# Promoting Technological Innovation to Address Climate Change

Technological change is undoubtedly one of the keys to ensuring that climate change can be addressed without compromising economic growth. In order for this to be the case it is vitally important that climate and innovation policies provide the right incentives for the development and diffusion of 'climate-friendly' technologies. The OECD is assisting countries in their efforts to improve the design, implementation and evaluation of their policies in this area.

## *Key Messages*

- Provide predictable and long-term policy signals in order to give potential innovators and adopters of climate-friendly technologies the confidence to undertake the necessary investments.
- Use flexible policy measures to give potential innovators incentives to identify the best way to meet climate objectives, and to avoid locking-in technologies that may become inefficient in future.
- Put a price on GHG emissions, for example through taxes or tradable permits, in order to provide incentives across all stages of the innovation cycle.
- Provide an appropriate mix and sequencing of complementary policy measures in order to overcome barriers to development and diffusion of breakthrough technologies.
- Balance the benefits of technology-neutral policies with the need to direct technological change toward climate-saving trajectories, by diversifying the portfolio of technologies for which support is provided and identifying general purpose technologies with environmental benefits.
- Since the sources of innovation are widely-dispersed, support research and development in a broad portfolio of complementary fields, and not just energy, 'climate-friendly' or 'environmental' R&D.
- Ensure that international policy efforts maximise the potential for sharing of knowledge and technologies of mutual benefit, for example through international research-sharing agreements.
- Support international technology-oriented agreements as an important complement to other international efforts (*e.g*. emissions-based agreements).

## Government Policy Aimed at Promoting Innovation

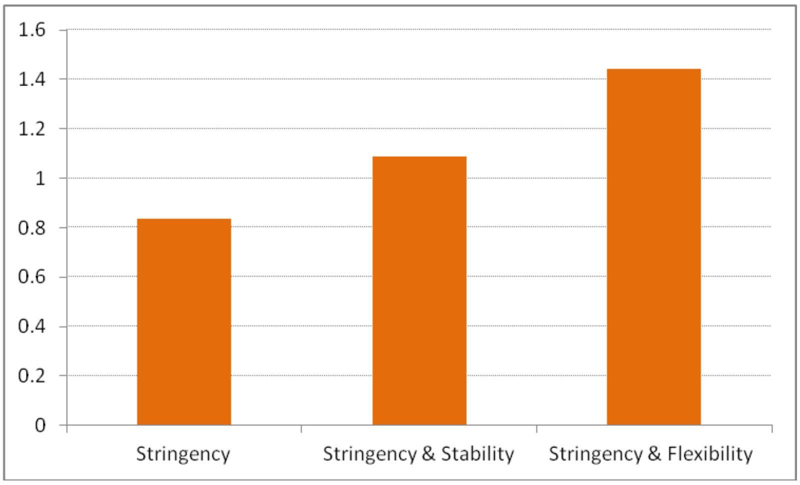
### Provide Predictable and Flexible Signals

In addition to commercial and technological uncertainty, investors in climate-related sectors face an additional source of uncertainty – that which is associated with climate policy. There can be uncertainty about the future stringency, timing, nature or durability of the policy framework. Irrespective of the nature of the uncertainty, an uncertain policy framework will result in less innovation in environmental and climate mitigation technologies. For instance, recent empirical analysis by the OECD supports the hypothesis that increased volatility of public R&D spending has a negative impact on innovation, undermining the benefits of a given level of support by one-half to two-thirds (see Figure 1).

Why is this the case? Policy signals that are difficult to predict encourage investors to postpone investments, including the risky investments that lead to innovation. In the face of unpredictability there is an advantage to waiting until the 'policy dust settles'. As such, adding to the risk that investors already face in the market, an unpredictable or unstable policy regime can serve as a 'brake' on innovation, both in terms of technology invention and adoption.

However, it is important to note that changing the policy parameters does not necessarily provide more uncertainty to investors, as long as this is done in a predictable manner. For instance, periodic adjustments made in response to market developments are likely to be predictable to market participants. More generally, as new information becomes available, whether environmental or economic in nature, then adjustments in policies are likely to be necessary and desirable.

***Figure 1. Effect of Environmental Policy Characteristics on Innovation***




*Source*: OECD (2011) *Invention and Transfer of Environmental Technologies.*

Note: The Figure shows the estimated coefficient of different combinations of characteristics of environmental policy framework in encouraging inventive activity in environmental technologies.

In addition, the more 'flexible' a policy regime, the more innovation takes place since this gives innovators the incentive to seek out the best means of meeting given environmental objectives (see Figure 1). This implies that rather than prescribing certain abatement strategies, wherever possible governments should give firms stronger incentives to engage in search for new innovations. Flexibility of policy regimes also ensures that markets are not fragmented across different countries. Given the risks associated with expenditures on research and development it is important that markets for innovation not be chopped up into different regulatory silos.

### The Importance of Prices

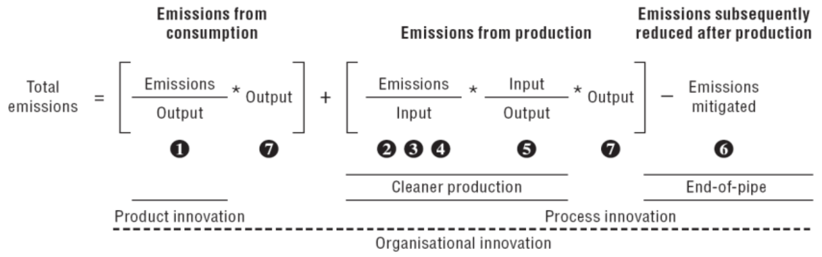
Predictability and flexibility is partly a consequence of policy choice, and market-based instruments can be designed in such a way as to give potential innovators a degree of foresight, as well as space for innovation. However, this depends upon the details of policy design. For instance, the precise characteristics of the tax instrument can have a large impact on the resulting innovation (and environmental impacts). Tax instruments applied at different points in the chain of production and on consumption provide differing levels of incentive for both the development of innovations and their adoption.

When both the production and consumption of a product result in pollution, the total direct and indirect emissions of the producing firm can be thought of as being composed of the components illustrated in Figure 2. Three factors determine the firm's direct and indirect emissions: how much its outputs pollute when used, how much the firm itself pollutes when making the outputs, and what the firm does to negate its emissions from production after the pollution has been created.

Figure 2 also outlines the various types of innovations that can be used to reduce emissions for each component. The numbers represent specific actions that can be taken to reduce emissions:

1. Create new products for consumers that generate fewer emissions when used.
2. Use less emission-intensive inputs (of the same type).
3. Use less emission-intensive inputs (of a different type).
4. Reduce pollution intensity per unit of input (without modifying inputs).
5. Reduce input use per unit of output.
6. Undertake remedial, "end-of-pipe" measures.
7. Of course, the firm (and the consumer) could simply produce (and consume) less.

***Figure 2. Ways of impacting total emissions***




*Source*: OECD (2010) *Taxation, Innovation and the Environment*.

Each of these alternatives is a way in which emission levels can be reduced in the economy. The choice of environmental policy instrument has a direct bearing on which actions are stimulated. Figure 3 outlines each of the five main tax measures and the strength of the innovation creation and adoption incentive that they have on each emission reduction possibility, assuming they are used in isolation.

***Figure 3. Innovation impacts of different tax instruments***

| | Invention propensity | Adoption propensity |
|---|---|---|
| Taxes on pollution | ❶ ❷ ❸ ❹ ❺ ❻ | ❶ ❷ ❸ ❹ ❺ ❻ |
| Taxes on proxies to pollution | ❶ ❷ ❹ ❺ | ❶ ❷ ❹ ❺ |
| Accelerated depreciation allowances | ③ ⑤ | ❸ ❺ |
| R&D tax credits | ① ③ ⑤ | ① ③ ⑤ |
| Reductions in VAT rate | ① | ❶ |

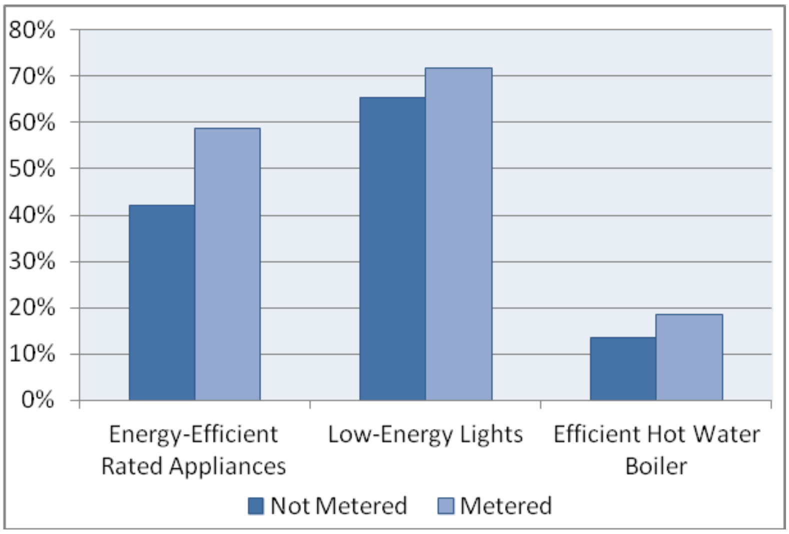
Note: White numbers on black background indicate strong inducement effect; black numbers on white background indicate weak inducement effect; absence of number indicates no inducement effect.

*Source*: OECD (2010) *Taxation, Innovation and the Environment*.

It is clear that some tax instruments encourage a wider range of actions (and therefore provide greater incentives for innovation) than others. Taxes on pollution provide incentives for all of the potential abatement measures, as levying the tax directly on the pollutant does not exclude any potential abatement measure and provides the greatest range of incentives for invention and technological change. As the incidence of the tax moves further from the actual pollutant, the range of potential measures for abatement decreases. Taxes on proxies to pollution provide much the same incentives, except where the abatement actions become disconnected from input use. Accelerated depreciation allowances encourage greater investment in physical capital. Such an instrument does not affect mitigation measures that are generally not capital intensive, such as actions one, two and four. Even for capital-intensive measures, an accelerated depreciation allowance as the sole policy instrument provides no incentive for abatement unless it is through the greater rationalisation of other inputs (such as fuel).

Similarly, generally available or environmentally targeted R&D tax credits do not provide incentives for mitigation, unless they help reduce the cost of existing processes or create new products. Without a price on carbon, R&D that significantly reduces the cost of carbon capture and storage, for example, would still have no economic rationale to be adopted. As such, only actions one, three and five are stimulated for invention and adoption. Finally, reductions in value added taxes for "green" purchases provide direct incentives for consumers to adopt new innovations, as they lead to a direct and identifiable price reduction versus non-reduced goods and services. The incentives for firms to invest in innovation activities are less strong, as the firm receives no direct benefit from the consumption tax reduction (although it will benefit from increased demand and can increase its prices somewhat) and these measures are frequently temporary.

*Figure 4. Effect of Electricity Metering on Adoption of Energy-Efficient Appliances*



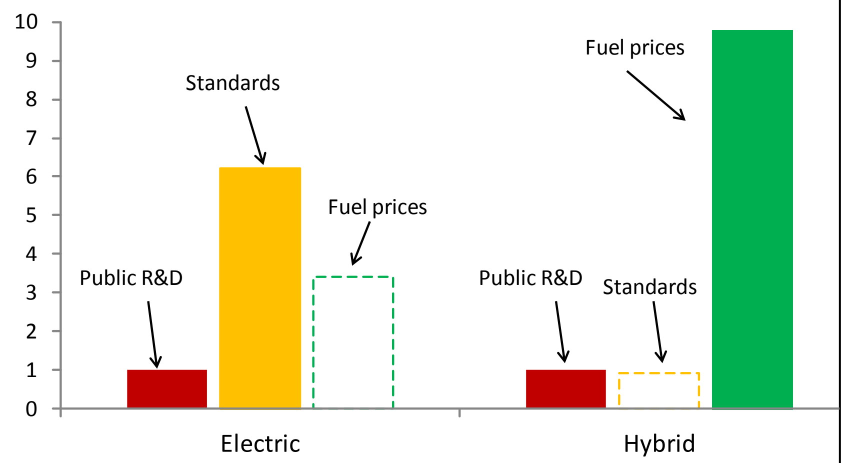

*Source*: OECD (2011) *Greening Household Behaviour*.

The ideal policy instrument is, therefore, one which targets the environmental 'bad' directly and gives innovators flexibility to identify the best means of meeting given environmental objectives. For these reasons, price signals arising out of the implementation of emissions taxes and tradable permit systems are likely to be an efficient means of inducing innovation (OECD 2010). Indeed, they may be a necessary condition for innovation since in the absence of clear price signals which penalise environmentally-damaging behaviour, other policy measures may be 'pushing on a string', with little impact. This is likely to be particularly true for the adoption of technologies. For instance, Figure 4 presents data on the adoption of energy-efficient appliances depending upon whether or not the household pays for electricity per unit consumed.

### *Policy Mixes and Breakthrough Technologies*

However, price signals may not always be sufficient, particularly if breakthrough technologies are to be induced. For instance, recent work undertaken in the area of alternative-fuel vehicles assessed the relative importance of fleet-level fuel-efficiency standards, after-tax fuel prices, and state support for R&D on innovation in electric and hybrid vehicles. It was found that relatively minor changes in a performance standard or automotive fuel prices would yield a much greater increase in patented inventions than a similar proportional increase in R&D budgets for some technologies (see Figure 5.)

*Figure 5. Relative Effect of Technology Standards, Fuel Prices and Public R&D on Innovation in Electric and Hybrid Vehicles*

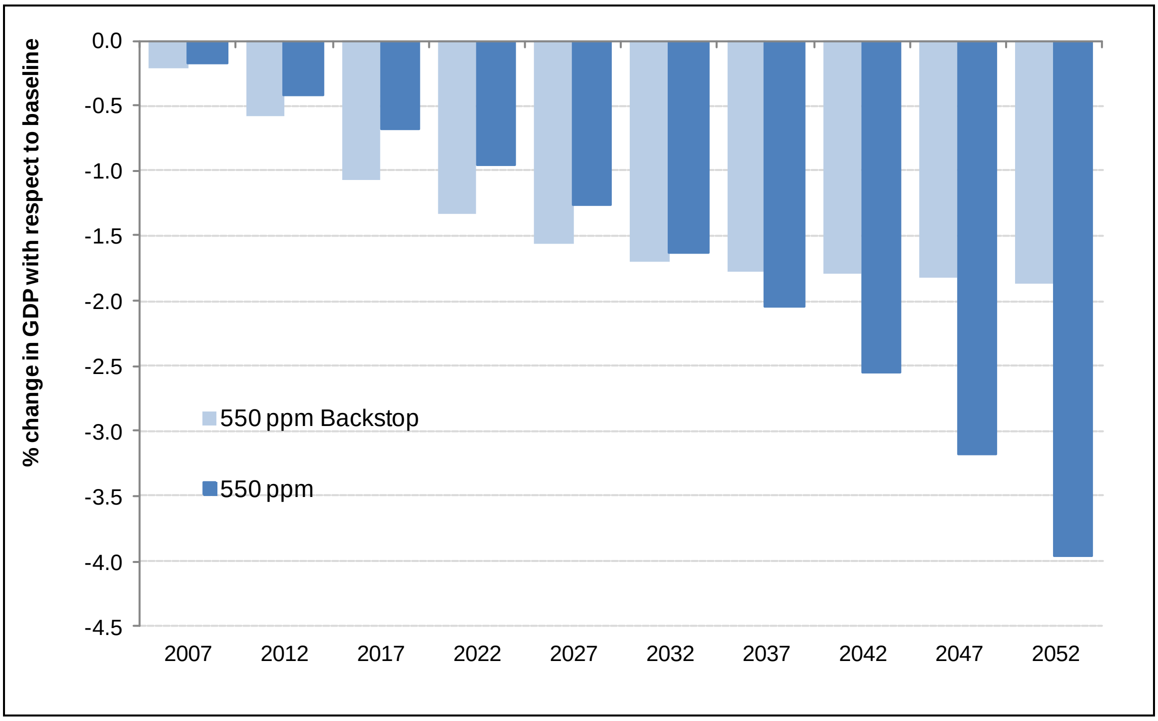



*Source*: OECD (2011) *Invention and Transfer of Environmental Technologies*. Note: For ease of interpretation. Elasticities have been normalised such that effect of R&D=1. Unfilled bars indicate no statistical significance.

However, the results also suggest that there are significant differences between the effects of different policy measures depending on the type of technology, whether electric or hybrid vehicles. While the latter technologies are nearing the situation where they are competitive with interenal combustion engine vehicles, this is not the case for electric vehicles. This indicates the importance of the appropriate mix of policy measures. Relative prices may have a lesser role to play than ambitious performance standards or significant public support for research the further a technology is from being directly competitive with the incumbent technology (petrol- and diesel-driven technologies). While in theory a price sufficient to induce an equal level of innovation for such technologies could be introduced, such a measure would likely be politically infeasible in practice. Moreover, even if introduced, potential innovators may not perceive it as credible over the longer-term.

The importance of inducing investment in breakthrough technologies has been examined recently at the macroeconomic level. More specifically, the effects of the emergence of backstop technologies through dedicated R&D spending was modelled, making it possible to compare the economic costs of reaching a 550 ppm GHG concentration target with and without such technologies. The analysis finds that, although there is an initial GDP loss due to the large increase in R&D, in the longer run – especially beyond mid-century – the costs of meeting the stabilisation target are significantly reduced by the availability of backstop technologies (see Figure 6).

***Figure 6. Projected world GDP costs under 550 ppm GHG concentration stabilisation scenario, with and without backstop technologies***



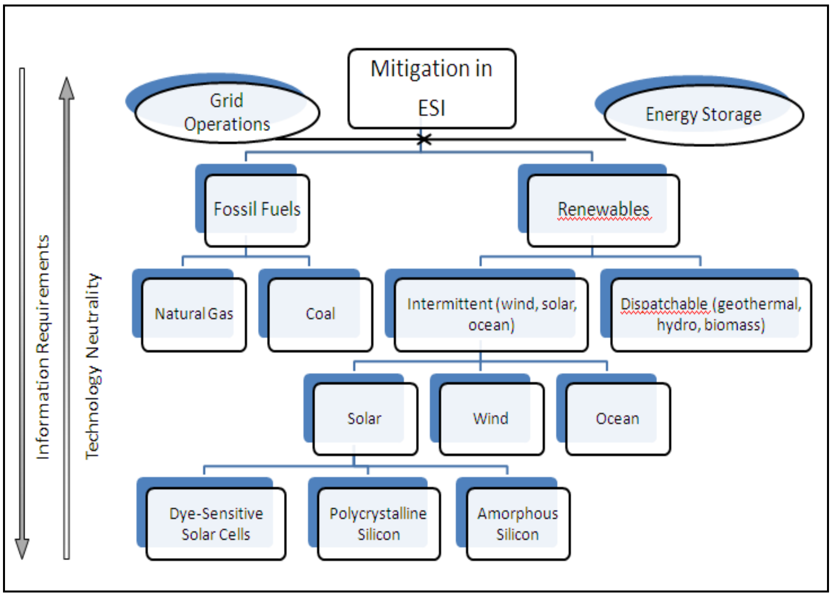

*Source*: OECD (2009) *The Economics of Climate Change Mitigation* Note: Emissions of non-$CO_2$ gases are not covered by the model used in this analysis and are therefore excluded from these simulations. The 550 ppm greenhouse gas concentration stabilisation scenario run here is in fact a 450 ppm $CO_2$ only scenario and greenhouse gas prices are $CO_2$ prices. Stabilisation of $CO_2$ concentration at 450 ppm corresponds to stabilisation of overall greenhouse gas concentration at about 550 ppm.

### *Public Support for Directed Innovation*

In practice, market-based instruments such as environmental taxes and tradable permits are often complemented with other policies, which target specific technologies. While the case for the role of the government in supporting basic and long-term research has been made and serves as an important source of future technological change, the issue of supporting specific technologies is less straightforward. Basic and long-term research has a public good character and is therefore unlikely to be undertaken by the private sector. Public support helps address fundamental scientific challenges and fosters technologies that are considered too risky, uncertain or long-gestating for the private sector. However, at the level of applied research the issue is more complicated. Should governments seek to minimise risks and support those technologies that are closest to the market, or should they seek to maximise returns and support technologies with the greatest mitigation potential? The OECD has started to examine these issues. For example, in recent years many governments have intervened directly in energy markets in order to promote increased investment in low emission technologies, such as renewable energy power plants. Increasing the penetration of intermittent renewable energy sources (wind, solar, ocean) presents significant challenges to electricity grid management. Improved energy storage and grid management can overcome this constraint by increasing system flexibility.

The benefits of targeting public R&D expenditures at system flexibility (energy storage and grid management technologies) may be greater than directly at intermittent generating technologies. Preliminary empirical evidence suggests that focussing policy incentives on innovation in system flexibility may obviate some of the problems associated with trying to "pick winners" amongst a portfolio of generating technologies of unknown potential (see Figure 7). The reasoning is simple - improved grid management and energy storage will yield benefits, irrespective of which intermittent renewable energy technologies ultimately prove to be 'winners'.

***Figure 7. Policy Incidence and Technology Neutrality***

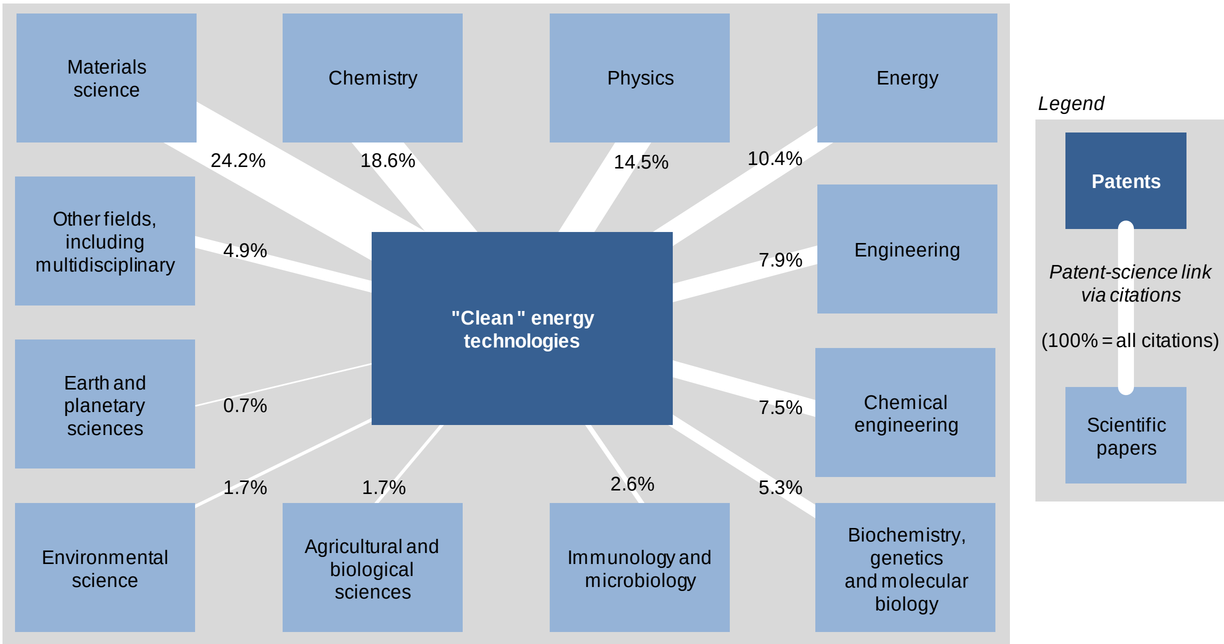



*Source*: OECD (2012) *Energy and Climate Policy and Innovation.*

Where governments do provide targeted support, the design of policy mechanisms is of great importance. Good policy designs need to ensure competitive selection processes, focus on performance rather than specific technologies, avoid favouring incumbents or providing opportunities for lobbying, ensure a rigorous evaluation of policy impact, and contain costs. Proven ways to meet these design considerations include multi-year appropriations, independence of the agencies making funding decisions, use of peer review and other competitive procedures with clear criteria for project selection, and payments based on progress and outcomes rather than cost recovery or choice of technologies. Support for commercialisation should be temporary and accompanied by clear sunset clauses and transparent phase-out schedules, which requires a good understanding of the state of development of alternative technologies and the market structure in which they are being developed. Government support policies also need to be aligned with existing international commitments, notably under the WTO, and with competition policy.

OECD analysis shows that innovation in clean energy technologies depends on a wide range of research, notably material sciences, chemistry and physics, and not just on energy or environmental research. (See Figure 8). Investing in research to foster environmental technologies will therefore require a broad portfolio of investments, and not just energy or environmental R&D. Moreover, such investments will increasingly need to be undertaken through approaches that involve multi-disciplinary funding, rather than funding along scientific disciplines.

*Figure 8: The innovation-science link in "clean" energy technologies, 2000-2009 (Share of scientific fields cited in total non-patent literature cited in patents for "clean" energy technologies)*




*Source*: OECD calculations, based on Scopus Custom Data, Elsevier, December 2010 and EPO, Worldwide Patent Statistical Database, April 2011.

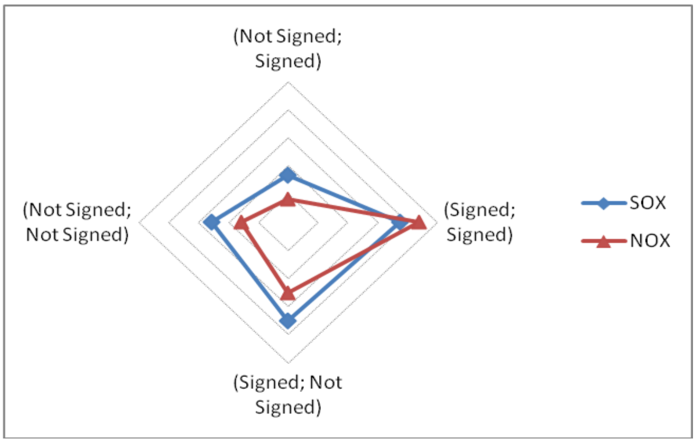
Public investments in research will need to be well designed to complement private investments in research and should aim for scientific excellence and areas in which social returns and spill-over effects are potentially the greatest. Exploratory research focused on potentially radical innovations - characterised by high risk and uncertainty - should be included in the funding mix. Given the significant potential for research to reduce the costs of meeting environmental goals, greater public investment in research at the global level is needed.

However, governments can also provide greater direction to the existing research effort, *e.g.* in prioritising thematic and mission-oriented research programmes aimed at addressing specific challenges such as climate mitigation, without necessarily specifying the nature of the research required. Moreover, governments can take action to improve the process of translating research into innovation, *e.g.* in strengthening the links between science and business. To enable research efforts to materialise the policy commitment to such research should be stable over a long period.

### *International Environmental Governance*

For environmental concerns of international concern, there are benefits to be gained from international policy coordination which extend beyond joint commitment to emission reductions. Recent OECD work has examined the role multilateral environmental agreements (MEAs) play in encouraging the international diffusion of abatement technologies. More specifically, the role that adherence to a series of international agreements on reducing $SO_X$ and $NO_X$ emissions - the Long-Range Transboundary Air Pollution Protocols - has played in inducing the transfer of technologies between signatories has been assessed. The major finding is that there is a positive effect on technology transfer between pairs of countries which have both joined the LRTAP Protocols (see Figure 9). Conversely, the effect is less pronounced when only either country joined or when neither one joined.

***Figure 9. Protocol Signature and International Transfer of Air Pollution (SOx and NOx) Abatement Technologies: 1980-2008***




*Source*: OECD (2011) *Invention and Transfer of Environmental Technologies.* Note: The relative importance of cross-border transfer of emissions abatement technologies, measured as the number of duplicate patent applications. The corners indicate whether one, neither or both countries have signed the Protocol.

International research collaboration can be an important vehicle through which countries can share costs and increase knowledge spillovers. While this has often occurred international research collaboration has been common amongst OECD economies, it is interesting to note that for 'environmental' technologies inventors in many emerging countries are collaborating with partners in the OECD. Table 1 shows the most active co-invention pairs for four environmental technologies (wind power, solar photovoltaic, energy storage and carbon capture and storage), as well as for all technologies combined. While major OECD economies dominate the latter the situation is much more mixed in the environmental fields, with emerging economies and small OECD economies in greater evidence. Indeed, geographical patterns of research collaboration are increasingly diverse (see Figure 10 for the case of wind power).

***Table 1. The Top Co-Inventing Country Pairs for Environmental and General Technologies***

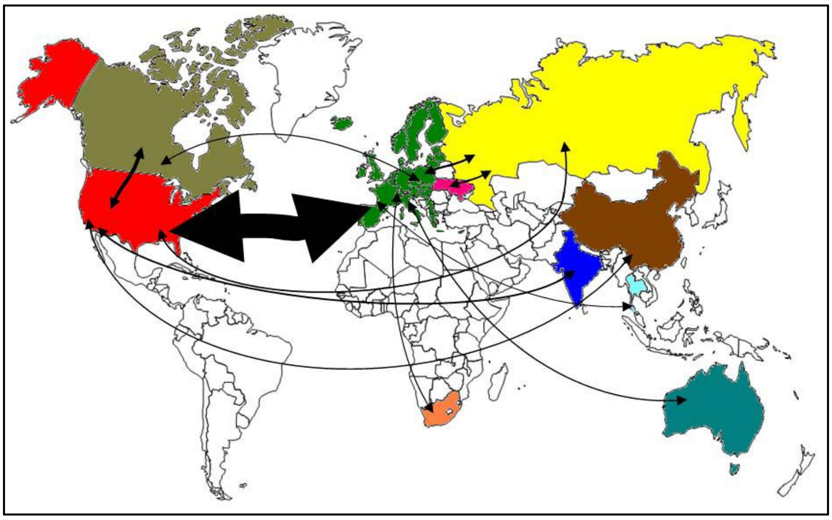
| Sector | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **All Technologies** | GB-US | DE-US | CA-US | CH-DE | JP-US | FR-US | NL-US | DE-FR | CH-FR | CH-US |
| **Wind** | DK-GB | DE-US | CA-US | DE-NL | NL-US | DE-DK | IN-US | BE-**ZA** | **RU**-US | DK-ES |
| **Solar PV** | JP-US | DE-US | GB-US | CH-DE | AT-DE | CA-US | **CN**-US | DE-FR | DE-NL | GB-IT |
| **Energy Storage** | GB-US | CA-US | DE-US | JP-US | JP-KR | FR-US | CH-DE | CA-FR | **CN**-US | KR-US |
| **CCS** | CA-US | NL-US | GB-US | FR-US | DE-US | AU-NL | DE-GB | GB-NL | NO-US | **CN**-US |

Note: Co-invention is measured as country of residence for patented inventions. Emerging economies in bold.

Given the potential benefits from international research collaboration it has been suggested that technology-oriented agreements may be a potentially useful means to complement emissions-based agreements at the international level. Measures that support international collaborative research activities across countries can be a helpful mechanism to encourage the development and diffusion of climate mitigation technologies internationally.

In order to gain an improved understanding of why international research collaboration occurs, recent work has investigated the relationship between the International Energy Agency's "Implementing Agreements" (IA) and co-inventive activities between participating countries. The evidence suggests that co-invention is significantly affected by membership of a country in the Implementing Agreement, although the magnitude of this effect varies across the different IAs (indicating that institutional arrangements and the substance of collaborative efforts play an important role (Kahrobaie *et al*. 2011). It is interesting that countries such as India, China, Brazil and South Africa have started to play increasingly important roles in different IAs with implications for the development of climate mitigation technologies. Moreover, they have become important research partners (see Figure 10). Given the urgency to develop effective international mechanisms to mitigate climate change, these results are encouraging.

***Figure 10. International Research Collaboration in Development of Wind Power Technologies: 1988-2007***



*Source*: Haščič *et al*. (2010).

## *Further Reading*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OECD (2012), *Energy and Climate Change Policy and Innovation*, (forthcoming 2012) (http://www.oecd.org/environment/innovation)


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