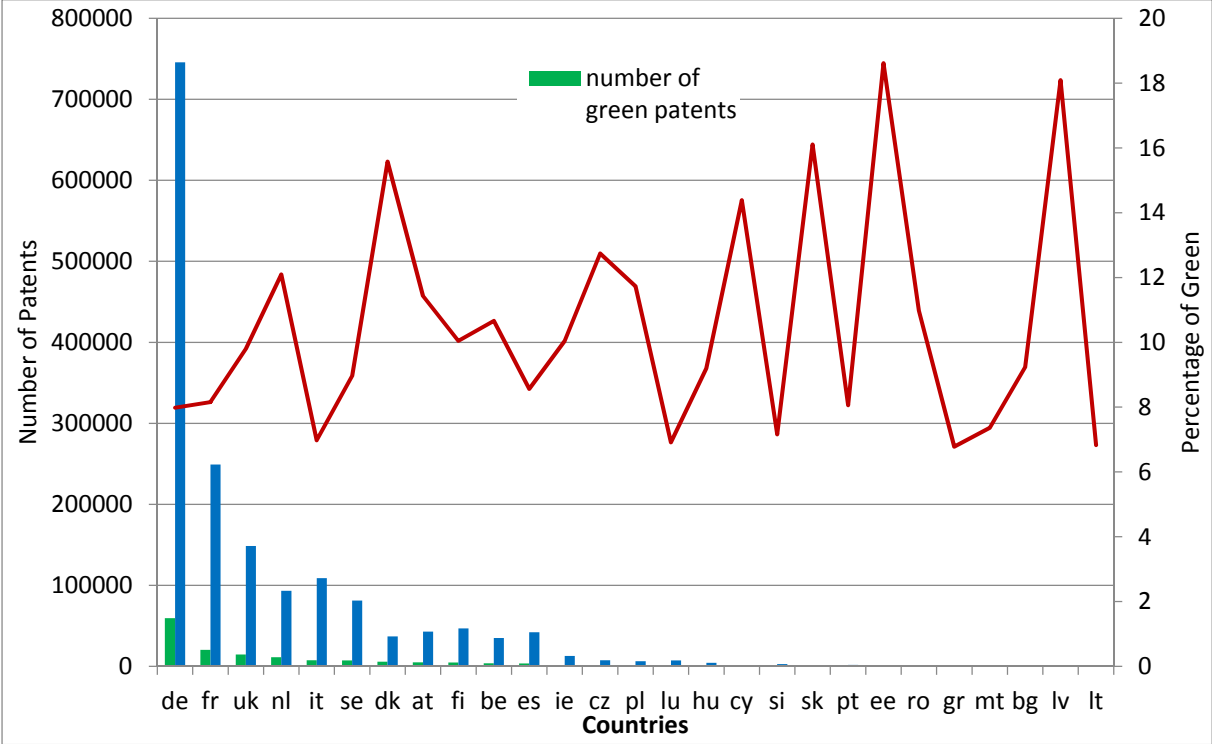
Source: Companies belong to EU-27. Source: Amadeus, Patstat (1990-2011).

What is interesting is that companies that fall under EU Emission Trading System hold a significantly higher share of 'green patents' (9.7%) than other companies (8.7%). But as we do not control for sector composition and size we cannot prove that companies covered by the ETS are more prone to invest in green innovation.

### Countries

Finally, mainly because of differences in size and sector composition, different countries perform differently in terms of green patent share. Denmark (16 percent) stands out, while the patenting heavyweights Germany, France and Italy, have lower than average shares of green patents.

**Figure 3: Number of patents held by companies, by country, 1990-2011.**



Note: Percentage of green patents is described as the percentage of green patents in total number of patents for the specific country. Countries are EU-27.  
 Source: Patstat (1990-2011).

### 3. Key policies to drive innovation in low-carbon technologies

There are numerous policy instruments to support innovation, ranging from patent protection to public research funding and public procurement to subsidies for private investments in innovation<sup>9</sup>. Given the evolution of a complex array of policy designs to support innovation, there is no consensus on a single best practise<sup>10</sup> – but there are conventional “dos and don’ts,” such as a call to regularly conduct independent evaluations of innovation policies, to avoid excessive risk aversion in the project selection and to determine clear triggers for cutting support<sup>11</sup>.

While all this is also true for ‘low-carbon innovation’, supporting ‘low-carbon’ presents the particular challenge of targeting innovation that brings down the cost of decarbonisation. To achieve this targeting, there are three main policy approaches: (i) set a price for carbon, (ii) directly support public and private investment in research, development and demonstration (RD&D) of targeted low-carbon technologies, and (iii) create demand for such technologies to foster private innovation in this field.

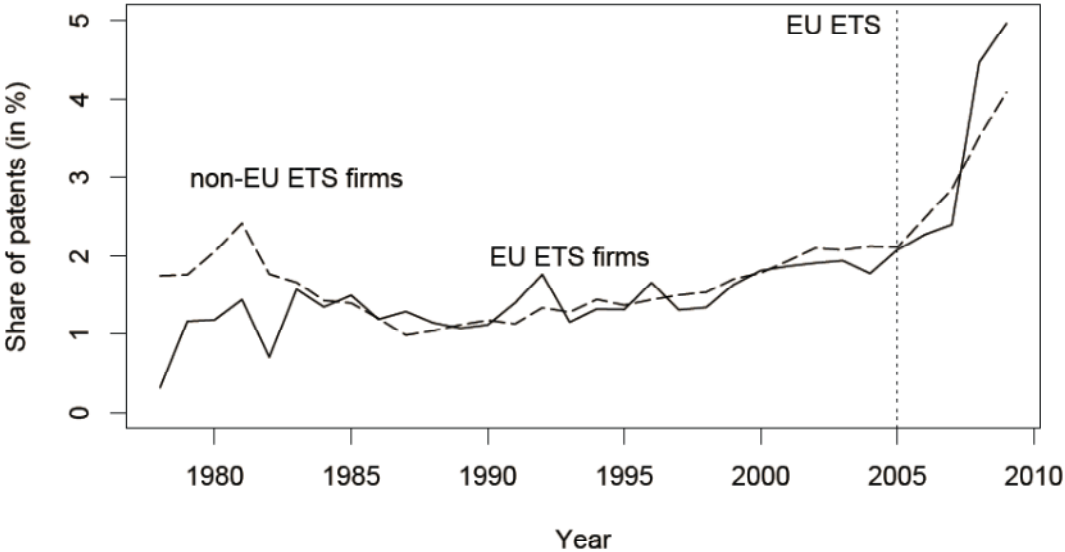
#### 3.1. Pricing Carbon

If companies know that they or their (potential) customers will be faced with high carbon prices in the future, they will have every incentive to invest in development of low-carbon alternatives. Calel and Dechezleprêtre (2012) provide evidence that carbon pricing in the EU has increased low-carbon

<sup>9</sup> Steinmueller (2011) four main themes - policies affecting supply of technology, of complementary factors, and demand as well as changes in institutional design.  
<sup>10</sup> For example, according to Steinmueller (2011): there is a “need to improve the theoretical frameworks for [innovation] policy formulation.”  
<sup>11</sup> See for example World Bank (2014) for the case of Poland.

patenting by companies directly covered by the carbon pricing scheme (ETS) and companies not falling under the ETS<sup>12</sup>. Creating the expectation of a high future carbon price has one big advantage over all other innovation policies (such as predictably tightening fuel standards that otherwise work in the same way) – it is completely technology neutral. So it, at the same time, improves the incentives to invest in low-carbon power generation technologies (e.g. solar photovoltaic), energy-efficient appliances, carbon capture and storage or more resource-efficient processes (e.g. recycling of aluminium). Therefore, the policy challenge for the EU is to create the ‘right’ price and to make it durably credible.

**Figure 4: Share of low carbon patents by companies falling under the ETS and companies not falling under the ETS (start of the ETS: 2005)**



Source: Calel and Dechezleprêtre (2012)

But even at a perfect EU carbon price there will still be private under-investment in low-carbon innovation. The main reason is that private investors will not be able to reap the climate benefits that the low-carbon technologies they produce have beyond the EU – if no carbon price exists there. For example, the sale price of an innovative wind turbine in Europe could be as high as that of the next-cheapest low-carbon technology, while in Vietnam the innovator might only be able to sell it if the price stays below the cost of a corresponding coal plant. Consequently, the innovator is not compensated for the climate benefit of its innovation beyond the EU, and thus has a below-optimal incentive to invest in improving its design. In addition, as with all innovations, the innovator might not be able to fully appropriate all the benefits (such as spillovers onto other innovators) and it has even been argued that these spillovers are particularly large for green technologies<sup>13</sup>. So additional support schemes are justified.

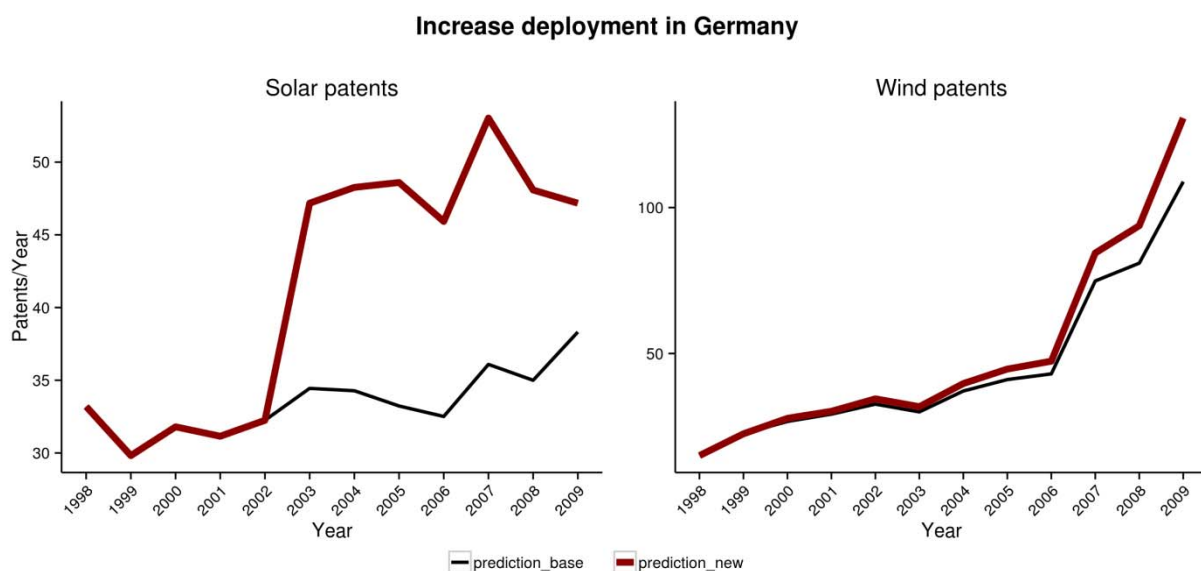
<sup>12</sup> The effect on companies outside the ETS might be due to the fact that most of the low-carbon innovation due to carbon prices would be expected to take place at the technology providers (such as ABB) that are not directly covered but that supply companies that fall under the carbon price (such as RWE).

<sup>13</sup> See for example Dechezleprêtre *et al* (2013).

### 3.2. Supporting the deployment of as yet uncommercial technologies

The prospect of deployment is the carrot for industry to commercialise new technologies. Hence, a long-term deployment target – such as the 20 percent the EU adopted for renewable energy for 2020<sup>14</sup> – is indeed helpful, not least because it incentivises innovation and investment in complementary technologies such as storage or networks. For example, the creation of a 40 gigawatt global market for the deployment of photovoltaic panels between 2000 and 2010 was arguably responsible for reducing the cost of solar cells from \$5 /watt to \$1 /watt. In Zachmann *et al* (2014) we find that increased deployment indeed coincides with more patents in the corresponding technology.

**Figure 5: Predicted impact of an increase in deployment by one standard-deviation of solar panels (left) and wind turbines (right) on the number of corresponding patents**



Source: Zachmann *et al* (2014)

There is an active discussion on how deployment can best be supported. German technology-specific feed-in tariffs were very effective in creating a significant market for onshore wind, solar PV and biogas – but the costs were also significant and there was some concern that guaranteed tariffs for everyone do not sufficiently push innovation<sup>15</sup>. Other countries went for tendering schemes, renewables certificates, tax breaks, renewables-premium models etc. For certain sectors (e.g. buildings, cars or appliances) predictably tightening standards provides the prospect of deployment of as-yet uncompetitive technologies.

Deployment policies are often evaluated by the short-term cost per deployed unit of low-carbon generation technology<sup>16</sup>. From an innovation standpoint this is only of secondary importance because the aim is to bring down the cost of future generations of the supported technology.

<sup>14</sup> This European target was broken down to different national targets (e.g. 18 percent for Germany or 49 percent for Sweden).

<sup>15</sup> Too generous support in fact appears to reduce the producers incentives to aggressively compete on innovation. The ten largest solar panel producers all spend below 5 percent – most of them below 2 percent – on research and development (R&D), compared to 10-20 percent in the semiconductors sector [www.pv-tech.org/friday\_focus/friday\_focus\_rd\_spending\_analysis\_of\_top\_10\_pv\_module\_manufacturers].

<sup>16</sup> This often relates to how effectively the policies shielded investors from regulatory and market risks.

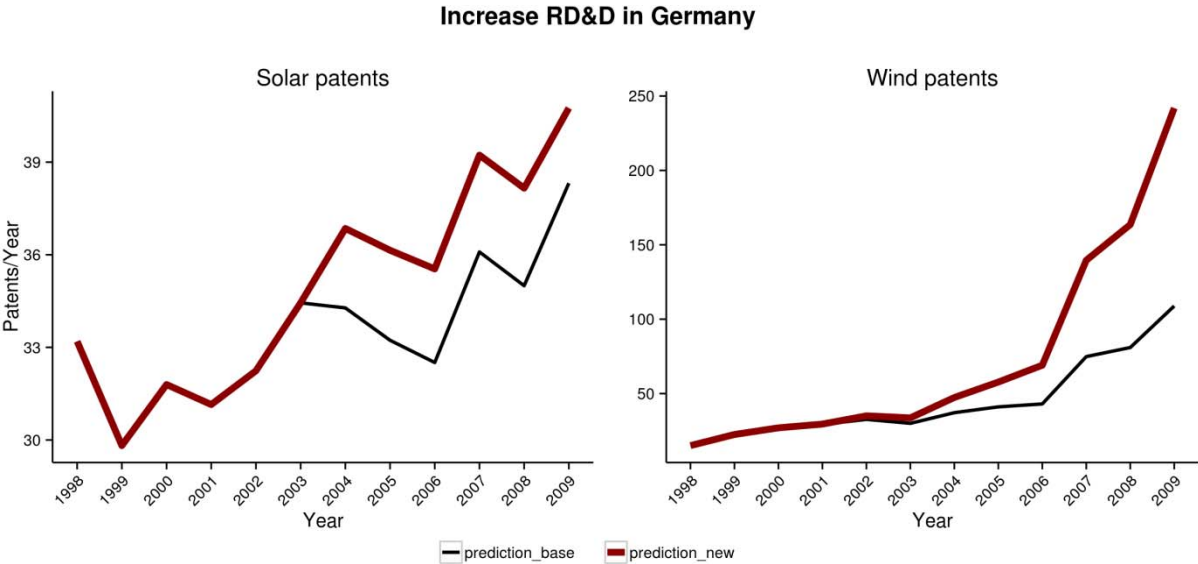


Consequently, we see three main policy questions from an innovation standpoint: (i) How predictable is the size of the future market (e.g. the year-to-year decision on tax breaks in some US states is not helpful in deploying an efficient value chain)? (ii) Does the set-up remunerate innovative solutions, e.g. by setting feed-in tariffs that are likely to be only sufficient for next-generation technology? (iii) And how openly does it deal with different technologies (e.g. the German feed-in tariffs support only a narrow set of 'proven' technologies)?

### 3.3. Public RD&D spending, and support to private RD&D

Public research in universities, research centres and research programmes is an important source of basic innovation. In addition, the publicly-funded education of researchers reduces the private sector's cost of innovation. Furthermore, all governments of OECD countries have specific policies to support private investment in RD&D. In Zachmann *et al* (2014) we provide evidence that increased public RD&D spending indeed coincides with more patents in the corresponding technology.

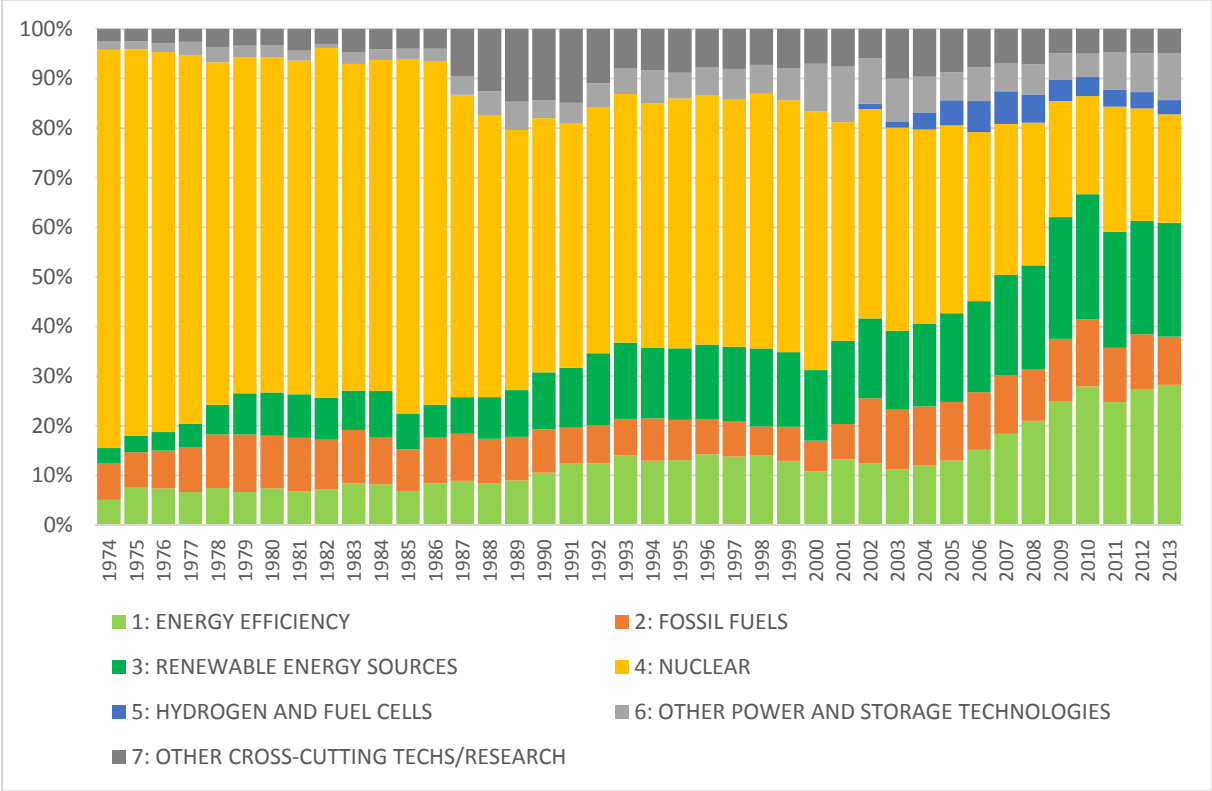
**Figure 6: Predicted impact of an increase in public RD&D by one standard-deviation for solar panels (left) and wind turbines (right) on the number of corresponding patents**



Source: Zachmann *et al* (2014).

While some of the mechanisms work irrespective of the area of innovation (e.g. investment in all RD&D is made tax-deductible in some countries), most public funding for RD&D is explicitly or implicitly targeted at certain sectors. In this context, energy technologies are a striking example of technology 'fades'. Since the second world war, nuclear fission, hydrogen, photovoltaics and other technologies have all been supported massively for some years – before falling out of fashion (see Figure 7).

**Figure 7: Share of energy RD&D spending by governments in OECD Europe<sup>17</sup> by technology sector**



Source: IEA (2015). Estimated RD&D budgets by region.

So a key question is: how is public spending targeted at individual technologies or objectives? This is particularly relevant when the aim is to develop technologies that make decarbonisation cheaper, because those technologies are often competing with each other. In fact, there are not only individual technologies (such as solar PV and onshore wind) that are competing for a future market, but also entire energy systems. Decarbonisation might take very different routes, such as: (i) low-carbon electricity production (from either renewables, nuclear or CCS plants) plus electrification of transport and heat *versus* hydrogen as a new carrier and storage for energy; (ii) centralisation of energy supply with strong networks *versus* decentralised solutions with local storage; (iii) massive reduction in energy demand *versus* decarbonisation of energy supply.

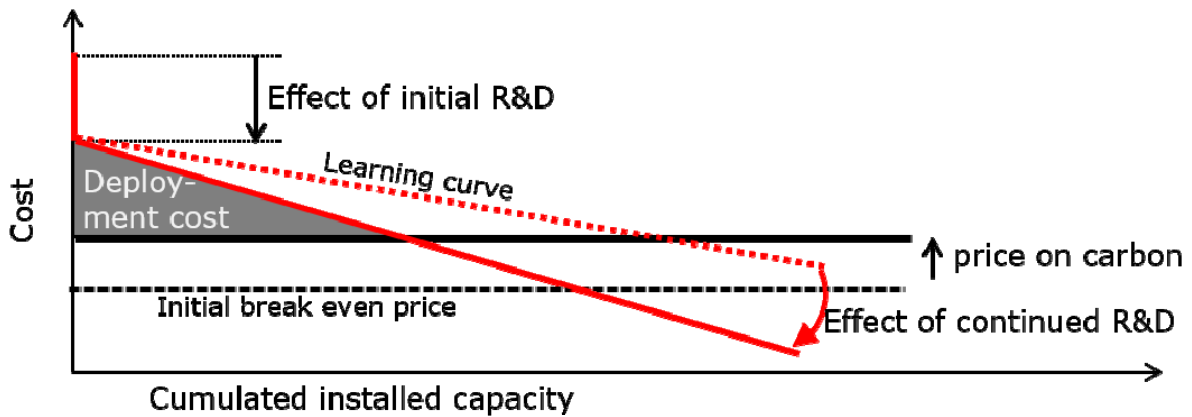
### 3.4. Policies working together

Public funding of RD&D, public support for the deployment of low-carbon technologies and a forward-looking price on carbon can all contribute to innovation. Figure 8 schematically describes the interaction. Before a technology is deployed, some basic RD&D brings down the cost to a level at which some deployment can be started. Deployment leads to learning – so the more a new technology is deployed, the lower the cost becomes (‘learning curve’). This ‘learning curve’ can be bent down by continuous funding of RD&D. At some point the technology will be able to compete with other technologies on the market. This point will be reached earlier (and hence encourage private investors to do more RD&D and deployment on their own) if there is a predictable carbon price.

<sup>17</sup> Austria, Belgium, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, the Netherlands, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

For any given technology, one might ask what is the right timing and combination of these three major instruments to most effectively and efficiently bring down their cost.

**Figure 8: Schematic picture of cost reduction for renewable energy technologies**

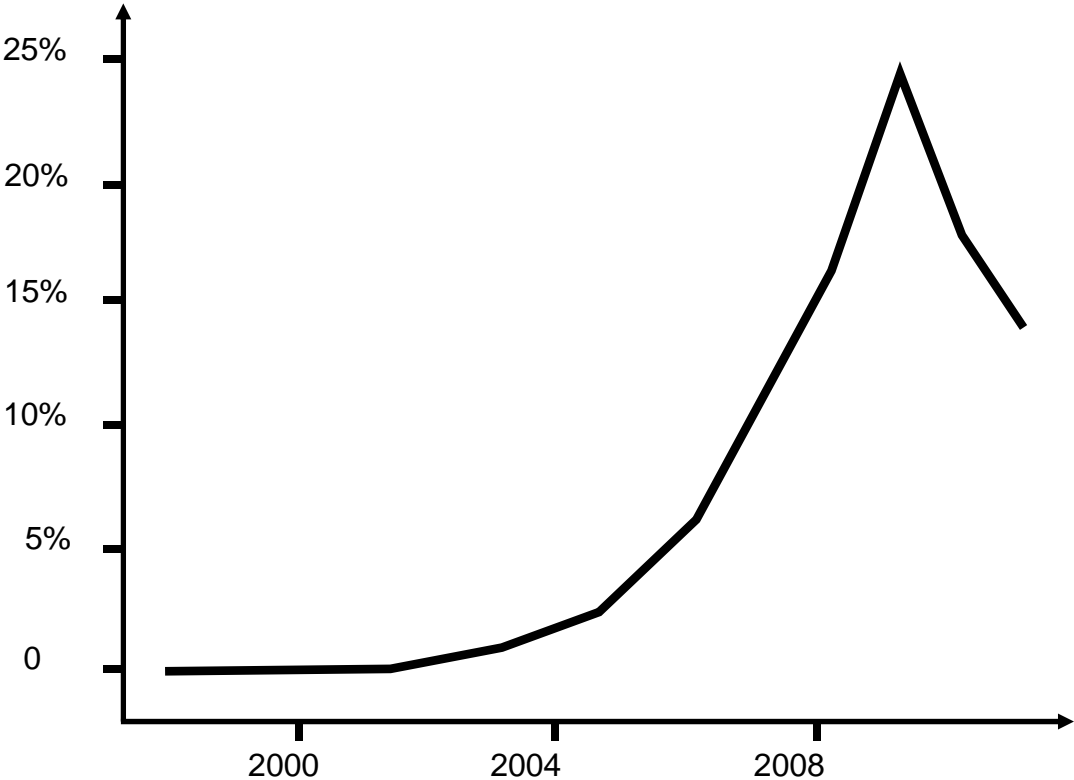


Source: Bruegel.

In Zachmann *et al* (2014) we find that both deployment and public RD&D support matter in terms of innovation. Our results indicate that there is a benefit in combining deployment and RD&D. The patenting of wind turbine technology in particular is strongest in countries that combine strong RD&D support and deployment (see Figure 9). In fact, support for deployment some years after substantial investments in R&D coincided with the strongest development of corresponding patents. That would be in line with the hypothesis that it is not massive actual deployment<sup>18</sup>, but the prospect of deployment, that is the carrot for industry to commercialise the technologies developed through publicly-supported R&D.

<sup>18</sup> Too-generous support in fact appears to reduce producers' incentives to aggressively compete on innovation. The ten largest solar panel producers all spend below 5 percent – most of them below 2 percent – on research and development (R&D), compared to 10-20 percent in the semiconductors sector [[www.pv-tech.org/friday\\_focus/friday\\_focus\\_rd\\_spending\\_analysis\\_of\\_top\\_10\\_pv\\_module\\_manufacturers](http://www.pv-tech.org/friday_focus/friday_focus_rd_spending_analysis_of_top_10_pv_module_manufacturers)].

**Figure 9: Predicted benefit of combining RD&D support and deployment for wind turbines in Germany**



Source: Zachmann *et al* (2014).

Note: The graph shows the difference between the increase in wind patents predicted for (i) a combination of a one standard deviation increase in deployment and a one standard deviation increase in RD&D and (ii) the sum of the individual effects.

In terms of balance, we observe that in recent years Europe has focused on deployment. Public spending on deployment of wind and solar technology has, for example, been two orders of magnitude greater (about €48bn in the five largest EU countries in 2010) than spending on RD&D support (about €315mn). This raises the question of whether this bias is the most efficient way to stimulate innovation.

#### 4. Four recommendations for making technology support smarter

##### 4.1. Better carbon pricing

The EU ETS could in principle provide a valuable signal for investments in the development and improvement of low-carbon technologies. In its current design, about 55 billion allowances (each worth one ton of CO<sub>2</sub>) are allocated. Given the allocation schedule over time and the expected annual emissions, allowances are likely to become scarce in the late 2020s. From then on the market will rapidly tighten. This future scarcity of allowances should translate into a high price. And market participants should anticipate the growing prices and hence buy unused allowances today and set them aside – thus bringing up current prices. Consequently, the ETS would bring about a valid and forward-looking carbon price signal. However, the allowance price today does not reflect future scarcity (expected prices in 2030 are about €40 while prices today are below €10). This indicates a

lack of confidence in the instrument, which can be explained by volatile policies driving the supply and demand of allowances. Accepting 1.4 billion international carbon credits into the system and constantly discussing the allocation mechanism showed market participants that the 55 billion allowances are not set in stone. And national decarbonisation policies in sectors covered by the ETS – such as the UK carbon floor price or the discussion about a forced German coal-phase-out – undermine the efficiency of the instrument. Lower demand for allowances in member states that conduct decarbonisation even in sectors with high abatement costs will reduce the price, causing more emissions from sectors with low abatement cost in other member states. Eventually, the latter will also introduce additional measures to avoid these emissions – rendering the ETS completely redundant. As the ETS is a long-term decarbonisation device, the challenge is to isolate it against short-sighted intervention, while still allowing the system to respond to structural shifts.

So, to establish the necessary confidence in the ETS, policymakers need to credibly commit to the system. One promising mechanism would be to sell guarantees of the future carbon price. This could be organised in the form of a private contract between those making low-carbon investments and the public sector. A public bank (e.g. the European Investment Bank) would offer contracts that agree to pay in the future any positive difference between the actual carbon price and a target level. Investors would bid to acquire such contracts to hedge their investments. Hence, public budgets would be significantly exposed to the functioning of the ETS. If future climate policymakers take decisions that lead to increases in the number of available carbon allowances, they might be called back by the treasuries, because this would activate the guarantees pledged to investors. Consequently, all parties – also investors not covered by the scheme – would know that there is money on the table. This would serve as a much stronger and hence more credible commitment device for preserving the integrity of the ETS. The lower risk associated with the future carbon price would immediately imply a higher carbon price. The scheme would introduce a soft form of a floor price by making it expensive but not illegal for policymakers to accept very low carbon prices in the future.

## 4.2. More Europe

Although the EU has a joint carbon-pricing mechanism, deployment and RD&D support are only weakly coordinated among member states. In terms of deployment in particular this is regrettable because a more European approach could achieve the same deployment at significantly lower cost. For example, much more electricity could be generated from the same capacity of deployed solar panels if they were not installed in the member states that provide the highest subsidies – but in the sunniest locations. A European approach also tends to be more stable than national policies, and stability is crucial for encouraging private investments in complex new value chains and energy systems. A European approach also enables more competition because of its larger market size and could ease the integration of new technologies into existing systems. Ultimately, a European approach to deployment of low-carbon technologies could be more easily integrated into the internal energy market, while the prevalent national schemes are partly responsible for the currently-observed costly renationalisation of the energy sector.

A more European support to green innovation makes sense because the positive effects of supporting innovation tend to spillover to neighbouring countries. In Zachmann *et al* (2014) we find, for example, that deployment appears to have substantial cross-border effects for innovation – increased deployment in one country coincides with increased patenting in nearby countries. Consequently, a national evaluation of the costs and benefits might underestimate the benefits of deployment – hence a more European approach would be more suitable.

In terms of technology-choice more European coordination is also worthwhile. Individual member states cannot meaningfully support a sufficiently large portfolio of technologies necessary to ensure resilient decarbonisation. For transport decarbonisation, for example, there is still no certainty whether the future will be fuel-cell hydrogen, battery electric, modal shift, biofuels or something else. So European coordination should ensure that we do not put ‘all eggs in one basket’ by only going big on one single technology, but coordination should also ensure that fragmentation cannot prevent efficient support to the most promising technologies.

### 4.3. Support deployment and RD&D

Support for renewables in Europe has been focused on deployment, while support for other technologies (e.g. hydrogen) has been focused on RD&D. We see no clear innovation-economic rationale for this dichotomy, which appears to have arisen for political economy reasons. As a consequence, policymakers should reconsider this balance, for example, by shifting support from deployment to RD&D funding for renewables. So the focus of renewables support should be shifted from a ‘deployment target’ that encourages the quick build-up of the cheapest currently-available renewable energy technology, to an ambitious ‘innovation target’ that encourages investment in reducing the cost of renewable energy technologies. In addition, deployment programmes should be coordinated with RD&D programmes. It should be ensured that technology-specific deployment is organised in a way that stimulates competition between providers, especially by developing programmes with a volume and time horizon that will enable the build-up of innovative value chains. If successful, an ‘innovation target’ will be the greatest possible contribution of Europe (and its partners) to saving the global climate, and it might be instrumental in developing a competitive edge in what will eventually become an important global market<sup>19</sup>.

### 4.4. Technology support mechanism

Political decisions about which technology to support, and when and how to do so can have very far-reaching consequences. Without public support for the nuclear industry in the 1960s and 1970s, for example, the fuel mix, electricity networks and even electricity consumption patterns<sup>20</sup> would look markedly different today. But also in the future, policymakers can and will not abstain from technology choices. The challenge is therefore to enable them to make good choices.

One proposal we have made in Zachmann *et al* (2012, p.96ff) is to set up a transparent evaluation process of ‘support schemes for individual technologies’. A level playing field for public support for new technologies requires that governments’ choices of a technology portfolio should not be driven by the question of ‘which’ but by the question of ‘how’. Governments should adopt choice mechanisms that are dynamic and adaptive, able to digest new information and optimise support in a quick, reliable and effective manner. Transparency is critical for the success of any choice mechanism, so that industry and consumers can form the right expectations about the direction of technology. The only way to control the potential impacts of public policy on industry investment choices is through a transparent policy that clearly communicates government priorities and decision-making parameters. Transparency also promotes fair competition and inspires trust on the part of industry and consumers. Stakeholder trust is fundamental to the success of energy transition

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<sup>19</sup> Primary energy consumption of oil, natural gas and coal amounts to about 6 percent of global GDP. Adding the value of existing non-fossil electricity production (about 2 trillion USD) and all the energy downstream cost and the demand side appliances (from cars, over heat pumps to refrigerators) it is likely that a global market for new energy technologies would amount to more than 10 percent of world GDP.

<sup>20</sup> The role-out of electric heating in France and Germany can partly be explained as a response to the availability of unused electricity in night-time.

policy. Finally, it is important to note that the mechanism should be utilised to select not only one, but a portfolio of technologies.

The first step in constructing a technology-choice mechanism is to define a transparent set of metrics and priorities (which can later be updated, as the demands of society and climate action change). The interest of governments is to support the optimal portfolio of technologies in terms of certain metrics – such as cost, timeline, efficiency, benefits and safety. These metrics and priorities should be as technology-neutral as possible, and should be the driving force behind the technology-choice mechanism.

All stakeholders involved in the selection of new technologies face the problem of imperfect information. However, the developers of different technologies might have an interest in overstating the capabilities, or understating the cost, of their respective technologies in order to attract more support (or even lock out competitors). Therefore, the public technology-choice mechanism must be one that iteratively elicits unbiased estimates from industry.

One example of a mechanism for achieving this would be for companies/consortia/academia to offer a ‘menu’ of different support options for the development/deployment of their new technologies. This menu would contain promises about the metrics defined in the first step of the mechanism’s design, and the expected form and volume of support. Attached to each option would be a requirement to meet certain quality metrics by a certain date, penalties for failing to meet the metric by the date and a reward for achieving it<sup>21</sup>. An open and transparent energy and transport transition model would be used to evaluate the proposed packages. The model would suggest a combination of support options to develop a sufficiently resilient portfolio of technologies at lowest cost. The model should be run and maintained by a central authority such as the Strategic Energy Technology Information System.

At the very least, such mechanisms could provide a better avenue for choice-mechanism definition than a simple ‘shot-in-the-dark’ definition of thresholds or numbers. A European mechanism for allocating support to technologies can create a level playing field for competing technologies. It would promote more coordination between regions, nations and companies. The cost of the transition is put at several percentage points of GDP. Therefore, large-scale government intervention will be unavoidable. Consequently, a structured approach adapted to the complexity of the challenge is warranted to avoid extensive inefficiencies. This approach should not be applied mechanically to determine technology-support policies, but as a reference tool to inform policy decisions and structure the political debate.

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<sup>21</sup> So a consortia might for example, either propose a low-benefit, risk-free project and accept a high ex post penalty for failure (if they fail they give all money back), or a high-risk project with a potentially spectacular breakthrough for which only a small penalty (e.g., 10% of the public money) would be foreseen in case of failure.

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