Towards EU climate neutrality

Progress, policy gaps and opportunities

Chapter 13: Innovation

Assessment Report 2024

European Scientific Advisory Board on Climate Change

Contents

13 Innovation

Key messages

A more ambitious policy on research, development and deployment (RD & D) is needed to accelerate innovation and support competitiveness.

Needs. The EU aspires to be a global leader in climate ambition, action and innovation. This requires increasing investments in climate-related RD & D, and both private and public sectors have a role to play in supporting this objective. The EU needs to make RD & D investments and enact additional demand policies that stimulate innovation and crowd in private investment. Spending on innovation needs to increase, to ensure that Europe remains competitive in the global landscape of clean technologies. Planned expenditure on R & D across all research areas (not just climate related), including through the European Green Deal, continues to fall short of the 3 % GDP target that was set back in 2010 and reiterated in 2021. Despite the increasing needs for cleaner technologies across all sectors, public funding on innovation stagnated over the last decade, at 0.8 % of the EU-27's GDP in 2021 compared with 0.8 % of the EU-27's GDP back in 2011.

Gaps. The main EU policy instruments aiming to catalyse private investment are Horizon Europe and the Innovation Fund. One of their main focuses is climate-related technologies; however, their administrative complexity hinders the crowding-in of private investments **(implementation gap)**. Public funding instruments can sometimes be slow in reacting to the changing needs of the fast-paced global clean technology arena. This should be monitored at the EU level, particularly beyond early-stage research **(policy gap)**. For example, public funding in the United States took many years to begin providing more substantial support for RD & D in energy storage.

Recommendation In1. There is a role for increasing various forms of public climate-related RD & D investments, including supporting private sector activity. They need to be distributed strategically, encouraging the participation of start-ups and small and medium-sized enterprises. Increased RD & D investments are needed to ensure that the EU can remain in a position to invent, patent and commercialise the mitigation technologies of tomorrow. The administrative complexity of the EU's funding instruments can be streamlined in order to encourage the participation of small and medium-sized enterprises and start-ups, given that they often lack the resources to participate in time-intensive and complex processes. Spending on climate- and energy-related technologies currently represents only about 9 % of total spending on innovation. An effective policy mix that combines instruments such as carbon pricing, fiscal incentives and grants can direct a larger amount of public and private RD & D towards technologies that directly contribute to the climate neutrality objective (please see Chapter 10 'Pricing emissions and rewarding removals').

Currently there is a significant funding gap for projects that are towards the end of the RD & D process, the demonstration stage, and for commercial deployment. Policies that support innovation need to ensure that there is sufficient investment to give them a chance to cross the 'valley of death'.

Needs. While the EU originates more than 30 % of all top scientific publications, there is a significant lag in innovative solutions for clean energy. Part of the disconnect between scientific excellence and commercialisation can be attributed to the scarcity of funding at the demonstration and early commercialisation stages. Climate technology projects that evolve from the early stages of R & D and prototyping towards piloting have fewer sources of funding available than those in other subject areas and in other countries.

Gaps. Current policy intervention instruments focus their support at the two ends of the RD & D process, the early R & D stage and the late maturity and diffusion stage (the former through the European Research Council and Horizon Europe, and the latter through pricing and other demand-pull incentives). This policy mix leaves a funding gap for climate technology manufacturing or deployment projects aiming to complete the piloting and demonstration stage and move towards the early deployment of clean technologies **(policy gap)**. This funding gap is further widened by the relative lack of support from venture capital, as this concept remains less developed in Europe than in the United States, for instance **(policy gap)**.

Recommendation In2. Access to finance needs to address all the stages of the RD & D process and across to deployment, as innovation is only as close to market as the weakest link in the development process. The current system of support for RD & D could give additional attention to the demonstration and early commercialisation phases in the forms of additional grants, loans, loan guarantees and government procurement. The combination of increased investments in R & D (recommendation In1) and in demonstration and commercialisation through additional tools and market-pull policies, such as carbon prices and other, more targeted, incentives, can help attract additional venture capital and other types of investments.

Across the EU, funding support for innovation and early deployment needs to further diversify and support a wide range of early stage technologies with high mitigation potential in industry, some transport applications, agriculture and food, and CDR.

Needs. The EU's leadership position in mitigation technologies is underpinned by a strong position in a small number of mature technologies such as wind power and rail transport. Strengthening Europe's strategic autonomy in key sectors, which could reduce its exposure to various geopolitical risks, requires developing a portfolio of early-stage clean technologies to support the transition. Some of that may involve developing capabilities in parts of the supply chain for climate technologies that are more mature, but also in sectors where there are currently fewer mature technologies, including agriculture, some key industries and CDR. Europe lags behind international peers in the development of emerging technologies, such as lithium-ion batteries and electrolytes used in hydrogen production, in terms of its relative position over time in the number of patents for those technologies.

Gaps. The Net-Zero Industry Act aims to partially address the need to strengthen the knowledge and industrial manufacturing capacity in key technologies, but an explicit link to the earlier stages of the innovation process could help strengthen the EU's position **(policy gap)**. Policy instruments such as the strategic energy technology plan, which aims to strengthen collaborations between industry and research, also need to address behavioural barriers to innovation such as the fear of failure, emphasising the value of the knowledge generated when trying to innovate, and the value of sharing that knowledge **(ambition gap)**.

Recommendation In3. Policy intervention instruments such as the revamped strategic energy technology plan should strengthen collaborations and networks in novel technologies with high mitigation potential, encouraging knowledge sharing and the wider dissemination of lessons learned.

Innovation policies need to crowd in private investments, fostering closer collaborations between private and public knowledge organisations.

Needs. The innovation cycle needs to accelerate. This requires stronger collaborations between private and public knowledge organisations. Longer-term frameworks, including incentives and regulations, are needed in order to successfully crowd in more private investments in early-stage technologies with high mitigation potential. When potential future support is unpredictable, there is a risk that a project may be ended prematurely owing to lack of resources, and the knowledge generated may be lost. Policies supporting innovation need to prioritise learning, iteratively upscale, engage the private sector, disseminate knowledge and create robust demand.

Gaps. Policy instruments on innovation need to foster collaborations between private and public knowledge organisations, creating opportunities for building stronger collaborations **(policy gap)**. The existing EU funding architecture offers limited predictability beyond 2030, which increases uncertainty for long-term projects **(ambition gap)**. The Net-Zero Industry Act aims to increase the EU's manufacturing capacity in strategic technologies to reach at least 40 % of domestic needs; however, the existing reporting mechanisms offer limited means to track progress towards achieving this target **(policy gap)**. It is also unclear if the same level of coverage is needed to advance the EU's transition in a way that is just and that increases the resiliency of supply chains.

Recommendation In4. The revamped strategic energy technology plan needs to foster a closer collaboration between private and public actors and broader dissemination of the knowledge generated, so that more private investments can crowd in. In order to monitor progress towards the policy objectives of the Net-Zero Industry Act, relevant and reliable information is needed on investments across the supply chains of key climate technologies and on asset deployment.

Innovation should not be seen as an argument for postponing climate action.

Innovation cycles typically take decades from first proposal to full commercialisation. While an important enabler, R & D alone cannot be considered a panacea. Innovation can bring important benefits in, for example, reducing costs and improving efficiency. However, expected developments of new technologies should not be relied upon to delay action or social innovation that can curb emissions.

13.1 Scope

According to IPCC AR6 (contribution of Working Group III, Chapter 16) innovation in climate mitigation technologies, encompassing the process from R & D to technology deployment, has seen 'enormous activity and significant progress in recent years' in supporting system transitions to limit warming. This is evidenced by the recent rapid cost reductions and diffusion of climate-friendly products such as the electric car, the solar panel and the heat pump. Technological challenges remain in a range of economic activities including freight, agriculture, shipping and aviation, metallurgy (steel and aluminium) and cement production. These sectors rely on burning fossil fuels or using them as feedstock, as mitigation alternatives either do not exist or are not available at the necessary scale.

The development of new decarbonisation technologies and the improvement of existing ones are essential to move towards a carbon-neutral economy in a cost-efficient way, while simultaneously pursuing economic growth opportunities that strengthen productivity (IPCC, 2022, (Grassano et al., 2020) and driving the economy's overall competitiveness (Anadón et al., 2017). The last few decades of experience with low-carbon technologies show that a combination of technology-push investments and policies with demand-pull interventions to create or grow early markets is needed in order to accelerate technology unit cost reductions and scale up more rapidly. A recent synthesis of experience with policies shaping innovation in clean energy technologies around the world also shows that policies need to be adaptive, make choices, address questions about inclusion and justice, and harness tipping points in cost reductions (EEIST, 2022). To some extent, these insights are already reflected in some European policy efforts: investments in mitigation technologies have taken centre stage in the recent RRF, REPowerEU, Net-Zero Industry Act and Green Deal industrial plan. However, a number of policy areas need to be further addressed in order to accelerate innovation in clean technologies to continue supporting the competitiveness of European industry.

13.2 Progress on innovation

Methodology to track progress

Tracking progress on innovation remains challenging because innovation is a complex process that cannot be understood using one or even multiple metrics, each of which has limitations. In addition, the relationship between policy inputs (e.g. finance, education) and intermediate outputs (i.e. patents, pilot projects) is sometimes unclear (Moaniba et al., 2018). Policy objectives such as more affordable energy, industrial transformation and economic growth are hard to attribute to specific inputs (Grubb et al., 2021), although evidence is growing (Peñasco et al., 2021) that a range of indicators can be used as proxies for innovation, including RD & D investments, publications, funding and follow-on investments.

Total research and development spending

The EU is falling short on its objective of spending 3 % of its GDP on R & D.

The EU has a long-standing objective to increase spending towards R & D to at least 3 % of the GDP (Lisbon 2000 strategy and Europe 2020 strategy). This objective does not include any specific target for increasing R & D spending on energy and climate.

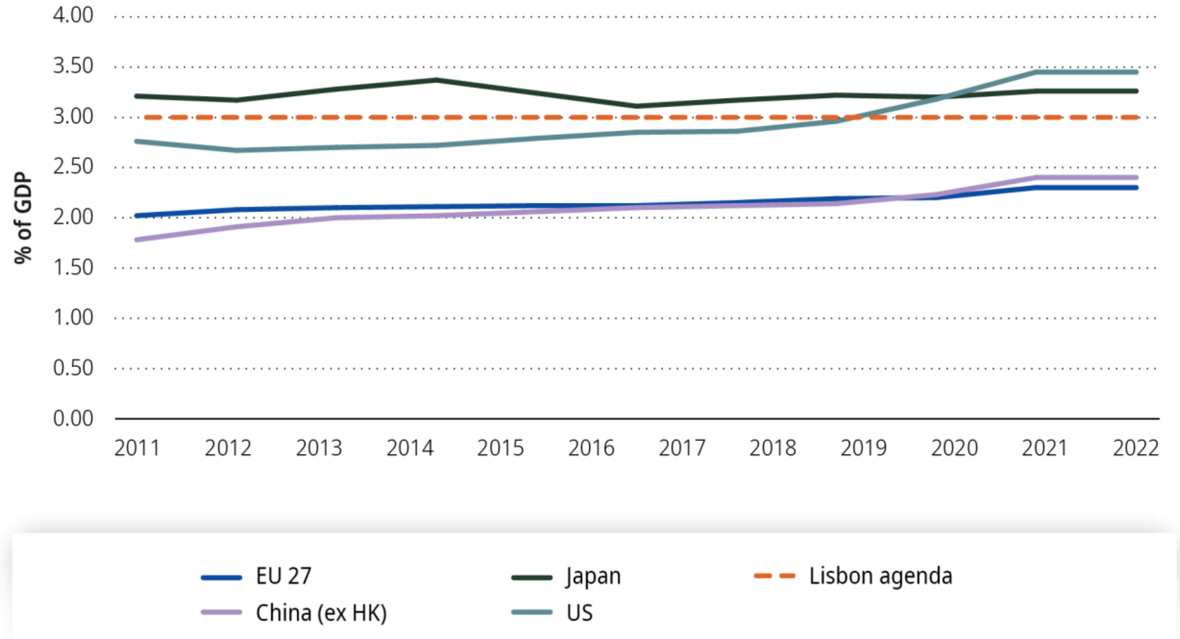
The ratio of R & D to GDP is also known as R & D intensity (Eurostat, 2021), and data about the EU and other major economies are shown in Figure 81. This ratio increased marginally in the EU during 2011–2021, rising from 2.02 % in 2011 to 2.31 % in 2020 but decreasing in 2021 to 2.27 %. The slight decrease in R & D intensity between 2020 and 2021 could be explained by the GDP rebound in 2021 after the significant drop in 2020 as a result of the COVID-19 pandemic. To compare it to the situation before the COVID-19 crisis, the R & D intensity of the EU saw a marginal increase from 2.02 % to 2.19 % between 2011 and 2019. In other words, over 2011–2021, the EU as a whole made limited progress in increasing R & D expenditure towards the 3 % target pledged in the Europe 2020 strategy.

In contrast, over the same decade, R & D intensity trends were different (and in some cases more dynamic) in other parts of the world. Between 2011 and 2021, R & D intensity in the United States increased from 2.76 % in to 3.45 %, and in China from 1.78 % to 2.4 %. Japan's remained consistently above 3.10 %. As a result, the EU is progressively falling behind other regions on R & D spending. That gap can erode competitiveness in strategic sectors such as energy and international transport. It is estimated that the energy sector represents about a tenth of the EU's total R & D expenditure, or 0.02 % of its GDP (IEA, 2023i).

Higher spending on R & D both in energy and beyond requires higher contributions from both public and private participants, and public spending needs to become more effective at crowding in private investments (Becker, 2015). An analysis of R & D expenditure by source of funds shows that about two thirds of the total expenditure within the EU is funded by the private sector whereas almost one third is funded by EU and Member State resources. According to the data from Eurostat, as evidenced in **Error!**

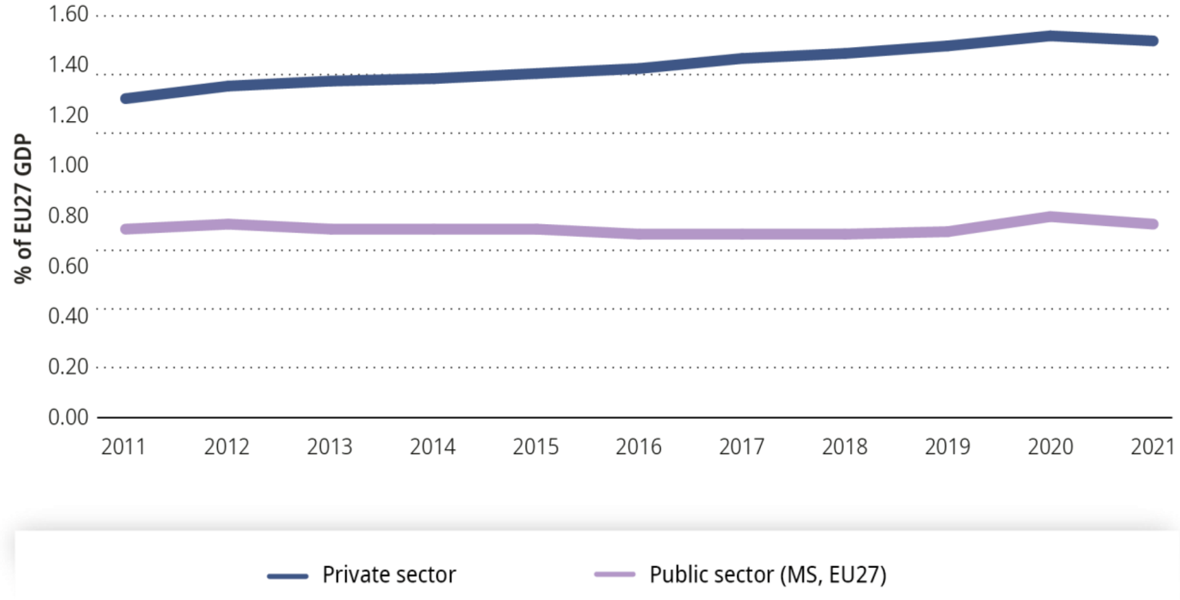
Reference source not found. 82, the main development over 2011–2021 was a fall in the share of funding by the public sector from 37 % to 34 %, with a corresponding increase for the private sector from 63 % to 66 %.

Figure 81 Gross domestic expenditure on research and development, 2010–2021



Sources: Eurostat (2023j), OECD (2023c) (US, Japan and China).

Figure 82 EU-27 R & D spending in the public and private sectors



Notes: Eurostat's statistics on R&D expenditure are compiled using guidelines laid out in the Frascati manual 2015, published in 2015 by the OECD. Public spending includes funding from both member states and the EU budget.

Source: Eurostat (2023j)

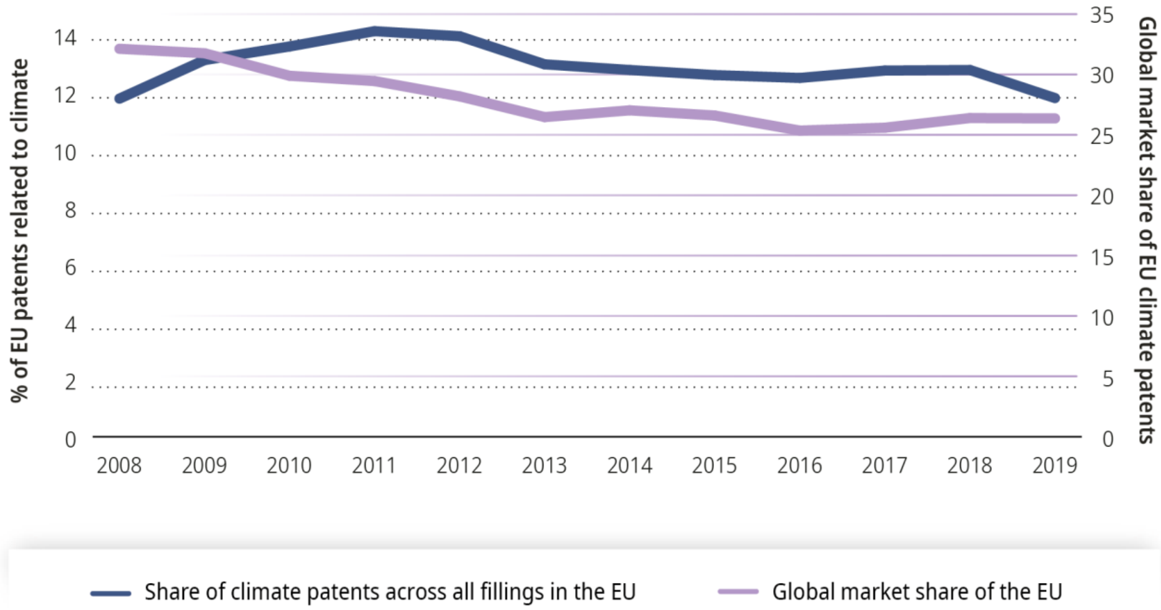
Research on energy R & D finds no evidence that increases in energy R & D draw out (or crowd out) R & D resources from other sectors (Goldstein et al., 2020; Popp and Newell, 2012). Moreover, other research, focused on public funding for defence R & D, shows evidence of public investments crowding in private investments (Noriega et al., 2018). Public institutions funding energy R & D and engaging with small companies have been associated, in some cases causally, with improved patenting outcomes or follow-on investments by firms.

Climate-related patenting

Climate-related patenting in the EU is slowing down.

Patents in climate-related technologies ([1]) have been increasing over the last 10 years, with European companies targeting high-value inventions with international protection, which suggests growing confidence in their competitiveness in the global energy technology market. However, the absolute number of EU patent filings related to climate change mitigation has stagnated more recently. The decline in patenting activity in 2019 may reflect the maturity of some technologies such as solar PV, bioethanol and wind (IEA, 2020), combined with low energy prices at the time (Probst et al., 2021).

Figure 83 Share of climate patents among all EU filings and the global market share of the EU in climate-related patents



Notes: Patents related to climate change mitigation include: Energy generation through RES: geothermal, hydro, oceanic, solar (PV and thermal), wind; Energy generation of nuclear origin fusion and fission; Technologies for efficient electrical power generation, transmission or distribution Reactive power compensation, efficient operation of power networks; Technologies for the production of fuel of non-fossil origin Biofuels, from waste. Technologies with potential or indirect contribution to GHG emissions mitigation; Energy storage (batteries, ultracapacitors, flywheels), hydrogen technology, fuel cells, etc.; and other energy conversion or management systems reducing GHG emissions.

Source: OECD (2023b)

([1]) The definition of climate-related technologies in the OECD database used for the analysis of patent trends includes the following sectors: solar, wind, hydro, geothermal, marine, sustainable biomass and waste to energy, biofuels and smart energy technologies (such as smart grids, energy efficiency and electric vehicles).

A closer examination of the share of climate-related patents in the overall number of patent filings in the EU suggests a loss of momentum, as this share initially increased from 11.9 % in 2008 to reach 14.3 % in 2011 and then reverted to near the starting point (Figure 83). This has a direct impact on the share of EU climate patents in the global market, as evidenced by the decline in the EU's market share from 32.2 % in 2008 to 26.4 % in 2019. Given that most new investments in clean energy technologies are expected to take place outside the EU, it is unlikely that this trend will reverse without a decisive change in the policy mix. Overall, the recent trends in climate-related patent filings and R & D expenditure suggest that the EU contributes less to the development of new green technologies than its ambition would suggest. As previously mentioned, patents have well-known limitations as an innovation metric, but can be helpful to identify and compare trends.

13.3 Policy consistency on innovation

Need for more public–private cooperation

At every stage of the RD & D process, both public and private sector actors play critical roles. The role of governments encompasses education, R & D funding, tax incentives, providing network infrastructure, protecting intellectual property, supporting exports, helping small and medium-sized enterprises, providing the regulatory framework, and shaping, and in some cases creating, early markets (Roberts and Geels, 2019).

In addition to increased funding, it is also important to take a more holistic and deliberate approach to shaping technology innovation to address the climate challenge in a way that advances societal goals (including climate mitigation) and is inclusive and just. Public investment in enabling infrastructure could support such an approach, increasing the probability that innovations will succeed (IPCC, 2022o). Research on public RD & D investments in the energy sector shows that these investments are generally associated with positive impacts on environmental, technological, innovation and competitiveness outcomes (Peñasco et al., 2017). There is also a growing literature indicating that, at least in the energy sector, public funding and tax incentives for RD & D are useful to small and medium-sized enterprises.

Given the magnitude and speed of the change needed, there are also indication that the institutions supporting and coordinating energy innovation need to better enable the fast commercialisation of technologies; in many cases, the time between the invention of a technology and its wide diffusion has spanned decades (Stephan et al., 2017). There is also evidence of a valley of death after R & D, when technology risks are high but investment costs increase. Finally, some analysis suggests that at some times the outcomes of start-ups in energy were not as positive as those in biotech and IT, reinforcing the need for additional types of finance to scale up and commercialise new energy technologies (Gaddy et al., 2016).

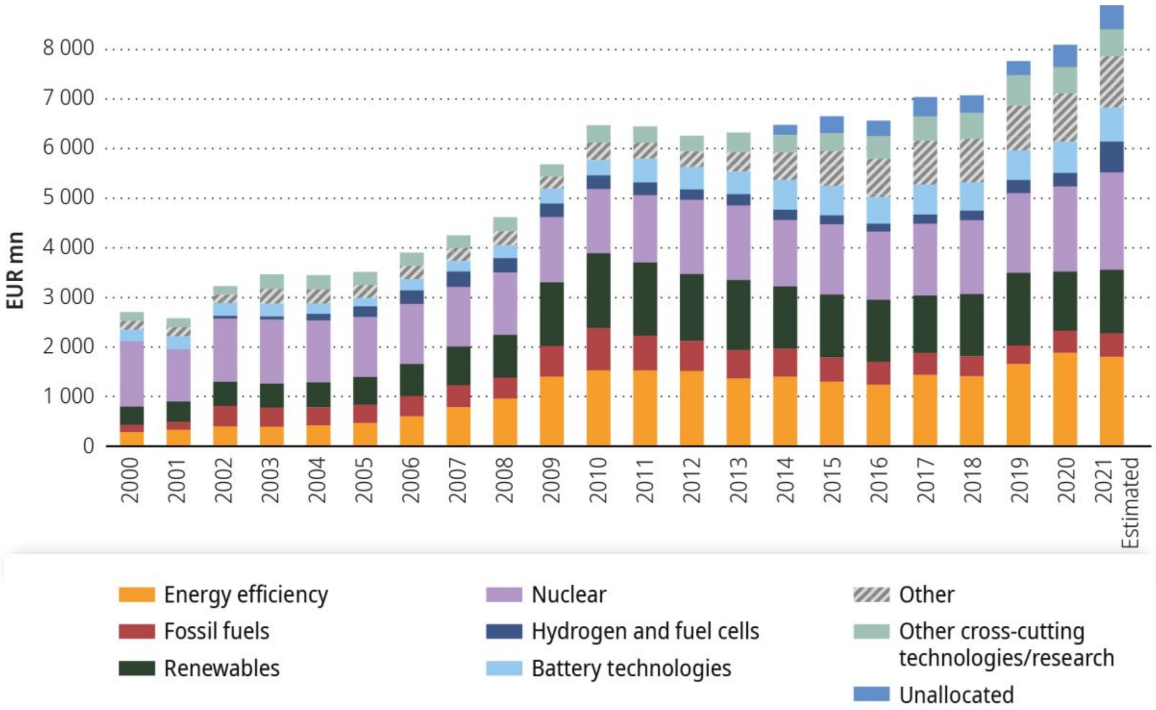
Public funding for key technologies lagging behind

Public funding of RD & D is lagging behind on key technologies that are necessary for the transition towards climate neutrality, such as batteries and hydrogen. Batteries are a key technology that enables the decarbonisation of the transport sector, but also serves for energy storage in the energy supply sector; this is also recognised in the 2018 strategic action plan on batteries. According to **Error! Reference source not found.** 84, public funding for RD & D in batteries has accounted for a relatively constant share of 9 % of total public expenditure on RD & D. The battery industry in the EU lags behind the growing global competition (Lebedeva et al., 2021), suggesting that a bigger effort in some storage areas may be valuable. The early investment associated with large-scale production allowed Asia to scale up and retain technological leadership in battery technologies (IEA, 2021b).

Hydrogen is also a key enabler in reducing emissions in industry (see Section 5.4) and long-range transport (see Section 6.4 under 'Lever: fuel switches', and for increasing flexibility in the energy supply sector (see Section 4.3 under 'Lever: system integration'). To realise this potential, more intense innovation is needed along the entire hydrogen supply chain, including electrolysers, to improve performance and reduce costs. Despite the significant increase in the proportion of spending on hydrogen-related RD & D from almost zero in 2000 to 7.9 % of the total spending in 2021, current levels of spending on deployment (EUR 621 billion) are about half the amount required (EUR 1 370 billion) to reach the REPowerEU targets of producing 10 million tonnes and importing an additional 10 million tonnes by 2030 (EC, 2022ad). This could suggest that additional support for early deployment could be helpful in complementing the R & D increases.

At the same time, public funding for fossil fuel RD & D including CCS remained above 5 % of the total energy RD & D budget between 2000 and 2021 (estimated total) (Figure 84). This support is inconsistent with the EU's pledge to phase out fossil fuel subsidies (EEA, 2023i). Reorienting funding away from fossil fuels and towards mitigation technologies would reduce funding gaps in key enabling technologies and also send a strong signal that the EU prioritises energy security and climate mitigation.

Figure 84 Public spending on RD & D by sector



Notes: Data collected at member state and EU level, in 2021 euro values.

Source: IEA (2023c) (indicator: 'Public R&D spending').

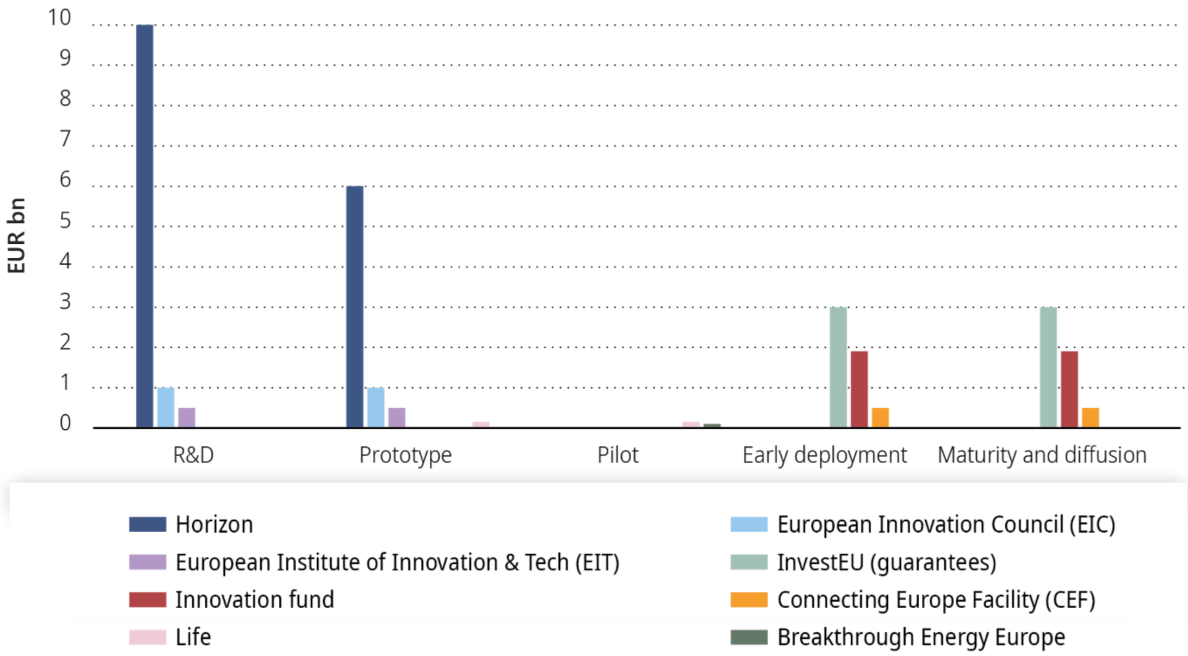
Persisting risk of funding gaps at the demonstration and early deployment stages

The RD & D process can be summarised in the following five key stages (IPCC, 2022o), which can vary in duration, as the pathway to maturity can be long and success is not guaranteed.

1. **R & D.** Creative work is undertaken on a systematic basis in order to increase the stock of knowledge, and this knowledge is applied to devise new applications and solutions.
2. **Prototype.** A research project is developed into a design and then into a prototype for a new device (e.g. a furnace that produces steel using hydrogen instead of fossil fuels).
3. **Pilot.** The first demonstration examples of a new technology are introduced at the size of a full-scale commercial unit (e.g. installing a carbon capture system at a cement plant).
4. **Early deployment.** At this stage, there is still a cost and performance gap between the new technology and established ones (e.g. electric versus combustion engine cars). Policy needs to address this to level the playing field.
5. **Maturity and diffusion.** As deployment progresses at scale, the product moves into the mainstream as a common consumer choice for new purchases (e.g. LED lamps).

The EU has a range of funding programmes to support climate-related innovation across all stages, including Horizon Europe, the Innovation Fund, the LIFE programme, the European Institute of Innovation and Technology, the European Innovation Council, InvestEU, the Connecting Europe Facility and Breakthrough Energy Europe. The availability of funding through these programmes across the main stages of the RD & D process (R & D, prototype, pilot, early deployment, and maturity and diffusion), is summarised in Figure 85. Despite the plethora of available mechanisms, there is a material funding gap at the middle stage of the RD & D process (pilot stage).

Figure 85 Available public funding by stage of the RD & D process

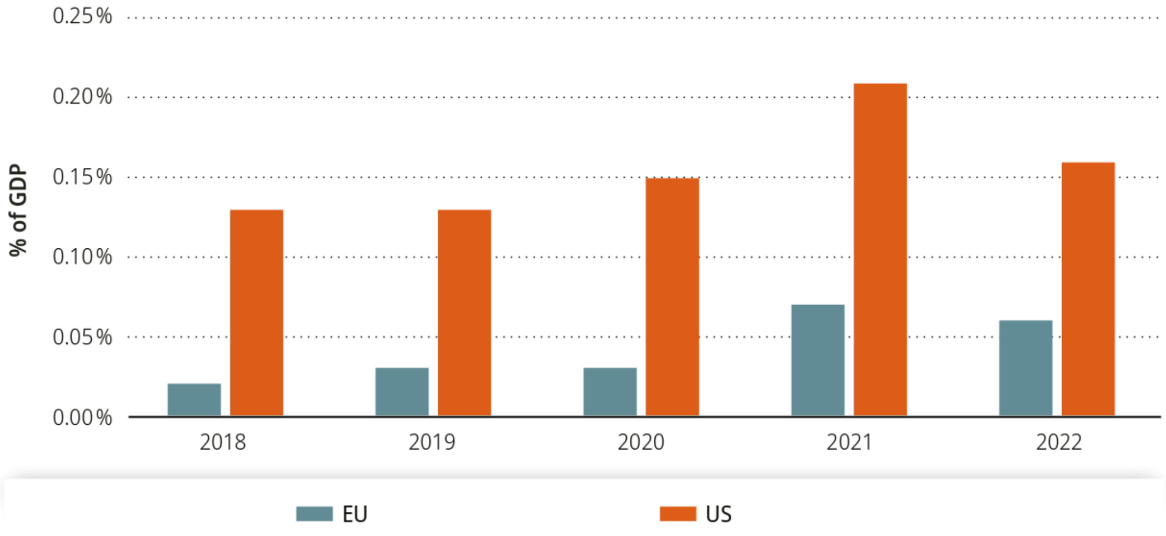


Notes: Annualised estimates for the period 2021 – 2027, except from the Innovation fund which is annualized for the period 2020-2030 and the Breakthrough Energy Europe which spans over the 2018-2023 period, in 2022 EUR values.

Sources: Policy documents for corresponding programmes (CINEA, 2021; EC, 2024, 2023ak, 2021p, 2019d, 2023bi; EIT, 2024; Wallace, 2019)

The venture capital financing model, used to overcome the valley of death in biotech and software technology, has not been as suitable for hardware start-ups in energy, because of their higher capital intensity and their dependence on network infrastructure. The current venture capital model and private finance do not sufficiently cover the need to pilot energy technologies at scale (Nemet and Greene, 2022). As Figure 86 demonstrates, investment in EU companies that specialise in clean technologies ([2]) lags behind that in the United States. This includes seed, series A, series B and growth investments. More specifically, in 2022 the EU invested only about 0.06 % of its GDP in clean tech start-ups whereas in the United States this investment amounted to 0.16 % of GDP.

Figure 86 Investments in cleantech across Europe and the United States (% of GDP)



Notes: All values are expressed in 2022 Euros. Includes funding in Seed, Series A, Series B and Growth investments. For a full definition of cleantech technologies please see footnote 97.

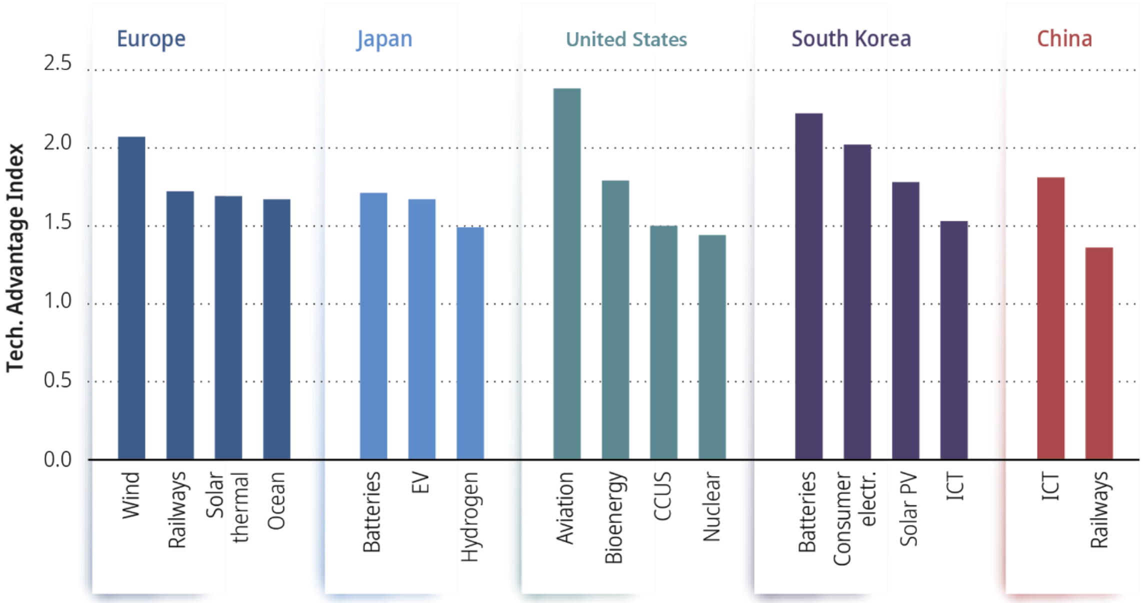
Source: Cleantech for Europe (forthcoming).

Need to diversify early-stage research and development to boost competitiveness

According to the recent joint publication by the IEA and the European Patent Office (IEA, 2021a), countries are specialising nationally in honing their competitive edge in specific technologies and collaborating internationally to foster regional technology advantages. In this respect, Europe ranks first in wind renewables and railways, two mature sectors, whereas sectors that are at an inflection point in their growth, such as batteries, hydrogen and carbon capture, are more developed in regions outside Europe. EU policies that support RD & D need to address a broader range of technologies that might currently stand at a low technology readiness level but have a high mitigation potential. This would enable Europe to remain competitive in ownership and control of the intellectual property necessary to enable the transition in sectors where mitigation alternatives to carbon abatement are limited.

([2]) The cleantech category in transport includes the following technologies: fuel cells, electric vehicle charging, ride sharing, micro-mobility, fleet management and route efficiency. Cleantech in energy includes wind power, solar power, geothermal, nuclear, energy storage, biofuels and hydrogen. Cleantech in agriculture includes precision agriculture, indoor farming, increasing crop yields, decreasing food waste, cultured meats and alternative proteins. Cleantech in industry includes biochemicals, process electrification, circular economy, recycling and innovative materials. Cleantech in buildings includes insulation, energy efficiency systems, heat pumps and waste heat reuse. Other cleantech activities also include satellite imagery, carbon offsetting, carbon accounting, weather forecasting and climate modelling.

Figure 87 Technology advantages of global innovation centres



Notes: The technology advantage index indicates a country's specialisation relative to its overall innovation capacity. It is defined as a country's share of international patent fillings in a particular filed of technology divided by the country's share in all fields. A value above one reflects a country's specialisation in a given technology.

Sources: Adapted from IEA (2021a, p. 18).

13.4 Summary table

Table 20 Policy consistency summary – Innovation

Policy gaps	– Public funding instruments can be slow in reacting to the changing needs of the fast-paced global clean technology arena. – There is a significant funding gap for projects aiming to complete the piloting stage and move towards the early deployment of clean technologies. – This funding gap is further widened by the lack of sufficient support from venture capital, as this concept remains less developed in Europe than in the United States – The Net-Zero Industry Act aims to partially address this, strengthening manufacturing capacity in key technologies, but it remains silent on innovation aspects. – Policy instruments on innovation treat private and public knowledge organisations separately, which hinders the opportunity to build stronger collaborations. – The Net-Zero Industry Act aims to increase the EU's manufacturing capacity in strategic technologies to reach at least 40 % of domestic needs; however, the existing reporting mechanisms offer limited means to track progress towards achieving this target.
Ambition gaps	– Policy instruments, such as the strategic energy technology plan, that aim to strengthen industry and research collaborations need to address behavioural barriers to innovation such as the fear of failure, emphasising the value of sharing the knowledge generated. – The existing EU funding architecture offers limited predictability beyond 2030, which increases uncertainty for long-term projects.
Implementation gaps	– While Horizon Europe and the Innovation fund aim to catalyse private investment in climate-related technologies, their administrative complexities hinder the crowding-in of private investments

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