BETTER POLICIES FOR BETTER LIVES

Driving low-carbon innovation for climate neutrality

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Key messages

- Achieving climate neutrality and energy independence will require the accelerated diffusion of existing technologies, further cost reductions, as well as innovation in new technologies.
- Climate-related frontier innovation, as measured by patent filings, has been declining since 2012. In contrast, the deployment of existing technologies seems on the rise.
- The focus on diffusion and commercialisation of existing climate-related technologies rather than the development of new innovations is the consequence of a policy emphasis on deployment rather than on R&D support.
- Reducing the costs of carbon-free technologies so that they become fully competitive with their high-carbon alternatives should be a primary objective of climate policy.
- Science, Technology, Innovation and Industrial (STI&I) policies are critical to accelerate technological progress. They can also complement – and partially substitute for – carbon prices.
- It is urgent to increase public RD&D expenditures targeted at technologies that are still far from market, but necessary to reach carbon neutrality by 2050.
- Public funding for low-carbon technologies needs to be better aligned with the innovations most needed to reach net-zero emissions.
- Carbon pricing and the removal of fossil fuel subsidies are necessary to encourage the adoption of clean technologies that are closer to market, as part of a broader climate policy package.

Climate neutrality requires massive technological change

Climate change is posing increasingly tangible risks for citizens across the globe with temperatures rising and extreme weather episodes becoming an everyday occurrence in many countries. Against this background, countries representing more than 80% of global GDP have announced targets of climate neutrality by mid-century. Reaching this objective requires the rapid adoption of zero-carbon energy sources and production processes across all economic sectors.

At the same time, reducing dependence on imported fossil fuels has become one of the most important policy objectives today, following months of rising energy prices and the Russian Federation's (hereafter, 'Russia') war of aggression against Ukraine. The role that low-carbon technologies can play to increase the security of energy supply presents an opportunity for countries to boost their clean transition.

Achieving climate neutrality and energy independence requires an acceleration in the diffusion of existing technologies as well as innovation in new technologies. Accelerating diffusion requires reducing the cost of relatively mature technologies, such as renewables, further r, so that they can become fully competitive with carbon-based alternatives and can be deployed at scale. On the innovation side, many technologies, such as green hydrogen and bio-based products, are still in their infancy and need to be further developed. For example, the production of green hydrogen is still about three times more expensive than grey hydrogen (made of natural gas through steam reforming), even under the most favourable conditions. Major cost reductions crucially depend on massive reductions in the cost of electrolysers through research and development (R&D) and large-scale demonstration projects. IEA estimated that half of the global reductions in energy-related CO2 emissions through 2050 will have to come from technologies that are currently at the demonstration or prototype phase.

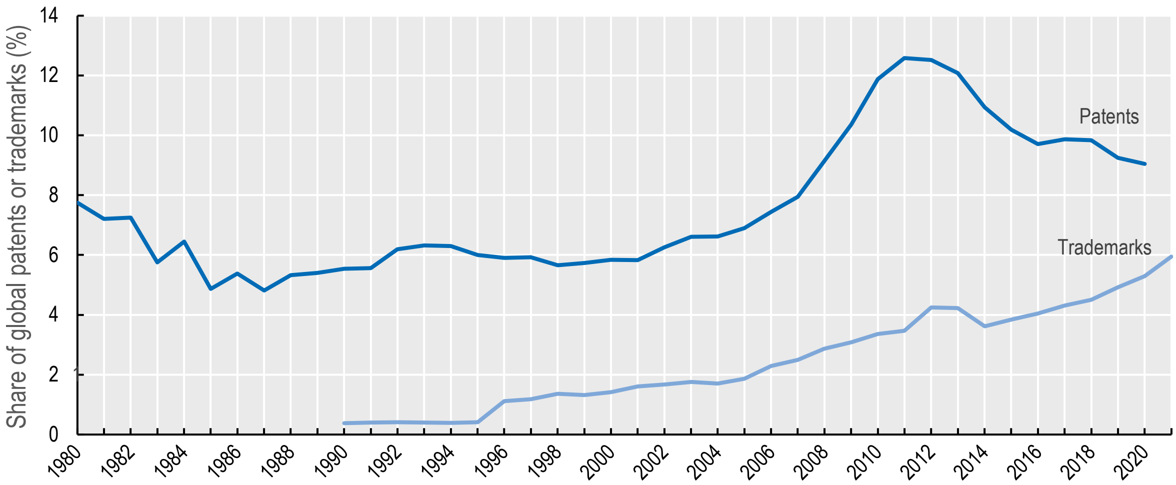
Climate neutrality also rests on innovation in other domains, in particular digital technologies and recycling. The digital transformation could be a key enabler for reaching climate goals, thanks to technologies such as smart meters, sensors, artificial intelligence (AI), the Internet of Things (IoT) and blockchain, and to digitally-induced changes in business models and consumption. Improved recycling technologies can also contribute to decarbonisation by reducing the need of fossil-based feedstock in the chemical industry or of primary steel in the metal industry. Mechanical or chemical recycling can transform existing products into new feedstock, thereby closing the materials chain, but many of these options need further technological development and cost reductions if they are to be deployed widely.

Low-carbon innovation is lagging and has moved from R&D to diffusion

Despite the urgent need for low-carbon innovation, the current pace of innovation is not in line with the challenge of carbon neutrality. Over the past decade, climate-related frontier innovation, measured as the share of patent filings in climate related technologies relative to all technology areas, has slowed down (Figure 1). Following a period of strong growth between 2004 and 2011, innovation efforts in climate-related technologies declined around 2012 despite the signature of the 2015 Paris agreement. Moreover, the decrease in low-carbon patenting affects nearly all relevant technologies except for energy storage (batteries) and can be observed across almost all major innovating countries in the world, except Denmark.

In contrast, the deployment of existing technologies seems on the rise, as suggested by the growth of trademark filings for climate-related goods and services observed over the last two decades. The proportion of such filings in total trademarks has tripled in the US and in Japan (from 1% to 3%) and has nearly quadrupled in Europe (from 2% to 8%). This suggests that, while firms have reduced R&D efforts toward climate-related technologies, diffusion and commercialisation have continued to increase.

Figure 1. Global low-carbon patenting efforts have declined over the past decade, but trademark filings in climate-related goods and services continue to rise

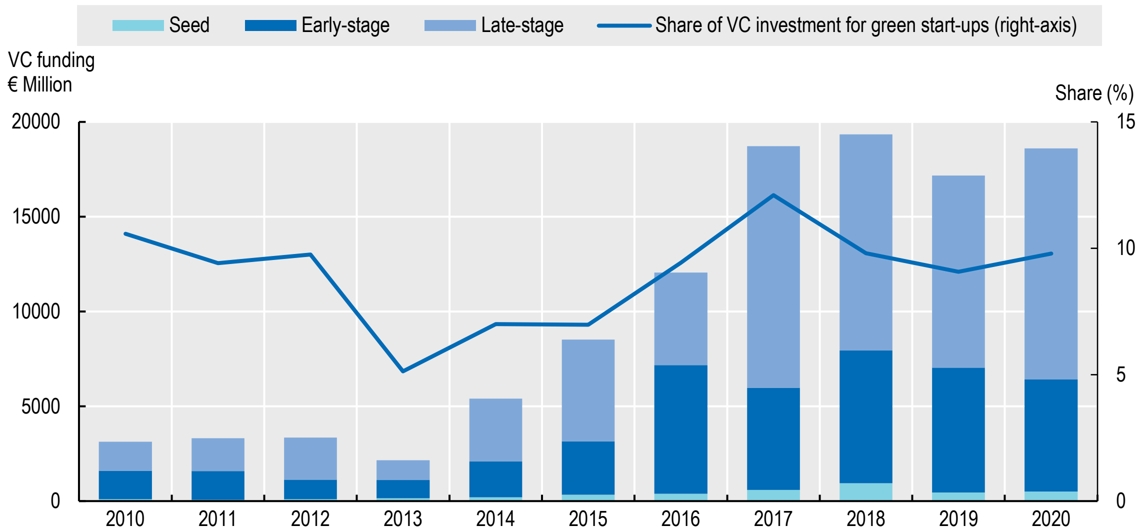


Note: Patent data refer to families of patent applications filed under the Patent Cooperation Treaty (PCT), by earliest filing date. Trademark filings are from the European Patent Office, the United States Patent and Trademark Office and the Japan Patent Office.
Source: OECD, STI Micro-data Lab: Intellectual Property Database, http://oe.cd/ipstats, February 2023.

Venture capital (VC) investment in green start-ups has seen a large increase in the last decade, from USD 3.1 billion in 2010 to USD 18.6 billion in 2020 (Figure 2). However, after a peak in 2018, global VC investment in green start-ups has stagnated in the last two years, and the share of total VC funding going to climate-related start-ups has remained fairly stable between 2010 and 2020. Moreover, since 2014 the observed growth in VC confirms the focus of investors on late-stage ventures, likely linked to the deployment of relatively mature technologies, as opposed to a focus on seed investment which would support the development of more exploratory solutions. Indeed, the share of VC directed at seed funding amounts to only 3.5% of total VC for green start-ups across the 2010-2020 period, against 7.8% for non-green start-ups.

The growth of climate-related trademarks compared with the decrease in climate-related patents as well as the decreasing share of green venture capital directed at seed funding suggest that **the business sector is currently more focused on the diffusion and commercialisation of existing technologies than on the development of new innovations.**

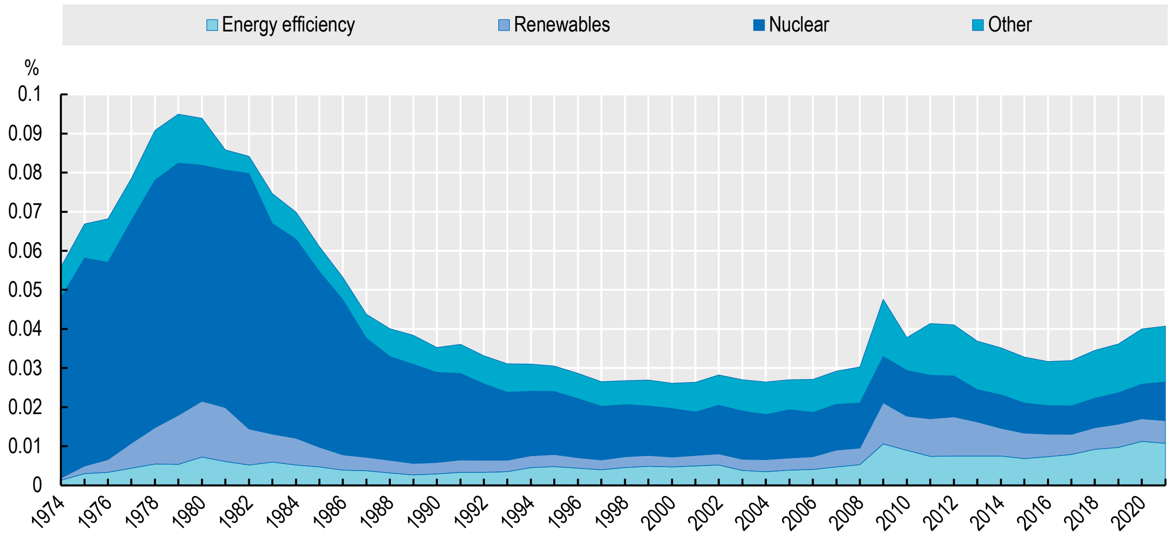
Figure 2. Global Venture Capital investment in green start-ups, 2010-2020



Note: Clean-tech start-ups are identified using information on their sector of operation (e.g. renewable energy) and on the textual description of their activity using natural language processing (NLP) methods, based on a climate change related vocabulary.
Source: Bioret, Dechezleprêtre and Sarapatkova based on OECD database of clean-tech start-ups, forthcoming

OECD evidence indicates that **this focus is a direct consequence of a policy emphasis on deployment rather than on R&D support**. Indeed, the slowdown in low-carbon innovation corresponds to a levelling-off of concrete climate policy measures across OECD countries between 2010 and 2020, and particularly so for innovation-related policies. Public expenditures on research, development and demonstration for low-carbon technologies have remained broadly flat (as a percentage of GDP) over the last 30 years (Figure 3), despite pledges by the Mission Innovation partners – a global initiative of 22 countries and the European Commission – to double clean energy research and development funding between 2016 and 2021. Between 2016 and 2020, total public expenditures on energy RD&D increased by a mere 38% amongst the 22 Mission Innovation partners and by less than 20% (to EUR 19 billion) across all IEA Member countries. However, recent policy actions adopted as a response to the Covid-19 crisis, such as the European Union member countries' Recovery and Resilience Plans and the U.S. Inflation Reduction Act may have recently given a key impetus to public low-carbon RD&D support.

Figure 3. Low-carbon public RD&D expenditures in GDP across IEA countries, 1974-2020

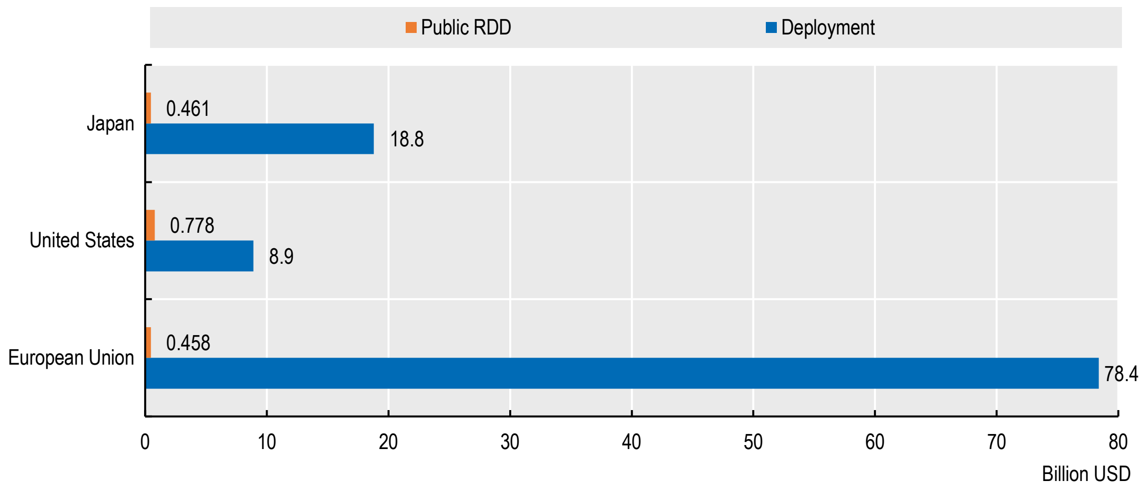


Note: The "Others" category includes Carbon capture and storage, Hydrogen and fuel cells, Other power and storage technologies, and Other cross-cutting technologies and research. See https://www.iea.org/data-and-statistics/data-product/energy-technology-rd-and-d-budget-database-2

Source: IEA Energy Technology RD&D Budgets database, December 2022

The contrast between R&D and support for deployment and adoption is striking. For example, European countries spent EUR 458 million in 2018 to support R&D in wind and solar power. The cost to society implied by subsidies for the deployment of wind and solar technologies that same year represented EUR 78 400 million – 150 times more than public R&D expenditures (Figure 4). The ratio is smaller in the US and in Japan, but – across these three major economic players – the emphasis is clearly on support for deployment rather than R&D.

Figure 4. Public RD&D vs deployment support in renewable energy, 2018 (bn USD)



Source: IEA Energy Technology RD&D Budgets database, December 2022; Taylor, Michael (2020), Energy subsidies: Evolution in the global energy transformation to 2050, International Renewable Energy Agency, Abu Dhabi.

Net-zero innovation and industrial policies are well justified

Given the large range of barriers and market failures discouraging low-carbon innovation, **the theoretical justifications for low-carbon science, technology, innovation and industrial (STI&I) policies are sound and well established.** This includes the existence of significant social benefits from innovation in new technologies, which have been shown to be particularly large for low-carbon technologies, but also learning-by-doing, which occurs when the costs to manufacturers or users fall as cumulative output increases. For example, production costs in renewable energy typically fall by around 15% each time the cumulative installed capacity doubles, with higher learning rates in earlier stages of deployment. The presence of learning-by-doing provides a strong justification for deployment subsidies. In the renewable electricity domain, these subsidies (in the form of feed-in tariffs and auctions) have been instrumental in inducing the massive cost reductions observed in the last couple of decades.

Imperfections in the capital market, such as reluctance to take risk and lack of information on the potential value of new innovations, also limit the amount of private capital available for low-carbon R&D. Small firms developing clean innovations face particularly high financial constraints.

Another major market failure is related to the traditional problem of environmental externalities. Because greenhouse has pollution (and the damages it generates) is not priced by the market, the market for technologies that reduce emissions will be limited because the lack of economic incentives imply low financial returns for environmental innovations. This in turn reduces incentives to develop such technologies.

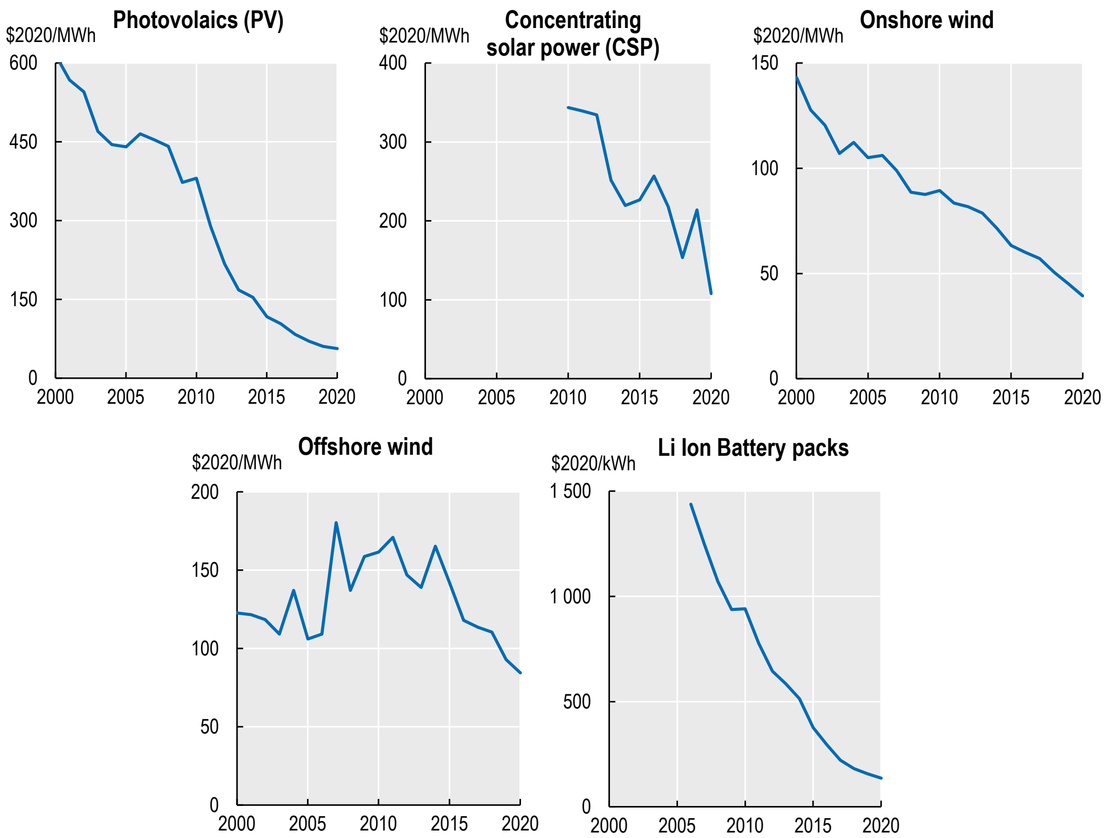
Beyond market failures, a number of additional factors impede low-carbon innovation. These include barriers to competition, technology lock-in and path dependence, lack of policy predictability and stability, and regulatory barriers. In particular, uncertainty over future climate policy strongly discourages investment in R&D and adoption.

STI&I policies are critical because technological progress – which originates from investments in R&D activities but also from diffusion, via learning-by-doing and knowledge spillovers – reduces the costs of emissions reduction policies, as demonstrated by the sharp decline, of the order of 90%, in the costs of batteries and solar over the past decade, as shown in Figure 5. As a result, many carbon-free activities (especially renewable energy) are already cheaper than fossil fuel.

A consequence of the cost reductions brought about by technological progress is that **STI&I policies reduce the social and economic costs of reaching climate objectives.** By reducing the cost of adopting low-carbon technologies, innovation and industrial policies also increase the responsiveness of emissions to carbon prices. Therefore, including effective STI&I policies in the climate policy mix allows for much lower carbon prices to reach the same climate target. Therefore, **STI&I policies can partially substitute for low carbon prices** (although not fully), which is important as these are often difficult to implement politically. With 60% of global carbon emissions not priced at all, STI&I policies have an even more important role to play for achieving the climate neutrality goal.

Finally, there is an important political argument for including STI&I policies in the overall climate policy mix. There is ample evidence that voters strongly prefer subsidies to low-carbon technologies over other climate policies such as carbon pricing, bans or regulations. Support for carbon taxes is also stronger if their revenues are used to fund green infrastructure or to subsidise low-carbon technologies. **From a public acceptability point of view, STI&I climate policies thus appear to be a highly attractive option**.

Figure 5. Declining renewable energy and battery costs since 2010



Note: The lines indicate average unit cost in each year. For batteries, costs shown are for 1 kWh of battery storage capacity; for renewables, costs are LCOE, which includes installation, capital, operations, and maintenance costs per MWh of electricity produced.
Source: IPCC (2022), Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change

What can policies do?

Bringing about the necessary cost reductions to make carbon-free technologies competitive with their high-carbon alternatives should be a primary objective of climate policy. This would also help accelerate the diffusion of available technologies, which is critical to reach medium-term carbon emissions reductions.

For these reasons, **innovation and industrial policies** – with a focus on both the development and deployment of low-carbon technologies – **should constitute a cornerstone of strategies to reach carbon neutrality**. Given the large range of barriers discouraging low-carbon innovation, the theoretical justifications for policy intervention are sound and well established. **Innovation and industrial policies can complement – and partially substitute – carbon prices**, which are often difficult to implement politically. In fact, STI&I policies are more popular among voters and citizens than other climate change policies (including carbon pricing, bans or regulations), making them an attractive option from a public acceptability point of view. In addition, by reducing technology costs and boosting the growth of new carbon-efficient firms and sectors, such policies will facilitate the adoption of more ambitious climate policies, including – through international technology diffusion – among emerging economies, where the bulk of future emissions growth is projected to take place.

A number of policies are key. First, **an increase in public RD&D expenditures targeted at technologies that are still far from market, but necessary to reach carbon neutrality by 2050, is urgent**. All models of climate policy show that the optimal policy mix relies heavily on research subsidies. Therefore, governments **should consider re-balancing their STI&I policies**, giving greater emphasis to the RD&D stages, particularly for technologies that are not mature yet.

As the increase might need the research system to adapt and so might be gradual, a larger forward leap can only happen if low carbon RD&D becomes the highest priority in governments' budgets. Such commitments should provide a long-term and stable perspective, like other climate policies. Post-COVID recovery programmes can help increase public RD&D budgets, but such increases will need to be sustained in the long run, rather than one-off increases.

Importantly, **specific R&D support instruments are required**. Governments can financially support the innovation activities of firms through direct and targeted instruments (e.g. research grants) or via horizontal and untargeted instruments (R&D tax credits). Empirical evidence suggests that R&D tax credits have positive effects on firms' innovative activity, but disproportionately more so on experimental development than on basic and applied research. Conversely, grants have positive effects on firms' innovative activity at the R&D stage (although these effects seem concentrated on small firms).

Horizontal R&D support has indisputable advantages, including low administrative cost and technological neutrality, but by construction, it benefits mostly technologies that have the greatest short-run returns. As such, **tax credits may not be the best policy tool to promote new technologies that are not close to the market and require long development timelines**. Support to an emerging technology – such as hydrogen – justifies a stronger focus on targeted instruments for R&D, complementing horizontal instruments. Therefore, **support to low-carbon RD&D undertaken by business should primarily be direct, rather than horizontal**. Climate neutrality will require innovation in breakthrough technologies, which cannot be incentivised through horizontal support. Technology neutrality – even between different low-carbon technologies – tends to favour technologies with the shortest payback time and is therefore not neutral in practice.

A critical part of the climate innovation policy package is to close the funding gap for large-scale demonstration projects, in order to help breakthrough innovators escape the well-known "valley of death" of clean technology venturing (between research and commercialisation). **The amount of funding which needs to be made available for demonstration support on technologies that still have a low technology readiness level is very significant**, particularly in the industry sector. For example, a single 100 MW electrolyser for green hydrogen production costs between EUR 50-75 million; CCS demonstration projects currently cost around USD 1 billion. In comparison, the amount of public funding available for demonstration projects appears small. For example, the new European Union's Innovation Fund for the demonstration of innovative low-carbon technologies has an annual budget of only around EUR 1 billion. The recent announcement by 16 countries at the September 2022 Clean Energy Forum to commit USD 94 billion for clean energy demonstration is therefore an important step in the right direction.

Support for early-stage deployment of clean technologies should continue, as it is justified by the existence of barriers and market failures at this stage (e.g., learning spillovers, second-mover advantage), **but additional efforts should primarily be focused on RD&D**.

The recommendation to re-balance STI&I policies towards more R&D support also has to be considered in the context of global value chains. While R&D support policies by nature target domestic firms only, deployment subsidies benefit domestic and foreign firms alike. Therefore, it is of utmost importance that deployment support policies are designed with a clear understanding of the domestic supply-side (firms, talent, infrastructure) so that they do not face constraints in the domestic economy, such as skill shortages and lack of infrastructure. At the same time, given the global nature of value chains in the production of goods and provision of services that will be needed to achieve climate neutrality, provisions limiting the foreign content of these goods and services might actually slow down the climate transition, especially in the presence of shortages in the domestic economy.

As regards what sorts of technologies should be a priority for funding, **governments should focus their support on technologies that are central to decarbonisation pathways** and that have a strong public good component (and are therefore less likely to be provided by the market). The goal is to avoid providing public support for research that the private sector would otherwise do on their own. This includes long-term research where the payoff occurs further into the future (such as hydrogen), as well as infrastructure that has a public good dimension (including transportation networks and storage for carbon, smart grids, public transportation and charging infrastructure for electric vehicles).

More specifically, **public funding needs to become better aligned with the innovations needed to reach net-zero emissions.** Carbon capture, utilisation and storage (CCUS), advanced high-energy density batteries, hydrogen electrolysers, direct air capture and biofuels account for a large share of emissions reductions until 2050 in all climate models, but currently receive only around one-third of the level of public R&D funding of the more established low-carbon electricity generation and energy efficiency technologies in IEA Member countries. These technologies should be the focus of governments' support.

In general, countries need to **adopt a portfolio approach** to diversify industrial and technology risks. Given the technological uncertainty inherent to the transition to a net-zero economy, countries should support an array of technologies, Within the supported technologies they should not focus on particular production processes to avoid lock-in and give all green technologies a fair chance.

Barriers to external funding should be reduced to help high-risk companies raise funds. Favourable tax schemes, low-interest or subsidised loans for young firms, and a greater mobilisation of government venture capital toward the green transition can help.

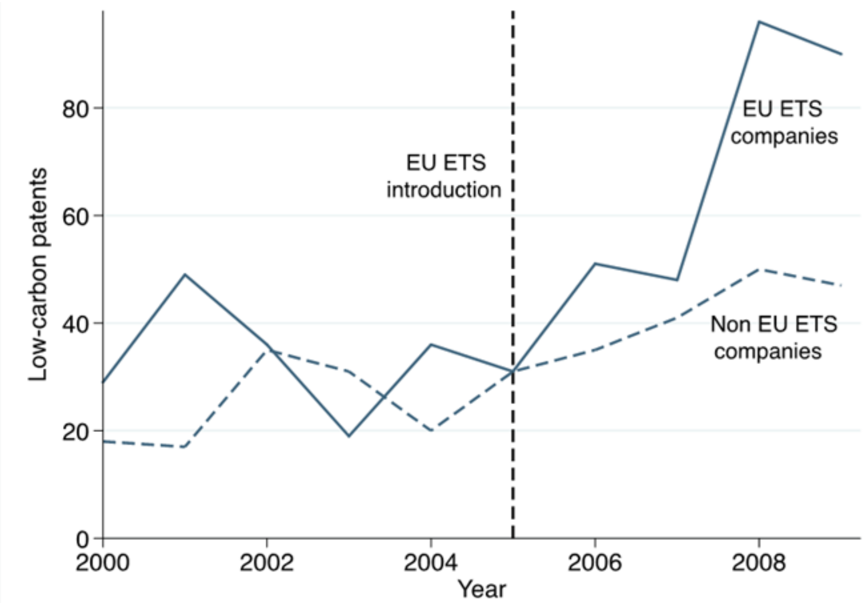
Collaboration in low-carbon innovation should be strengthened, both nationally and internationally. There is ample room for improvement in collaborative R&D, between firms, between firms and public research institutions and between countries, to capitalise on complementary skills and resources at the domestic and international levels. Strengthening international co-operation and technology transfer will be particularly important to accelerate the development and diffusion of low carbon technologies. Coordinated action can accelerate innovation, enhance economies of scale, strengthen incentives for investment, and foster a level playing field where needed. Sharing experiences between countries and industries can reduce individual risks and accelerate progress towards viable solutions. Measures and commitments to deployment can accelerate economies of scale and corresponding cost reductions. International co-ordination of R&D funding across different technologies and stages of innovation will be critical to developing the next generation of clean technologies.

Low-carbon innovation policies need to be embedded in a broader package. Although innovation and industrial policies should play a greater role in carbon neutrality strategies, they are insufficient on their own and need to be part of broader packages of climate policies. While innovation policy can help facilitate the creation of new environmentally friendly technologies, it provides little incentive to adopt these technologies, unless R&D activities manage to make clean technologies competitive with high-carbon alternatives on economic grounds. Until then, incentives for adoption need to be provided by demand-side policies, which can make low-carbon options more attractive economically. However, demand-side policy cannot supplant the need for innovation policy, given the presence of barriers and market failures at the R&D and demonstration stages.

In particular, **carbon pricing and the removal of fossil fuel subsidies are necessary to encourage the adoption of clean technologies that are closer to market** and thus "redirect" innovation toward low-carbon activities. There is ample empirical evidence that carbon pricing, by encouraging the diffusion of low-carbon technologies, affects innovation activity further up the technology supply chain, favouring R&D in clean technologies and discouraging it in conventional (polluting) technologies. For example, Figure 6 shows that the introduction of the European carbon market (EU ETS) led to a large and rapid increase in low-carbon innovation (as measured by patent filings) among regulated companies, compared to a carefully selected "control group" of similar firms that were not regulated because of sector-specific inclusion criteria. **Carbon prices can also prevent possible rebound effects (increased demand for energy) following efficiency improvements brought about by technological progress** and can provide a useful source of revenue which can be earmarked for technology support policy.

The current limited take-up of carbon pricing reduces incentives to develop and adopt new low-carbon technologies. Among OECD and G20 countries, 60% of carbon emissions are not priced at all, and only 10% are priced at or above EUR 60/ton CO_2. Commitments to raising carbon prices in the future and clear carbon prices trajectories can already induce innovation even if current carbon prices are low. Current experiments with Carbon Contracts-for-Difference (CCfD) in Germany and Ireland can decrease uncertainty thanks to forward-contracts on the price of abated greenhouse gases. The Dutch carbon levy, a top-up on the EU ETS with an explicit carbon price trajectory, is another example of how policy instruments can reduce carbon price uncertainty for investors.

Figure 6. Carbon pricing induces low-carbon innovation



Note: Around 3000 companies regulated under the EU ETS are included in the sample. "Non EU ETS companies" are a group of 3000 European companies that are not regulated under the EU ETS but operate in the same country and the same economic sector and are comparable in size and innovation capacity to companies regulated under the EU ETS.
Source: Calel, R. and A. Dechezleprêtre (2016), "Environmental Policy and Directed Technological Change: Evidence from the European Carbon Market", Review of Economics and Statistics, Vol. 98/1, pp. 173-191.

Standard setting is also necessary to reduce uncertainty and support the deployment of particular technologies. For green hydrogen, this includes the standardisation of guarantees of origin, on hydrogen purity, on the design of liquefaction/conversion and regasification/reconversion facilities, for equipment specifications and for blending hydrogen into the gas grid. Another example is standardisation of plugs for electric cars across vehicles and charging stations. Such standards are best set at the international level and require international coordination of national standards in the context of standard-setting organisations. Co-ordination on standards across countries could help to overcome barriers to first deployment created by international competition. Standards can also be helpful to restrict and phase out high-emitting activities or technologies that are particularly undesirable.

Finally, **the low-carbon transition will involve a massive structural transformation that will require the alignment of policy frameworks beyond STI&I and climate policies**. Competition and entrepreneurship policies play a critical role in encouraging business dynamism, the creation of new innovative firms and the reallocation of resources toward the most resource-efficient firms. Education and skills policies are necessary to make sure that the transformation can rely on the right set of skills and research. An efficient and cost-effective shift to a low-carbon economy thus requires the engagement of many parts of government beyond those traditionally mobilised in the development of climate change policies. Developing such a package requires the **development of mission-oriented strategies** across all countries committed to carbon neutrality. Mission-oriented innovation approaches can help to promote systemic change because of their integrated nature. However, existing net-zero missions remain for the most part focused on support to research and innovation, led by STI authorities and drawing almost exclusively on STI funds. To realise their transformative potential, missions for net-zero therefore need to move beyond STI&I policies.

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Further readings

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