CHAPTER 3

R&I FOR SUSTAINABILITY

R&I FOR SUSTAINABILITY

KEY FIGURES

About **2/3** of energy start-ups are clean in the EU in 2020	**4.4 m** jobs in the environmental economy sector the EU in 2018	**-29 %** is the drop in secure, clean and efficient energy patenting activity in the EU between 2012-2017

Almost **13 %** of material resources used in the EU in 2020 came from recycled waste materials	**1 out of 6** climate adaptation patented inventions has been transferred in at least one country between 2010 and 2015 least one country between 2010 and 2015

KEY QUESTIONS WE ARE ADDRESSING

- How does R&I support the achievement of a more sustainable and inclusive society?
- How should R&I policymaking be adopted to better support the deep transformation of our systems towards sustainability?

KEY MESSAGES

What did we learn?

- The scale of current research and innovation policy to achieve the green transition is insufficient for implementing the European Green Deal as the EU's new growth model.
- The EU is the global leader in patenting activity in the areas of climate action, environment and secure, clean and efficient energy.
- There was a general decline in clean and efficient energy patenting activity in the EU between the early 2010s and 2018. Since then, this decline has started reversing, but acceleration in patenting activity would be needed to make up for the lost years. This development is not unique to the EU but can also be seen in the US, Japan, and the UK.
- The EU is the global leader in scientific publications on topics related to sustainability, e.g. sustainable cities and communities, responsible consumption and production, industry, innovation and infrastructure, as well as the adaptation of food systems.
- The transfer rate between high, middle- and low-income countries for climate adaptation technologies is lower than for other technologies, even if adaptation is urgently needed in some developing countries.
- Net-zero-aligned investments can generate jobs as they can lead to activities that are both labour-intensive and fast in implementation.

What does it mean for policy?

- Given the complexity of transition and transformation processes (i.e. complex and interrelated socio-technical systems, goals and interests involved), the structures governing R&I policy processes could be designed to mobilise and support deep transformations across societal and economic systems.
- The five European Missions have the potential to deliver such changes and achieve the objectives of the European Green Deal.

- Emerging technologies, social and place-based innovations are highlighted as essential parts of the transformative change towards sustainable futures.
- The gap in profitability between clean and polluting technologies must be bridged by ensuring an internalisation of the environmental costs of non-green technologies while supporting market innovators seeking to scale-up.
- R&I policies could facilitate an acceleration in patenting activity on clean energy technologies, in particular in sectors with high potential, such as hydrogen and geothermal.
- The uptake of new and green technologies could be accompanied by a just transition approach, where the workers in the downscaling, polluting areas are supported in their transition into related fields of work through reskilling and financial incentives.
- At the European level, the industrial technology roadmaps for R&I under the New ERA for Research and Innovation policy outline the investment needs and conditions for some key products and processes to achieve sustainable transitions.
- Policy efforts need to boost technology transfer to the most vulnerable territories.
- EU R&I policies have a role to play in coordinating the main actors of the transition: industry, universities, and the nations and regions themselves (government and civil society), as they appropriate the transition and tailor it to their own strengths, challenges and opportunities.
- Foresight, experimentation, systems methodologies (e.g. system dynamics, life cycle assessment) and co-creation participatory exercises can bring novel ideas for policymaking and challenge dominant visions.
- EU R&I policies are critical in the policy mix to achieve the green transition and well complement net-zero policies.

Sustainability implies that we should thrive in a safe and just space between planetary boundaries and social boundaries[1] (Raworth, 2017). On the one hand, an environmental ceiling of planetary boundaries should not be crossed as this would mean unacceptable environmental degradation and potential tipping points for the Earth's systems. On the other hand, many dimensions of human deprivation lie below social foundations[2].

Moving into the space between these two boundaries is an aspiration that requires 'far greater equity in the use of natural resources, and far greater efficiency in transforming those resources to meet human needs' (Raworth, 2012). **Economic, social, and environmental sustainability are not separate**. They are interdependent and build upon one another.

1 Planetary boundaries' is a concept which refers to a series of sustainability limits beyond which lie tipping points for many earth systems that could result in the planet becoming inhospitable for humanity. In her book 'Doughnut Economics' (2017), Kate Raworth joined the idea of planetary boundaries with that of a social foundation to provide the 'safe operating space' for humanity.

2 Kate Raworth (2017) has summarised the social foundations in the Doughnut, which shows how the safe and just space for humanity lies between the social foundation of human well-being and the ecological ceiling of planetary pressure.

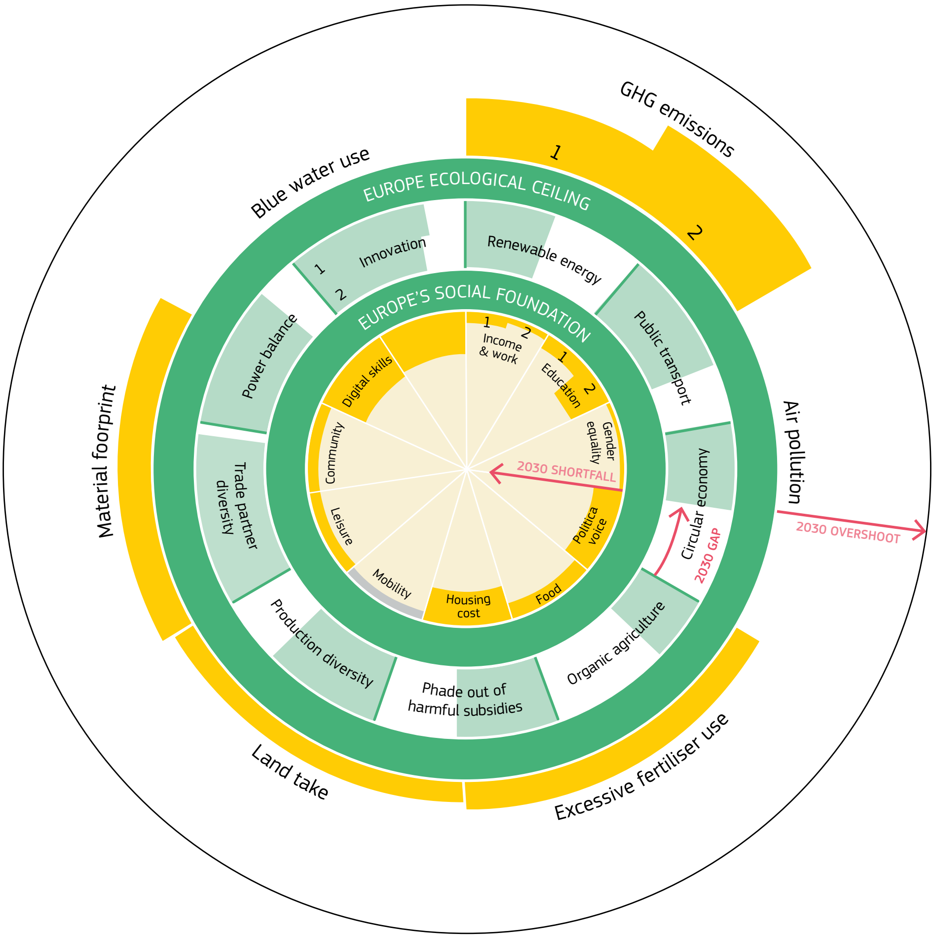
A fair and prosperous society, with a modern, resource-efficient and competitive economy thrives when there are **no net emissions of greenhouse gases and when economic growth is decoupled from resource use**. Thus, protecting, conserving and enhancing natural capital, and protecting the health and well-being of citizens from environment-related risks and impacts are key dimensions of economic sustainability (European Commission, 2019). Economic growth shall be seen as a means to achieving societal goals. These include environmental sustainability, reduced inequality, greater wellbeing and improved resilience (OECD, 2020) and it will require a shift in the economic paradigm (EEA, 2021).

Based on Jeffrey Sachs' thinking (2012 and 2015) and a long-lasting inclusive and participatory consultation process, the new 2030 Agenda for Sustainable Development adopted in September 2015 by all 193 member states of the United Nations (UN) 'embrace the so-called triple bottom line approach to human well-being' (Sachs, 2012, p. 2206). The complex interdependence and mutually reinforcing nature of the three dimensions of sustainable development – economic, social and environmental – is one of the hallmarks of the Sustainable Development Agenda, and paved the way for 17 Sustainable Development Goals (SDGs) and 169 targets to be '**integrated and indivisible, global in nature and universally applicable**' (UN, 2015, p. 13). A vast number of practitioners in R&I have engaged in implementing the approach of the Sustainable Development Goals and enabling deep, sustainable transformations in societal systems like energy, water, mobility, agriculture and health car. Through practice, they have collaborated with policy makers across governmental levels (local, regional, national and European) and strengthen the role of R&I policy in contributing to environmental preservation and climate mitigation while enabling social justice and human well-being, and economic development (European Environmental Agency (EEA), 2019; Fagerberg, 2018). The UN identifies four levers of change, governance, economy and finance, individual and collective action, and science and technology (UN, 2019).

In the previous edition, SRIP 2020, a key message was that **no country in the world seems to meet basic needs for its citizens at a globally sustainable level of resource use** (European Commission, 2020). Europe achieves the social thresholds for almost every indicator, but it does so by transgressing the safe levels for almost all biophysical boundaries. The only one that Europe does not exceed is water use. Besides, the situation is not likely to improve by 2030 as Figure 3.1 shows. At the other extreme, countries like Sri Lanka stand within the safe boundary for every single environmental indicator but only achieve an acceptable level for three of the social indicators. The situation in the United States is similar to the EU, with most social thresholds achieved and biophysical boundaries transgressed. In comparison, China presents more shortfalls regarding the social dimensions but less overshoot on the biophysical aspects.

The EU is fully committed to ensuring prosperity within planetary boundaries. The European Green Deal, a flagship of the von der Leyen Commission that aims to put the EU firmly on the path towards climate neutrality by 2050, is the EU's new growth model. Several packages have been adopted since then to ensure its achievement, in particular the Fit for 55 plan, which adapts existing climate and energy legislation to meet the new EU objective of a minimum 55% reduction in greenhouse gas (GHG) emissions by 2030. The EU endorses a holistic and integrated approach, mainstreams the SDGs into EU policies and initiatives, with sustainable development as an essential guid-

Figure 3-1: EU 2030 portrait using Doughnut economics



Source: ZOE-Institute for future-fit economies Transformation Policy Report #4 — 11/2021
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ing principle for all of its policies. This calls for policy coherence as economic activity needs to be increasingly aligned with the four dimensions of competitive sustainability: environmental sustainability, productivity, fairness, and macroeconomic stability[3]. Hence, it requires an integrated multidimensional policymaking approach, which is directional and evidence-informed. The sustainability transformation is also an unprecedented governance challenge at all levels, from local to global.

Well-conceived and coherent policies should stimulate the three sustainability dimensions – environmental, social and economic – to reinforce each other. In order to achieve this, **EU R&I policy could be guided by principles such as co-creation, diffusion, uptake, transformation and the directionality of R&I and be compliant with the 'do no significant harm' (DNSH) principle**[4] enshrined in the European Green Deal objectives.

3 As defined in Articles 17 of Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088.

4 Normalised with goalposts.

Box 3-1. The Transitions Performance Index

The Transitions Performance Index (TPI), a European Commission initiative by DG Research and Innovation, is a scoreboard that monitors, scores[5] and ranks countries on fair and prosperous sustainability. It provides a global ranking for 72 countries[6] in four transitions – economic, social, environmental and governance – over the 2011-2020 decade. These measurements are inspired by a model of prosperity that focuses on resilience, inclusiveness, sustainability and that supports the EU's 2022 Annual Sustainable Growth Survey. The TPI is based on 28 internationally comparable indicators, mostly hard data, and builds on the indicators for the UN's Sustainable Development Goals (SDG) and on the European Commission's current priorities. It offers an evidence-based tool for all who are striving towards fair and sustainable prosperity and intends to contribute to the Beyond GDP debate.[7] The TPI illustrates the specific contributions of each transition to the overall performance of a country, indicating strengths and weaknesses, room for progress, unbalances in their profile and possible trade-offs.

The second edition of the TPI was published in March 2022[8], and includes additional indicators on digital use and skills, and on material footprint compared to the previous report. The latter indicator aims to reflect environmental spillover effects and to better gauge the impact of consumption on the environment.

Figure 3-2: The Transitions Performance Index, 2021

TRANSITIONS PERFORMANCE INDEX			
ECONOMIC TRANSITION	SOCIAL TRANSITION	ENVIRONMENTAL TRANSITION	GOVERNANCE TRANSITION
Education	Health	Emissions reduction	Fundamental rights
Wealth	Work and inclusion	Biodiversity	Security
Labour productivity and R&D intensity	Free or non-remunerated time	Material use	Transparency
Industrial base	Equality	Energy productivity	Sound public finances

Source: Authors' elaboration

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-2.xlsx

5 Normalised with goalposts.

6 A total of 72 countries are included in the TPI: all EU countries, associated countries, Organisation for Economic Co-operation and Development (OECD) member countries, countries with at least 40 million inhabitants and a GDP per capita higher than USD 2 000 (IMF current dollar estimates).

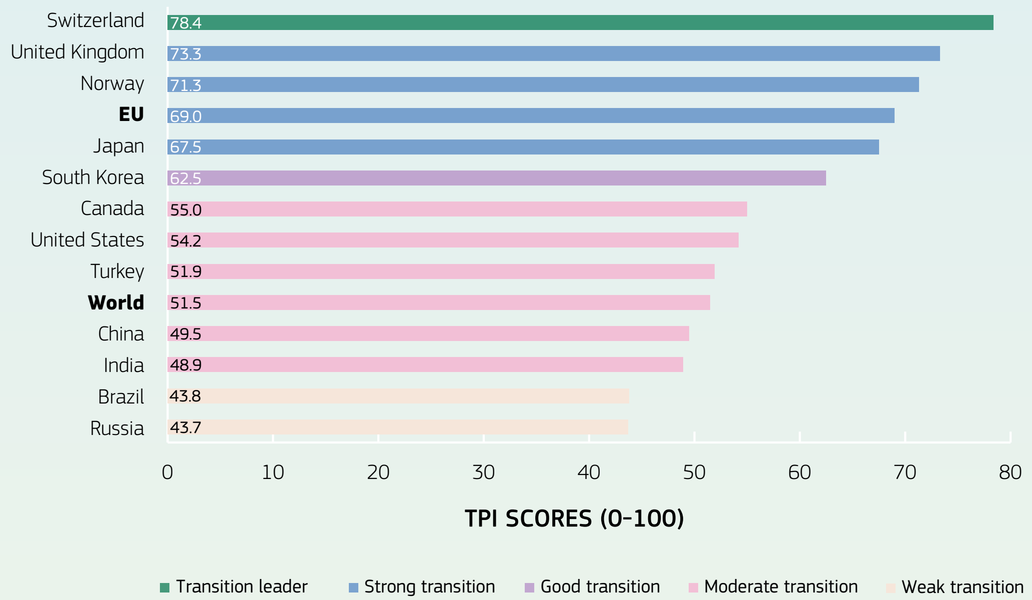
7 Background - Beyond GDP - European Commission (europa.eu)

8 https://op.europa.eu/fr/publication-detail/-/publication/50fff167-a34e-11ec-83e1-01aa75ed71a1/language-en/format-PDF/source-253126101

To respond to global challenges and benchmark countries beyond the EU, a global metric such as the TPI is needed. When looking at the EU's ten main trading partners, the EU[9] ranks fourth (Figure 3.3) and is in the strong transition group. The only main trading partner in the same transition group as the EU outside of Europe is Japan, while South Korea is not far behind in the good transition[10] group. The gap with Canada and the United States is substantial; both countries are in moderate transition, performing slightly better than Turkey, China and India. The world average represents an average moderate performance as well, whereas Brazil and Russia are in the weak transition group. In terms of progress, since 2011 China has progressed by 7.6 %, the United States by 3.3 % and the EU by 4.9 %[11].

All EU countries belong to the groups of leaders, strong or good transition: none belongs to the moderate or weak transition groups (Figure 3.4). It is therefore a robust indication of the overall positive impact of EU orientations. Denmark (ranking first among EU countries) and Ireland are transition leaders. In terms of

Figure 3-3: European Union and main partners TPI scores 2021 and transition group



Source: European Commission, Tranistion Performance index 2021

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-3.xlsx

9 Population-weighted average of the 27 EU Member States

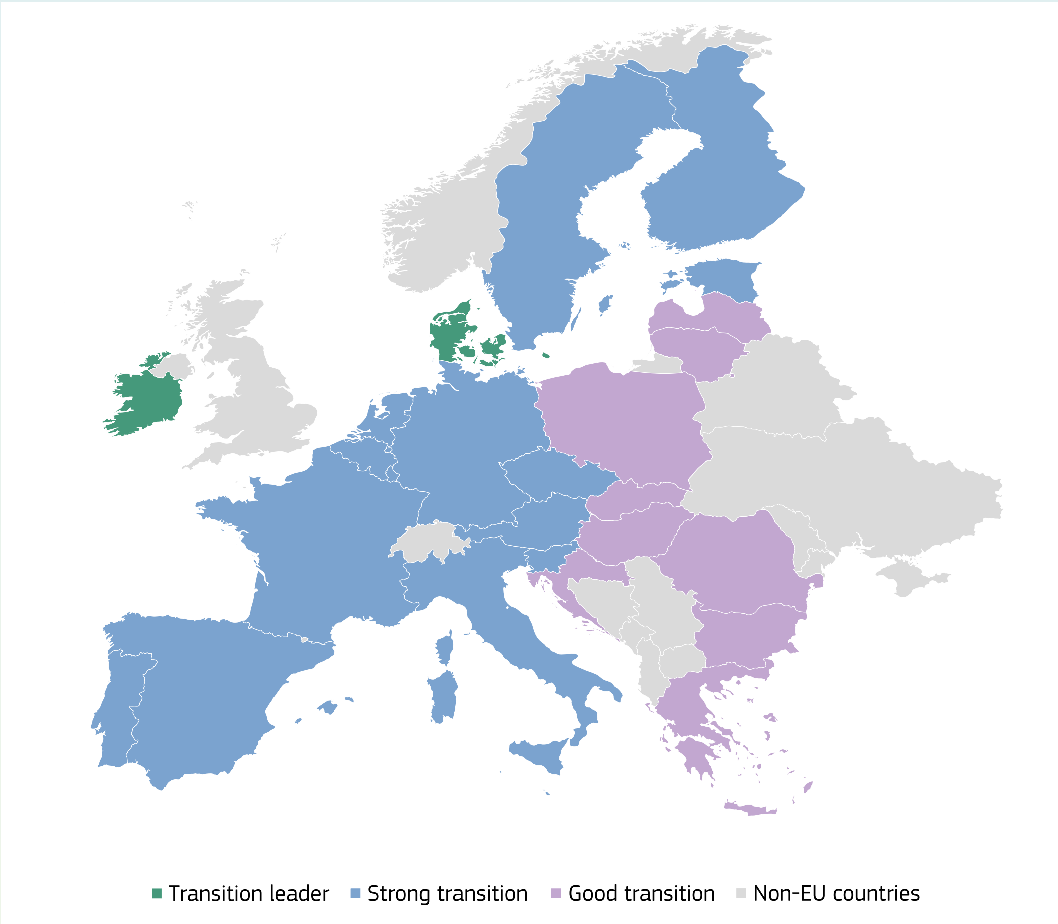
10 Five performance groups are defined with fixed score intervals.

11 For comparison the world TPI arithmetic average is 6.2 %.

progress in the EU, all but one EU country have improved their performances since 2011, particularly Croatia, which showed an exceptional result of catching up (13.5 %), and Greece and Estonia (above 10 % progress). Cyprus, Finland and Sweden progressed less than 2 %, whereas Hungary is the only EU Member State that stagnated over the last 10 years (-0.2 %). These countries are at risk of losing ground in the transition process unless they renew collective efforts. When looking at the performance by pillar, EU Member States have not improved sufficiently in the economic and environmental transitions. Pursuing ambitious targets and related investments in these domains is an absolute necessity if the EU and Member States wish to achieve balanced and sustainable prosperity.

Several other key features emerge from the TPI results. Country disparities highlight that performance and progress are not predetermined by income group or geographical position; they do require, however, relevant policy efforts. Looking at the results by transitions, progress has been significant in the Economic (10.1 %),

Figure 3-4: EU Member States Transitions Performance Index groups (2020)



Source: European Commission, Transition Performance Index 2021

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Environmental (6.0%) and Social (4.7%) transitions, whereas on average the 72 countries show a decline in governance (-2.6%). Nevertheless, these results hide large disparities between countries that are analysed more thoroughly in the report. The large heterogeneity in economic performance shows opportunity for progress. Social transition is the most successful pillar with 26 leader performers. The decline in scores for governance transition at the global level is partly driven by the strong deterioration of public finances. The environmental transition has a different dynamic than the three other transitions, showing that most countries have not bended their curves for their green transition.

While the effect of the pandemic is not fully captured statistically in this year' edition, the pandemic has had a considerable impact on transition processes and challenges social cohesion and resilience, both of which are key enablers for a fair and sustainable transition.

1. R&I delivering on societal challenges

1.1 R&I is fundamental to preserving biodiversity and enabling the transition to a net-zero world

All the scenarios that limit warming to below 2° C heavily rely on research and technology progress and its uptake. In addition to demand management, phasing-out, change in the functioning of the economic system, it is estimated that **half of the global reductions in CO_2 emissions by 2050 will have to come from technologies that are currently at the demonstration or prototype phases** (IEA, 2021). Besides, numerous studies confirm the positive impacts of green innovation on environmental protection (for a complete literature review, see Takalo et al., 2021).

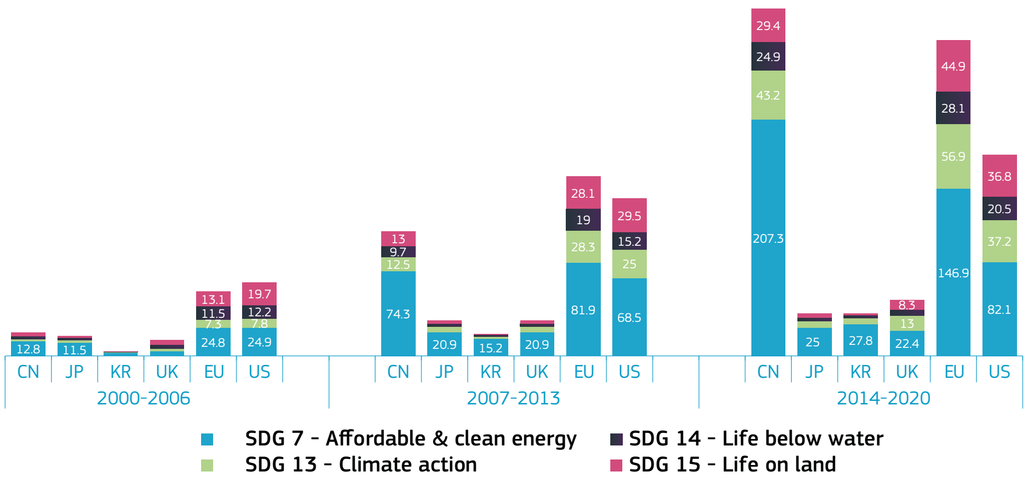
Strengthening the science base on the environment and nature is a key element to ensure the preservation of biodiversity and ecosystems. The EU has long been in the lead in terms of scientific publications dedicated to four environmentally related SDGs – climate change, clean energy, life on land and life below water – but has lately been surpassed by China. Figure 3.5 demonstrates that the volume and the share of publications dedicated to climate change, clean energy, life on land and life below water have increased worldwide over the past two decades, despite a slowdown in the pace of publications on clean energy in the EU and the United States beginning in the mid-2010s.

Over 2014-2020, China has substantially intensified publication in these areas and has also surpassed the EU in terms of quality for affordable energy and climate action (Table 3-1). **Scientific knowledge leads to continuing demand for strengthening strategies to preserve and restore ecosystems**, such as wastewater policies for sanitation, the definition of protected areas, which have proven to be essential for biodiversity conservation (Coetzee et al., 2014). For the life below water SDG, it is worth noting that the EU has established a significant toolbox containing nearly 600 policy tools (170 at the EU level and 417 at the national level) that together form a coherent framework to achieve this sustainable goal[12]. The **identification of protected areas across the EU relies on scientific criteria** to ensure that they have the highest potential for preserving biodiversity (wetlands for migratory waterfowl, sites gathering 1 % of the population of listed vulnerable species). **These protected areas also facilitate research on biodiversity, driving forward knowledge for refining preservation and protection policies.**

Environmental knowledge created but not yet brought to the market by incumbent companies or research organisations **shapes the creation and financing of green start-ups** (e.g. Audretsch and Keilbach, 2004). Environmental knowledge positively impacts new venture creation in green technologies as entrepreneurs and start-ups' new ideas for business are based on such knowledge (Colombelli and Quatraro, 2017; Cojoianu et al., 2020).

12 https://ec.europa.eu/oceans-and-fisheries/news/new-report-eus-performance-un-sustainable-development-goal-14-2021-05-11_en

Figure 3.5: Number of scientific publications[(1)] in climate action, life on land and below water and clean energy



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using Scopus database.

Note: [(1)] The data labels are expressed in thousands of publications and the publications for each SDG are not mutually exclusive. Fractional counting used.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-5.xlsx

Table 3-1: Percentage of highly cited publications per SDG, per country/region, 2018

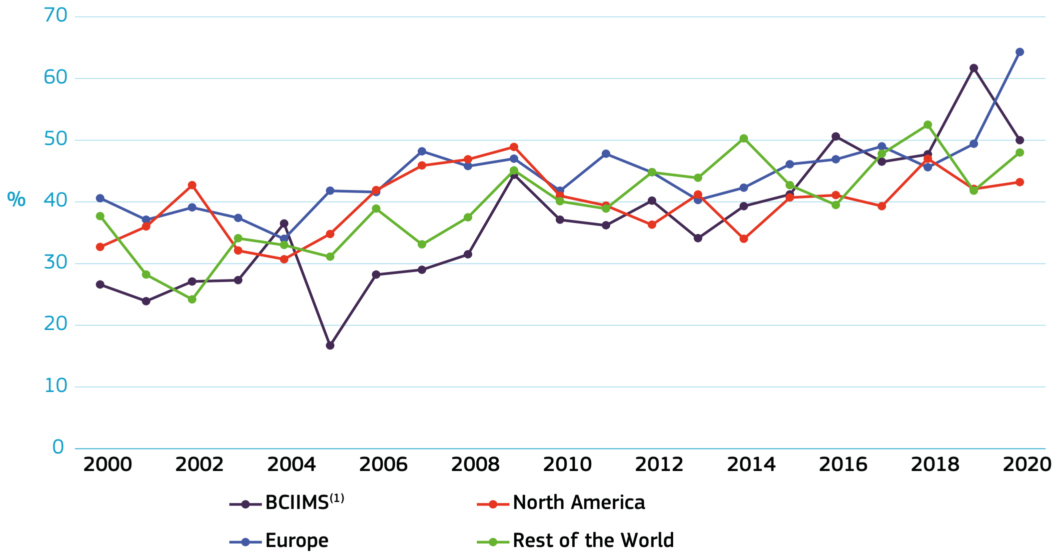
	CN	JP	KR	EU	UK	US
SDG 7 – Affordable and clean energy	**19.0**	9.1	11.6	13.6	19.9	19.5
SDG 13 – Climate action	**18.9**	10.8	10.2	16.5	20.9	19.9
SDG 14 – Life below water	**13.6**	8.2	9.3	16.3	21.2	16.0
SDG 15 – Life on land	**11.5**	7.0	6.1	12.7	17.9	11.3

Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using Scopus database.

Note: The data labels are expressed in thousands of publications and the publications for each SDG are not mutually exclusive. Fractional counting used.

Figure 3.6: Evolution of the share of clean energy start-ups[2] in total energy start-ups by region, 2000-2020



Science, Research and Innovation Performance of the EU 2022

Source: International Energy Agency calculations based on company-level data obtained from Crunchbase (www.crunchbase.com).
Note: BCIIMS – Brazil, China, India, Indonesia, Mexico, South-Africa. Start-ups are classified according to a taxonomy of over 700 labels, amongst which 26 tags have been identified as explicitly energy-related and tags characterised as 'clean' (e.g. renewables) by the nature of the tag itself, and those which separately list any energy tag in addition to a 'clean' tag in the descriptions of their business strategies.
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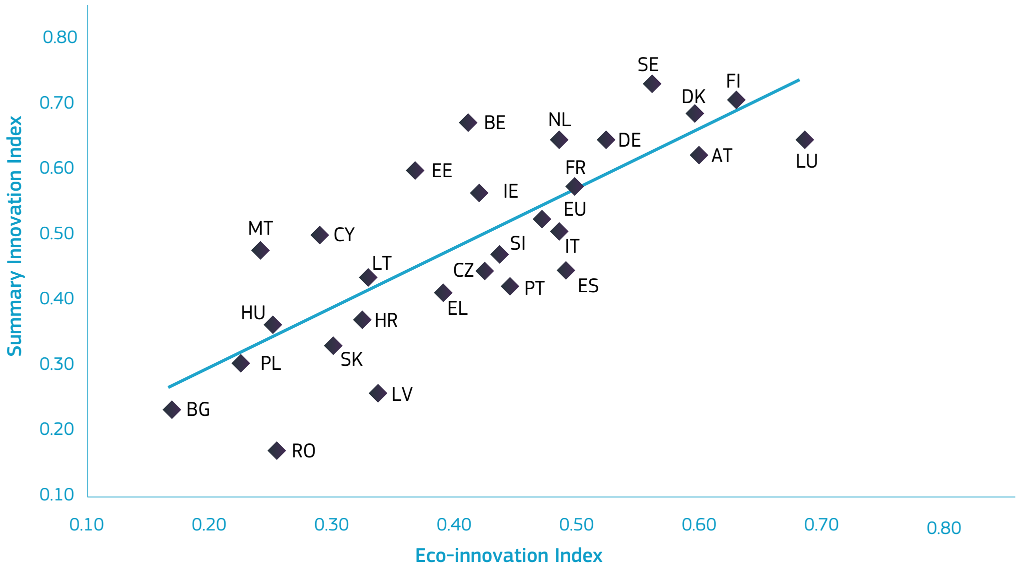
Strengthening the science base on both the natural capital and green aspects of our economy has developed new market opportunities for process and product innovations. Such knowledge feeds the creation of clean start-ups. For example, over 2000-2020, the share of clean start-ups in the total number of energy start-ups has increased significantly in each region of the world, including in Europe, which had an increase from 41 % to 64 % in 2020 (Figure 3.6).

There is a strong positive correlation between the Eco-Innovation Index and the Summary Innovation Index (i.e. the composite index of the European Innovation Scoreboard). The summary Eco-innovation index is a composite indicator, which measures the performance of EU Member States on environmental innovations (Figure 3.7). Given that both indices aim at measuring innovation performance, are based on a similar methodology and have a number of common indicators, this relation is not surprising. According to the Eco-Innovation Index 2021, there are nine Eco-Innovation leaders in Europe: Luxembourg, Finland, Austria, Denmark, Sweden, Germany, France, Spain and the Netherlands. Three of them, Sweden, Finland and Denmark, are also Innovation Leaders. Given that the EIS' Summary Innovation Index and the Eco-Innovation index are highly correlated, eco-innovation should be central to the strategic planning of national economies.

Figure 3-7: Comparison of the Eco-Innovation Index 2021 and the European Innovation Scoreboard 2021 (normalised scores)



Source: EU Eco-Innovation Index 2021 Policy brief July 2021
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Technological progress is critical in mitigating the effects of climate change as the use of technology reduces the investment costs of emissions reduction policies. Thanks to technological development, the global production costs of wind and solar energy have significantly decreased in recent years, even though there are substantial differences in total installed cost across countries (Figure 3.8). This reduction makes clean energy a realistic alternative to fossil-fuel resources, and solar and wind are currently the cheapest forms of new power generation in a large number of countries (representing over 70 % of global GDP, which includes several European countries, cf. Stern and Valero, 2021). The integration of clean energy technologies currently plays an important role in climate change mitigation (Perera et al., 2017). In the past, since the deployment of clean energy projects was not cost effective, any drop in oil prices induced a shift from renewable investment back to fossil fuel energy (Ozdurak, 2021). However, **for some other clean resources, such as hydropower and geothermal, installed costs have not significantly decreased over the past decade** (Figure 3.8). Besides, the cost of these clean energy sources still exceeds the cost of fossil fuels. Hence, deeper decarbonisation will likely require significant innovation-driven cost reductions, in particular for

Figure 3-8: Evolution of global costs and production capacity of renewable energy, 2010-2019

Source : DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on IRENA and Eurostat.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-8.xlsx

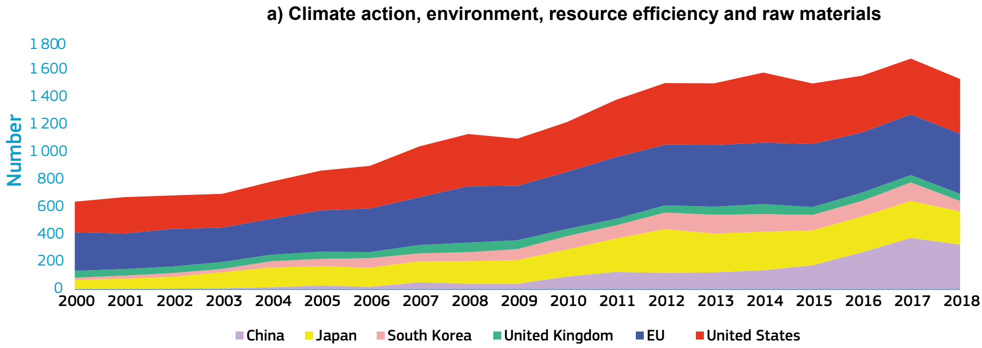
energy storage technologies, which can provide the power system with the flexibility required when intermittent renewables are present in the electricity generation mix (Giarola et al., 2021; Stock, 2021).

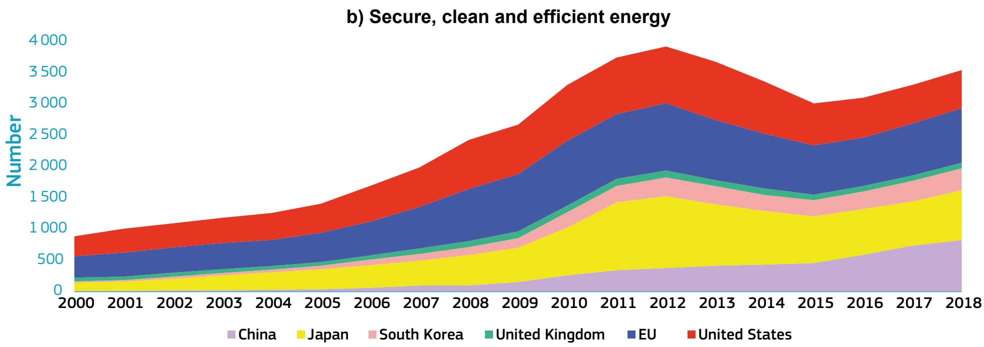
The EU is the global leader in patenting activity in the climate action, environment and secure, clean and efficient energy sectors. However, there has been a global decline in clean and efficient energy patenting since the early 2010s, though more recently this trend has reversed (Probst et al., 2021; IEA, 2019; Figure 3.9). During the 2010s, patenting in the areas of clean and efficient energy has indeed dropped drastically in Japan (-41 % over 2012-2017), the US (-36 % over 2013-2018), the EU (-29 % over 2012-2016), the UK (-24 % over 2011-2017) and South Korea (-15 % over 2012-2015). Conversely, China's patent applications in secure, clean and efficient energy have more than tripled from 2012 to 2018, even though the growth rate slowed down between 2013 and 2016. A detailed study of the IEA and EPO (2021) shows that, **after a rapid rise in the period to 2013, patenting activity in low-carbon energy technologies slumped as well between 2014 and 2016**. Market prices have provided insufficient incentives for the development of innovations that lower emissions, in particular following the significant fall in carbon prices set by the EU Emissions Trading System (ETS) after the start of the global financial crisis in 2008 and again around 2011 (EIB, 2020). Some of the decline could also be explained by the increasing maturity of climate change mitigation technologies in these markets, resulting in a lower propensity to patent. For example, many of the more recent developments that have brought down costs in the solar PV sector are likely to be related to improved know-how in exploiting the innovations from previous years (IEA, 2021).

An acceleration in patenting activity on clean energy technologies, in particular in sectors with high potential such as hydrogen and geothermal, is needed. However, while solar and wind technologies have reached a certain maturity, it is not the case for other technologies, such as energy storage or hydrogen applications for transport, as well as hydropower energy sources and bioenergy (including geothermal), for which total installed costs have not significantly been brought down (Figure 3.9). **Since 2017/2018, patenting activity in low-carbon technologies has been increasing again, but at a rate that remains below that witnessed before 2013. An acceleration in activity would be needed to make up for the lost years** (IEA, 2021). Patents in fossil energy have experienced a four-year decline starting in 2017, unprecedented since the second World War. This decline can mean a more definite shift to clean energy sources.

Should we have a limited but targeted focus on some key industries and technologies to achieve the transition? Figure 3.10 demonstrates that over 80 % of the GHG emissions by European industry comes from three sectors: electricity, gas, steam and air conditioning supply (34 %), manufacturing (31 %), and transportation and storage (18 %). Besides, **the manufacturing of only four categories of product**s – non-metallic products (in particular cement), metals (in particular steel and aluminium), chemicals and coke and refined petroleum –, **is responsible for about 27 % of all CO_2 emissions in Europe.** Large reductions in industrial GHG emissions would therefore seem possible by focusing on a limited set of product and process improvements (Risman et al., 2020). Furthermore, some scenarios to limit global warming foresee great efforts on a few key technologies, such as clean hydrogen, and innovative processes to achieve the transition to a net-zero world.

Figure 3-9: Evolution of number of patent applications[1] filed under PCT in climate action, environment, resource efficiency, raw materials and clean energy, 2000-2018





Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using EPO PATSTAT dababase.

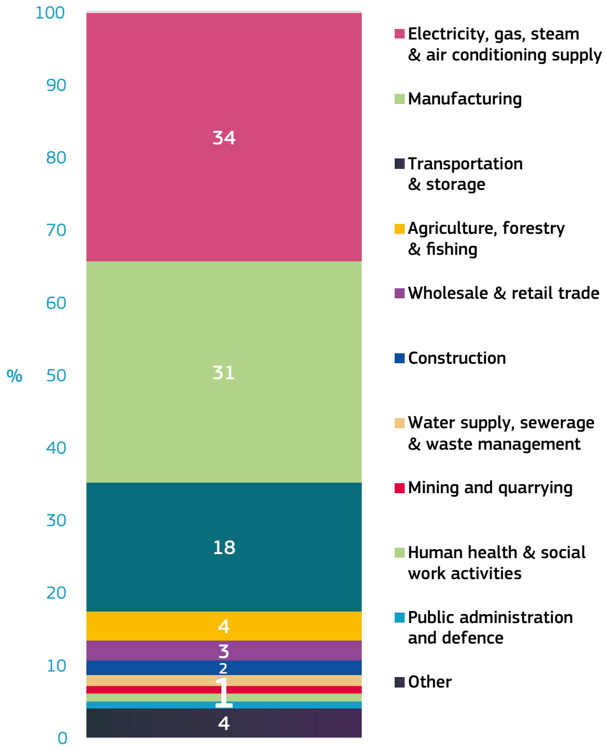
Note: [1]Fractional counting used.

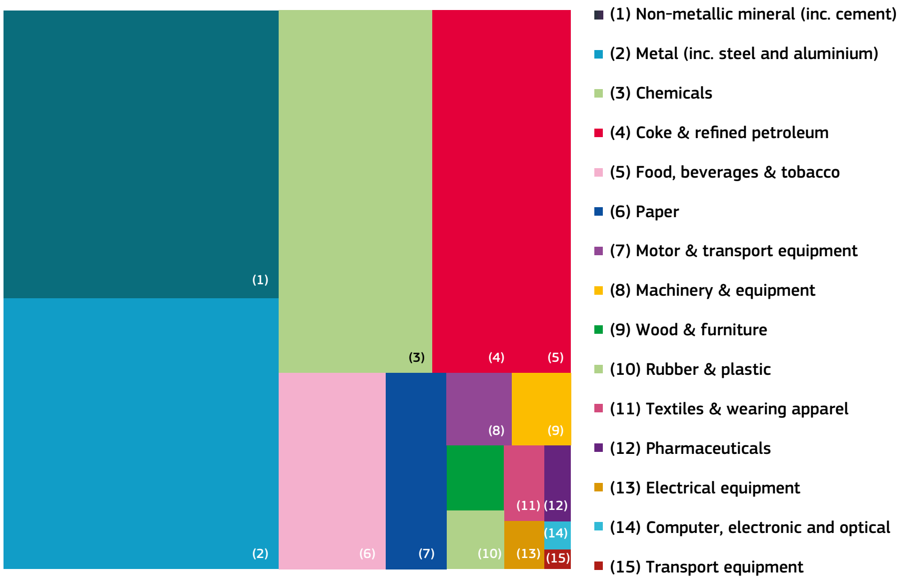
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-9.xlsx

The industrial technology roadmaps for R&I under New ERA for Research and Innovation', map the investments needs and the conditions for some key products and processes to achieve the sustainable transitions in the EU. The European industrial alliances in hydrogen, batteries, and raw materials, involving public authorities and industries, provide open platforms to establish the coordination of research, development and innovation investment plans for these key technologies (See Chapter 2.1 – Zoom out).

Figure 3-10: CO_2 emissions in the EU in some key sectors, 2019

a) CO_2 emissions per sector (% of total)





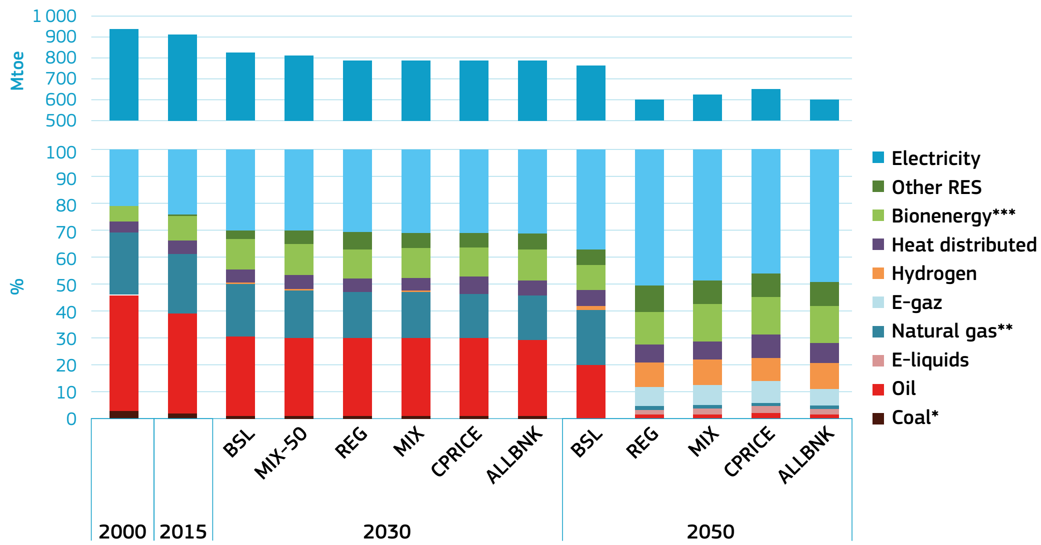
Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Eurostat (online data code: ENV_AC_AINAH_R2)

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-10.xlsx

The EU green transition and its pace rely heavily on geopolitical context. The EU Green Deal is expected to solve the EU's energy security problems related to the highly dependent relation between EU and its current main energy suppliers, notably Russia, but in the long run. Following the adoption of a new greenhouse gas emission target for 2030, the European Council concluded that EU member states were free 'to decide on their energy mix and to choose the most appropriate technologies to achieve collectively the 2030 climate target, including transitional technologies such as gas' . Estimations by the European Commission (2020) using different scenarios foresee that most of the change for oil and gas will happen between 2030 and 2050 and natural gas will contribute just a tenth of EU energy in 2050 (Leonard at al., 2021). However, it also shows that, between 2030 and 2050, gas, mainly imported, will be a transitional source (Figure 3.11). Some uses, like high-temperature heat in industrial processes, cannot indeed be easily replaced by green electricity. Only 40% of Europe's industrial use of gas is in low-temperature applications that can be readily electrified. Hydrogen for powering vehicles, generating electricity or providing long-term energy storage could support such a transition but not in the short term. Furthermore, between 2010 and 2014, 60% of imports of raw materials came from China.

Europe's demand for raw materials is forecast to double by 2050 (European Commission, 2020) and it has hardly any mining or processing activity for these primary minerals (see Chapter 2.1 – Zoom out). Substitution, the application of the circular economy principles with new business models for intensified use of products and components, along with the full use of secondary materials' resources are important knowledge intensive innovation pathways that may require more attention in the future to overcome these issues.

Figure 3-11: EU energy mix evolution – target: -55% lower emissions in 2030 compared to 1990 and climate neutrality in 2050



Source: European Commission (2020).

Note: All scenarios are considered: BSL, MIX-50, REG, MIX, CPRICE, ALLBNK.

Note: * includes peat, oil shale; ** includes manufactured gases; *** solid biomass, liquid biofuels, biogas, waste.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-11.xlsx

Box 3-2: Boosting R&I on strategic areas and technologies under the EU's R&I framework programme: examples of R&I projects funded by Horizon 2020

Semiconductor:

New-generation power semiconductors, made in Europe | Research and Innovation (europa.eu) An EU, industry, national and regional-funded research project has developed the next generation of energy-efficient power semiconductors using gallium nitride devices on innovative substrates.

Novel silicon lasers promise semiconductor revolution | Research and Innovation (europa.eu) An EU-funded project is enabling efficient intra-chip and chip-to-chip communication via a new type of silicon capable of emitting light. It is demonstrating a technological breakthrough that could revolutionise the electronics industry and make devices faster and much more energy efficient.

Batteries:

Boosting battery power for electric vehicles | Research and Innovation (europa.eu) EU-funded researchers are developing a high-energy lithium-ion battery to power a range of electric vehicles. They aim to meet growing demand for greener transport and to help Europe establish a competitive advantage in battery cell production.

A tiny battery solution with huge potential for Europe | Research and Innovation (europa.eu) Pioneering EU-funded research on new solid-state batteries is paving the way for tiny yet powerful batteries for safer and better space applications. Industry partners are advancing with plans to commercialise thin-film energy-storage technologies and processes at the heart of the project.

Technology:

Pioneering photolithography for 7 nm chips | Research and Innovation (europa.eu) Cutting-edge photolithography technology developed by an EU-funded consortium has enabled the launch of a new generation of high-performance smartphones featuring powerful and efficient 7 nm-node mobile processors

Cloud technology:

Building a cloud-based hub for all things research | Research and Innovation (europa.eu) The EU is developing a dedicated cloud repository for all the scientific research happening in Europe. To ensure easy access to and reuse of this information, the EU-funded EOSC-hub project developed an intuitive user interface and other tools. Researchers can now take advantage of the wealth of information already stored on the cloud, ultimately benefiting citizens as science becomes more open.

Sustainable technology:

Innovative metal recycling for sustainable tech | Research and Innovation (europa.eu) EU-funded researchers are developing low-polluting techniques for recovering valuable metals from communications and green technology waste. This urban mining could help to reduce pollution and ensure a secure supply of metals critical to a low-carbon, connected economy.

Hydrogen:

Using hydrogen to reduce industry's carbon footprint | Research and Innovation (europa.eu)
The steel industry is one of the world's biggest greenhouse gas emitters. To change this, the EU and industry-funded H2Future project is showing how a steel production plant can operate using green hydrogen made from renewable electricity. Once finalised, this new technology could play a key role in helping Europe meet its goal of becoming climate-neutral by 2050.

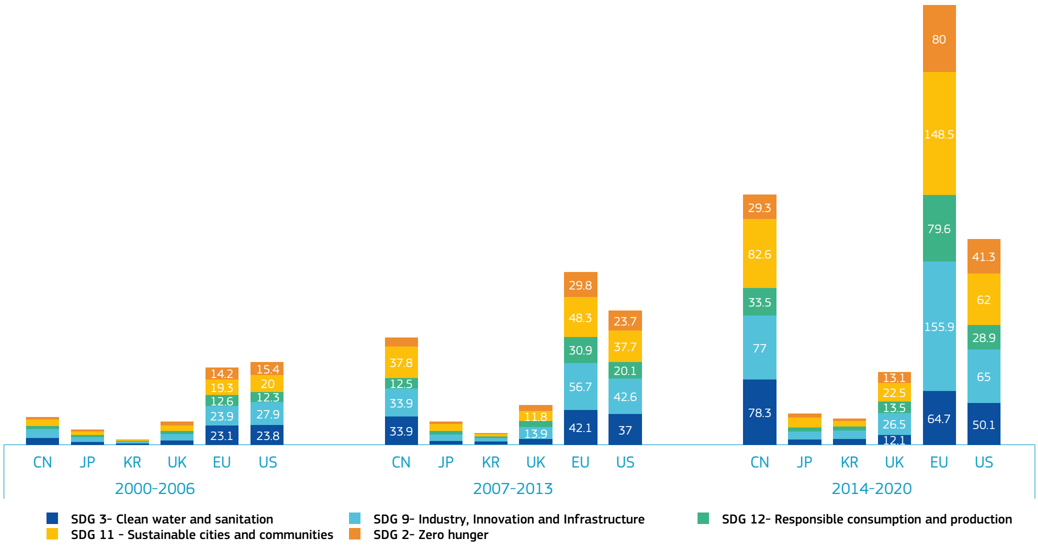
Pharmaceutical:

Replacing an enzyme to control a very rare disease | Research and Innovation (europa.eu)
Until recently, there was no treatment specific to alpha-mannosidosis, one of the many rare diseases that jointly affect some 30 million citizens in Europe alone. Today, there is as EU-funded research developed enzyme-replacement therapy to stop the illness in its tracks, and this medicine is on the market.

1.2 R&I is essential for adapting our territories, food, water systems, infrastructure, and our ways of producing and consuming

By providing us with real-time information and future scenarios, research can help us to foresee where and when populations could be affected by future shocks. Scientists, including the wide research community involved in the drafting of the IPCC reports, rely on the latest state-of-the art technologies and techniques such as remote sensing, imagery processes, soil evolution and water-streams mapping and modelling to understand and predict nature-related hazards, reduce error estimation in scenarios for the future and provide accurate evidence for policy development. The volume of publications on food, water, industry and infrastructure, including sustainable cities and communities, as well as on responsible consumption and production have significantly increased over the past two decades (Figure 3.12). From 2014 to 2020, Europe was a leader in publications related to sustainable cities and communities (1), responsible consumption and production (2), industry, innovation and infrastructure (3), with the EU share being respectively 43%, 40% and 41% of the global scientific output in these three fields. China has been catching up at a very high growth rate and has been in the lead in terms of number of publications related to clean water and sanitation in the 2014-2020 period and has overpassed the EU in terms of quality as well (Table 3-2).

Figure 3-12: Number of scientific publications (frac. count) in food, water systems, industry and infrastructure, sustainable cities and communities and responsible consumption and production



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using Scopus database.

Note: (1)The data labels are expressed in thousands of publications and the publications for each SDG are not mutually exclusive. Fractional counting used.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-12.xlsx

Table 3-2: Percentage of highly cited publications per SDG, per country/region, 2018

	CN	JP	KR	EU	UK	US
SDG 2 – Zero hunger	**13.6**	10.5	5.7	14.6	21.9	17.0
SDG 6 – Clean water and sanitation	**16.6**	9.0	13.0	12.5	15.4	13.0
SDG 9 – Industry, Innovation and Infrastructure	**16.1**	9.4	8.9	15.7	23.5	20.0
SDG 11 – Sustainable cities and communities	**13.4**	5.8	8.9	12.2	17.1	15.3
SDG 12 – Responsible consumption and production	**15.3**	7.2	8.8	13.6	20.7	15.0

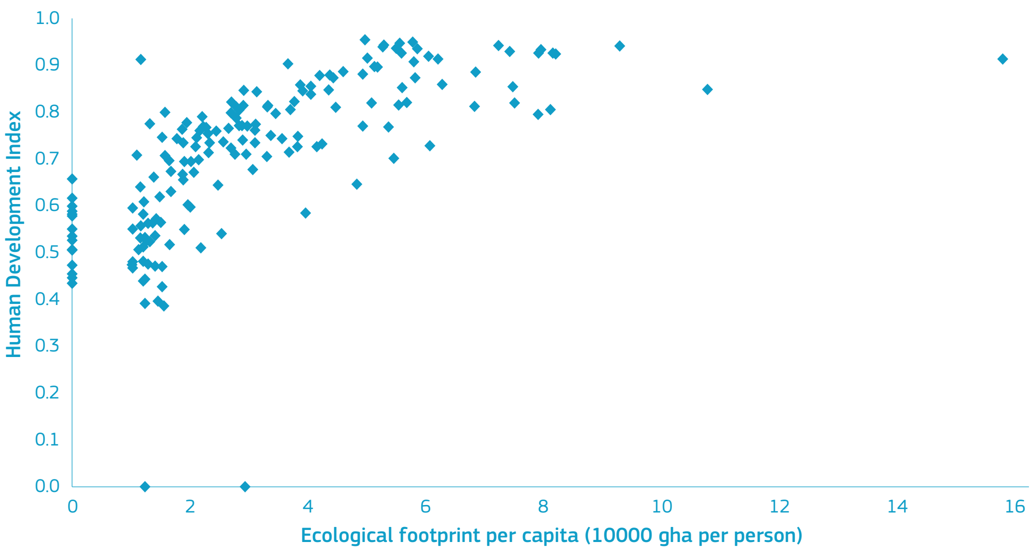
Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using Scopus database.

Research and innovation can help to avoid a trade-off between human development and ecological preservation through the development of innovative business models and sustainable and responsible ways of producing and consuming. In most countries there is increased pressure on the ecological resources and pollution rates due to urban expansion, unsustainable pathways of consumption and production, globalisation and population growth (Kassouri and Altıntaş. 2020). This leads to a clear correlation between human development and environmental footprint (Figure 3.13; UNDP, 2020), which may create a trade-off as both preserving our ecosystems and improving human well-being are at the centre of the SDG agenda. Technological progress can deliver solutions to this potential trade-off.

The circular economy, for example, proposes an innovative model in which materials are circulated in closed-loop production systems to reduce depletion and waste (Ellen MacArthur Foundation, 2012). In the EU, the circular material use rate went from 8.4 % in 2004 to 12.8 % in 2020, whereas the value-added and employment in recycling and secondary raw materials sectors, as defined by Eurostat, remained almost unchanged between 2011 and 2018 (0.97 % of GDP and 1.7 % of total employment) (Eurostat, 2021). Furthermore, some projects under the EU's R&I framework programme aim at increasing knowledge on lifestyles compatible with the respect for planetaries boundaries. For example the EU's 1.5 Lifestyles project connects an analysis of individual lifestyle perspectives with an investigation of structural influences on lifestyle choices and impacts. Transforming towards global sustainability requires a dramatic acceleration of current progress. Hence, **there is growing interest in finding positive tipping points at which small interventions can trigger self-reinforcing feedbacks**

Figure 3-13: Relation between the Human Development Index and ecological footprint (2017)

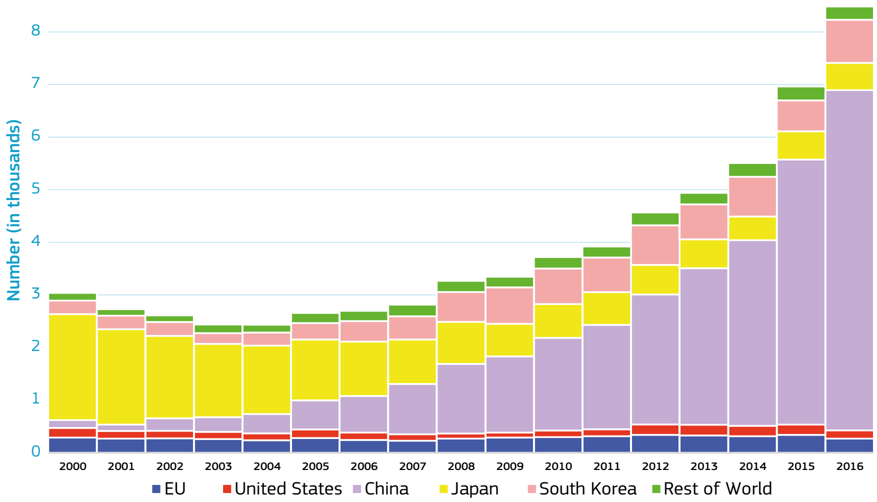


Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on World Bank and World Population review.
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-13.xlsx

that accelerate systemic change (Lenton et al., 2021). A better understanding of technical/social tipping points will be essential also to enable the transition to a sustainable and circular bioeconomy and a building block of a 1.5 Lifestyle.

The **EU's share of patents related to recycling and secondary raw materials is only 7.5 %, while China has become the leader in patented innovations in these sectors within less than 15 years, reaching a 74 % share in 2016** (Figure 3.14). The adoption and deployment of circular solutions are often associated with deep process transformation and long-term investments, which may need public support. Digital solutions are also essential for providing the information necessary for the introduction of circular solutions. They have enabled more potential for resource efficiency and productivity gains, such as smart grids to energy networks and automated manufacturing techniques (Stern and Valero, 2021). Digital solutions are also critical for raw materials supply security and resilient value chains. At the European level, the circular economy is being promoted and facilitated through the Circular **Economy Action Plan** (CEAP)[13], which was adopted by the European Commission in 2020 as one of the main building blocks of the European Green Deal and which introduces a set of legislative and non-legislative measures targeting areas where action at the EU level brings real added value.

Figure 3-14: **Evolution number of the patents related to recycling and secondary raw materials, 2000-2016**



Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation – Common R&I Strategy and Foresight Service – Chief Economist Unit based on Eurostat (CEI_CIE020).

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-14.xlsx

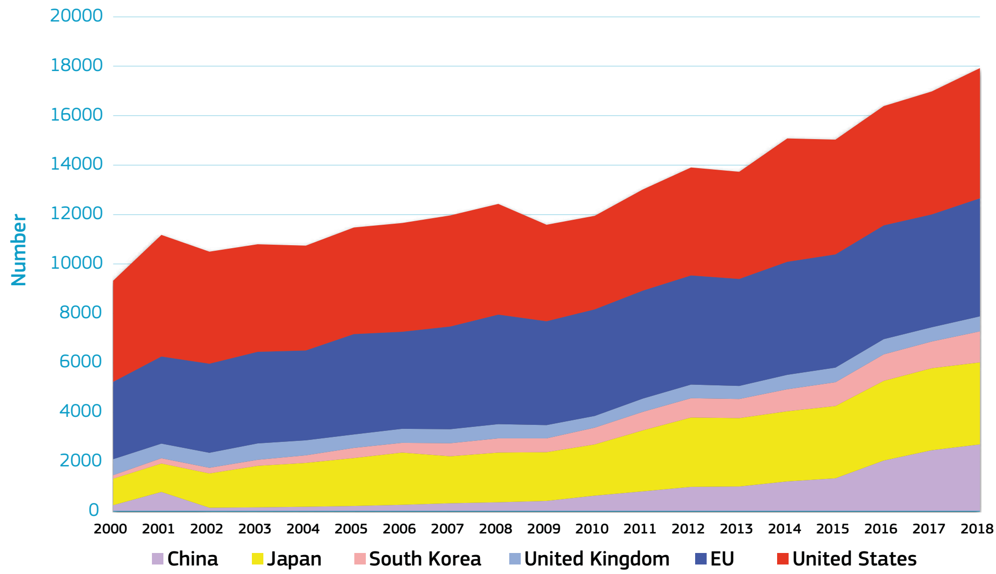
13 Circular economy action plan (europa.eu)

Despite the growing need for adaptation in our food and water systems, patenting activity in food security, sustainable agriculture, water and the bioeconomy has experienced lower growth rates over the past two decades compared to other areas. The overall volume of patents in food security, maritime and inland water and bioeconomy have increased from 2000 to 2018 (Figure 3.15). The increase in the EU and US happened at a much slower pace than for areas such as smart transport or climate action. China and Japan have multiplied their volume of patents in these areas by respectively per 10 times and 7.5 times between 2000 and 2018 (Figure 3.15). But in the UK, the volume has stagnated. Besides, the shares of patents dedicated to these areas have decreased in every major region. **Such declines may be linked with the stagnation of efforts towards adaptation**, which has been documented by a joint report from the World Bank and the International Bank for Reconstruction and Development (2020). These tendencies stand in contrast with the trends for climate change and clean energy technologies, whose shares in total innovation nearly doubled from 2000 to 2011 (Figure 3.9), but then experienced a decline until 2015. Considering the growing adaptation needs in our food and water systems, as well as the importance of the bioeconomy for the green transition, these tendencies raise concerns and justify more policy support.

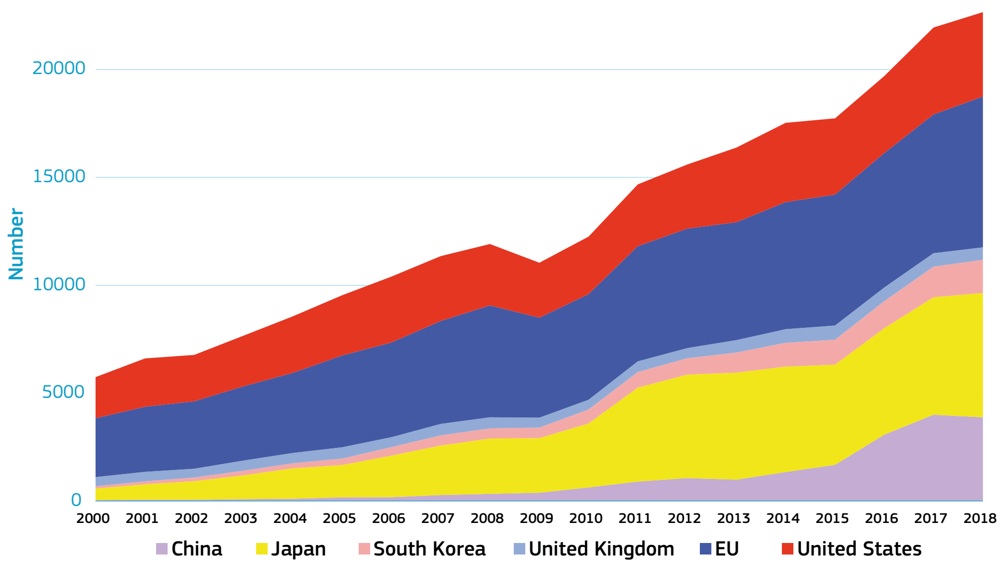
Patenting activity in **smart, green and integrated transport has experienced an increase in volume both worldwide and at country/regional level, even if the sector's share in the total number of patents has remained almost constant**. In these sectors, the deployment and adoption of innovative solutions should be a key focus. Horizon Europe integrated the need to transform our ways of consuming, and several projects, which will assess different lifestyle options, have already been launched. As an example, the EU-funded FULFILL project will explore the contribution of lifestyle changes and citizen engagement in decarbonising Europe and fulfilling the goals of the Paris Agreement.

Figure 3-15: Evolution in the number of patent applications[1] filed under PCT in sustainable agriculture and forestry, marine and inland water research, bioeconomy and transportation, 2000-2018

a) Food security, sustainable agriculture and forestry, marine, maritime and inland water research, and the bioeconomy



b) Smart, green and integrated transport



Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using EPO PATSTAT database.

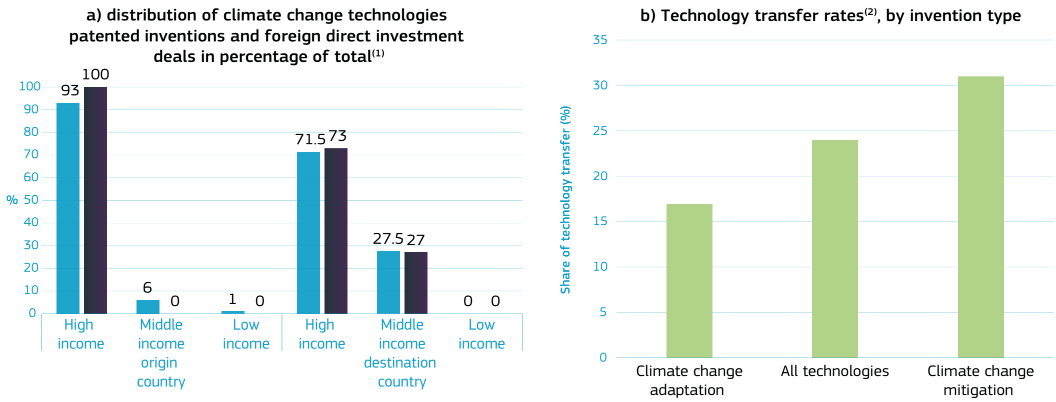
Note: [1]Fractional counting used. 2020 Societal Grand Challenge (SGC) considered over the total patents applications filed for all the SCGs.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-15.xlsx

Intermediaries and R&D organisations are critical in developing adaptation pathways fit to local specificities and for coping with the mismatch between territories' adaptation needs and technological capacity. Collaborations between industry, public institutions and R&D organisations are critical to get technical guidance and advice to adapt to the shocks to come (Huggel et al., 2015). Knowledge production needs to be done also at the local level. Besides, as value chains are now scattered worldwide, there is also a challenge to capture the international spillovers of EU consumption and production, and technology transfer is critical. Recent research has demonstrated a clear mismatch between adaptation needs, particularly those linked to climate change, and the technological capacities of countries, regions and communities (Dechezlepretre et al., 2020).

Only 17% of patented climate adaptation[14] inventions cross at least one border, which is significantly below the average for all technologies (24%) and about half that of mitigation

Figure 3-16: Technology transfer rate of adaptation technologies, cumulated volume 2010-2015



Science, Research and Innovation Performance of the EU 2022

Source: Dechezlepretre at al. Invention and Global Diffusion of technologies for climate change adaptation: a patent analysis. 2020 International Bank for Reconstruction and Development / The World Bank based on Zephyr database (Bureau Van Dijk, Brussels) and World Patent Statistical Database (PATSTAT) (European Patent Office).

Note: (1)The figure display the percentages of patents filed in both an origin country and at least one destination country and the FDI consider 243 deals in total. (2)The technology transfer rate is defined as the share of patented inventions that are filed in at least two different patent offices.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-16.xlsx

14 Defined using the Y02A category of the European Patent Office which identifies all patents in PATSTAT pertaining to 'technologies for adaptation to climate change'.

technologies (31 %) (Figure 3.16). Besides, **while 93 % of patented inventions in the field of climate adaptation originated from high income countries**, only 27.5 % of patents are filed in middle-income countries and none in low-income countries (data refer to the 2010-2015 period).

A similar distribution is observed for foreign direct investment related to climate adaptation: 100 % originates from high income countries, 27 % involve a middle-income country and none involves a low-income country (Figure 3.16; Dechezlepretre et al., 2020).

Finally, by matching technological capacities and risks as raised in the latest IPCC reports, it appears **that countries with strong technological capacities typically face lower adaptation needs, and reversely countries where adaptation needs are high are less equipped.**

Universities and research centres could play a critical role in supporting the diffusion of solutions for adapting our systems. Public policies can support collaboration and partnerships between research centres, industry and public authorities. Such an approach has been integrated in Horizon Europe's strategic planning, which features both European Partnerships and Missions (see Part 3 of this chapter). Furthermore, universities should be supported in their independence and ability to experiment with new models of education and societal interaction, in order to foster both technological innovation and innovative policy ideas to emerge and be taken up[15]. **The European Commission also adopted its new EU strategy on adaptation to climate change in 202**1. It sets out how the European Union can adapt to the unavoidable impacts of climate change and become climate resilient by 2050. The strategy has four principle objectives: to make adaptation smarter, swifter and more systemic, and to step up international action on adaptation to climate change.

15 https://ec.europa.eu/info/publications/transformation-post-covid-future-european-universities_en

Box 3-3: The contribution of the European framework programme for R&I to the knowledge base of recent IPPC reports[16]

To analyse the contribution of EU funding to the IPCC's evidence base, the paper uses the references of published IPCC reports, cross-checking them with databases containing publications originating from EU-funded research.

This analysis focuses on the reports of the IPCC's 6th assessment cycle and processes the references of the reports published so far: three special reports (*Global Warming at 1.5 °C, published in October 2018, Climate Change and Land from August 2019 and Ocean and Cryosphere in Changing Climate*, published in September 2019) and the contribution of Working Group I to the Sixth Assessment Report (*AR6 Climate Change 2021: The Physical Science Basis*, published in draft form in August 2021). For publications from EU-funded projects, a dataset combining, on the one hand, publications reported by grant holders as contained in the EU open data portal and, on the other hand, publications indexed in the OpenAire Research Graph[17]. Only data from the last two funding programmes: the 7th Framework Programme (FP7, 2007-2012) and Horizon 2020 (H2020, 2013-2020) are used.

Matching yielded over 2 500 unique publications to which FP7 or H2020 has contributed (Figure 3.17). Both the full set of references from IPCC reports and the subset which is linked to EU framework programme funding were matched to Microsoft Academic Graph (MAG). Overall, 87 % of all unique DOIs could be matched to MAG (and 99 % for those with EU funding). We further matched the publications to the country of affiliation of the authors. As a result, we got over 21 000 publications with a country affiliation (80 % of all records with DOIs and 92 % of records matched in MAG). This is the subset which will be used for most of this analysis. It includes over 2 400 publications linked to FP7 or H2020 funding (from over 640 projects).

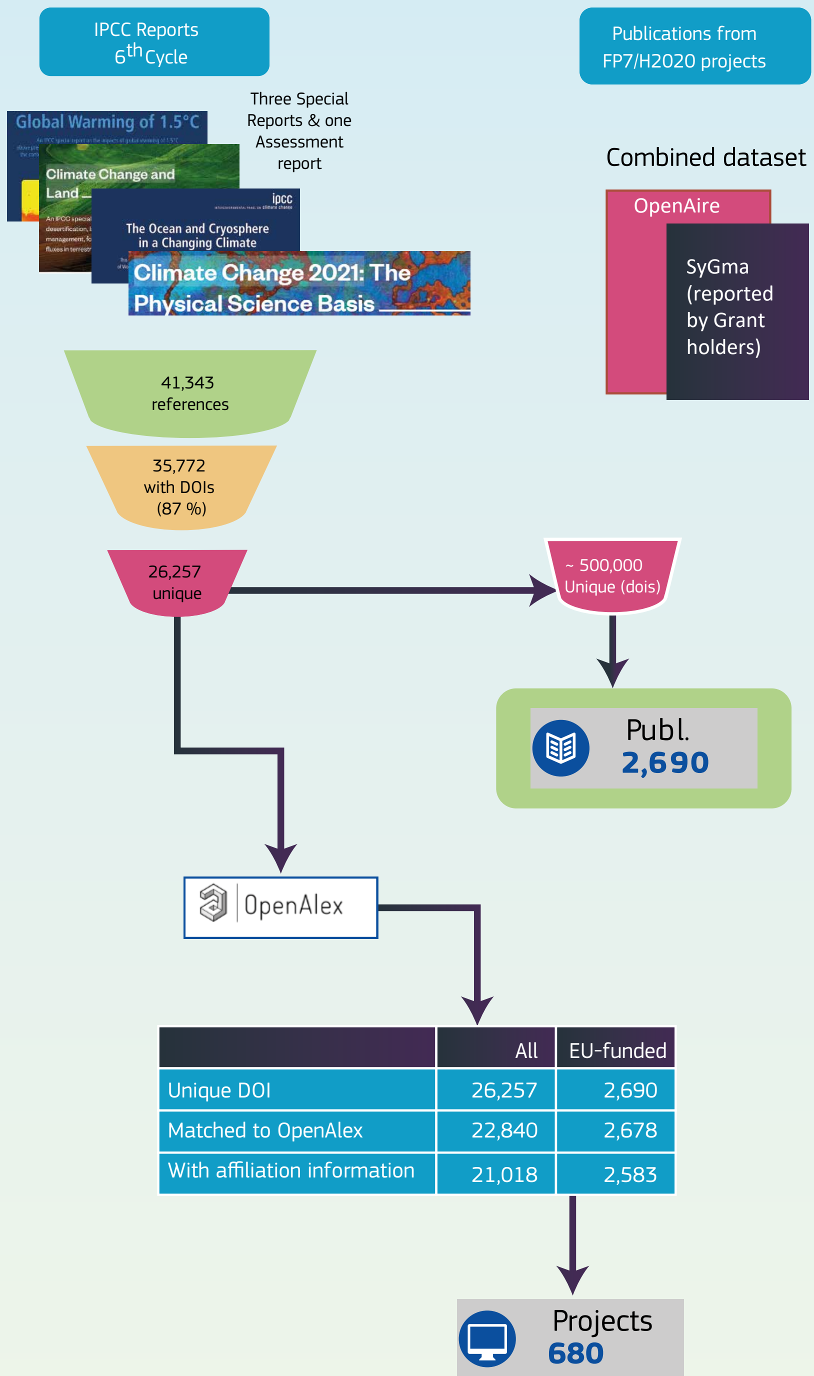
The data shows that the weight of EU-funded results in IPCC references is fairly constant across all the reports – deviating slightly from the means for all reports of 11.5 % and 21.4 % (for all references and for references from framework programme countries, respectively). We notice, however, the higher share of EU-funded research in the references of the most recent Working Group I[18] contribution to AR6. They make up 14 % of all references and a quarter of all references from framework programme countries.

16 Source: Mugabushaka A.M., Rakonczay Z. The contribution of the European Framework Programme for R&I to IPPC reports. Working paper 2022/03. R&I paper series.

17 OpenAIRE Research Graph is an open resource that aggregates a collection of research data properties (metadata, links). OpenAIRE - Research Graph

18 The IPCC Working Group I (WGI) examines the physical science underpinning past, present, and future climate change.

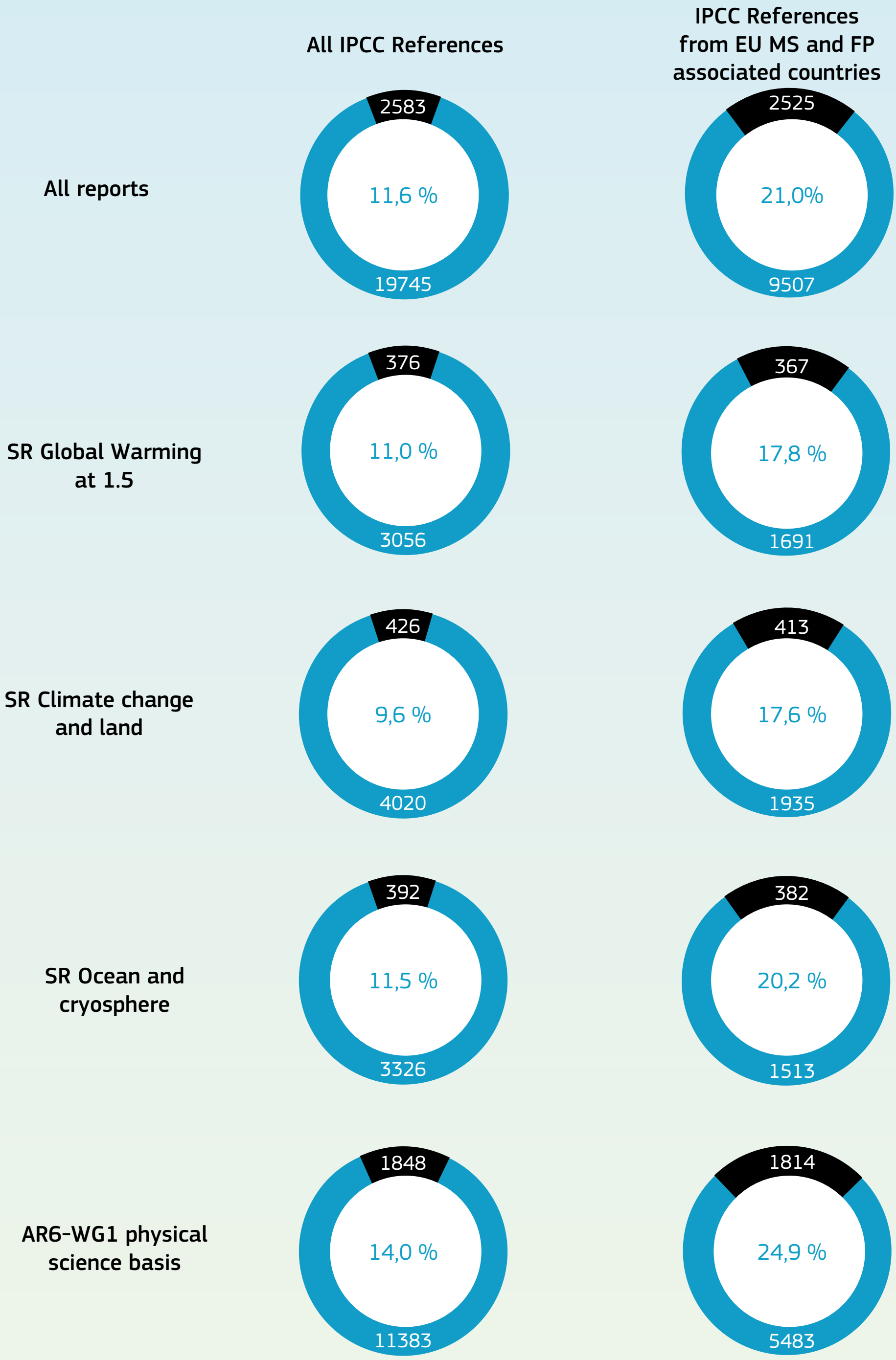
Figure 3-17: Linking IPCC publications to EU-funded projects and publications



	All	EU-funded
Unique DOI	26,257	2,690
Matched to OpenAlex	22,840	2,678
With affiliation information	21,018	2,583

Source: Authors' elaboration.
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-17.xlsx

Figure 3-18: Evolution of the number of patents related to recycling and secondary raw materials, 2000-2016

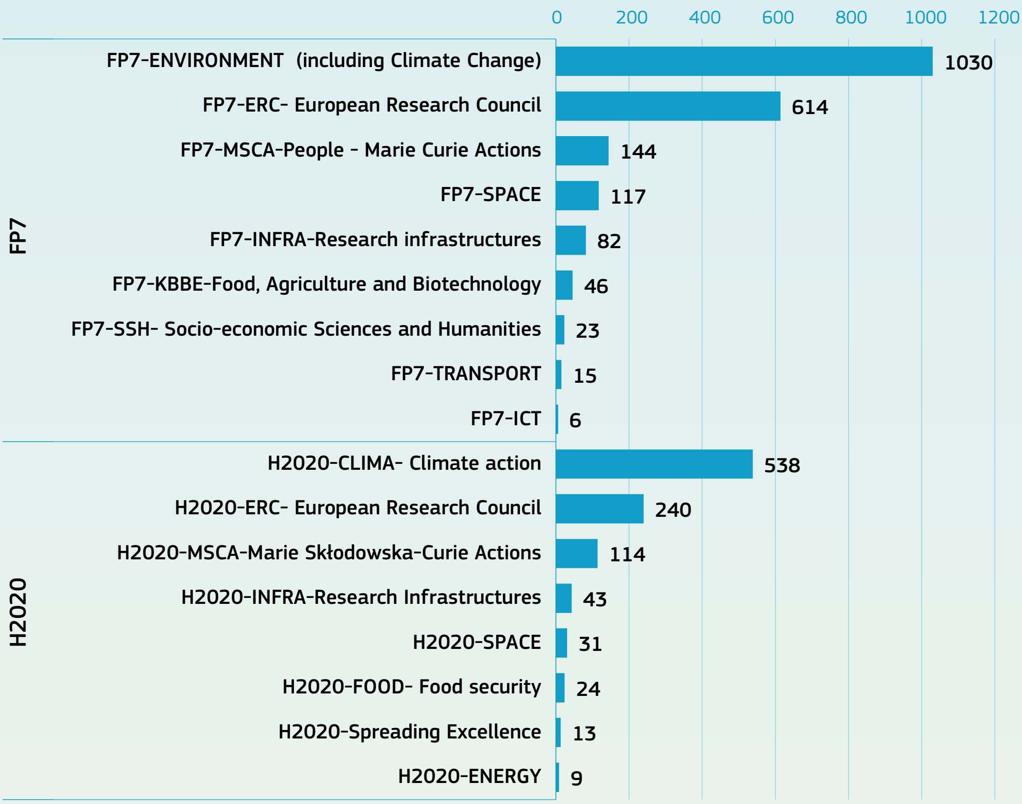


Source: Authors' elaboration.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-18.xlsx

The sub-programme with the highest number of publications referenced in IPCC reports is environment (FP7-ENVIRONMENT), both in FP7 (over 1000 publications) and in H2020 (over 300 publications). It is followed by the European Research Council (ERC) with about 600 and 200 publications for FP7 and H2020 respectively. Other sub-programmes with a high number of publications are Marie Skłodowska-Curie Actions (PEOPLE/MSCA), Space (SPA, LEIT-SPACE), and Infrastructure (INFRA).

Figure 3-19: Publications referenced in IPCC reports by FP sub-programmes

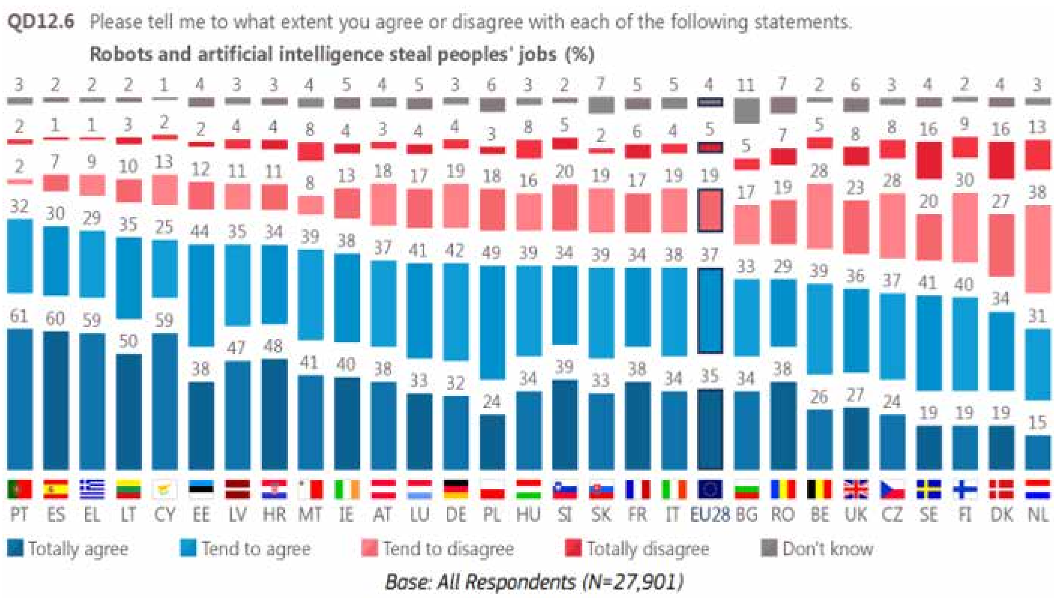


Source: Authors' elaboration.
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-19.xlsx

1.3 R&I driving the path from inequalities to inclusiveness?

The disruptive nature of technological change can generate challenges in terms of increased inequality through wage and income disparities, regional disparities, and 'winner takes most' markets and industries. These can seriously affect people's support for democracy (Milner, 2021). There is evidence from the EU and the US about innovation potentially leading to inequality, especially in terms of wages and earnings (Breau et al., 2014; Florida and Mellander, 2016; Lee and Rodriguez-Pose, 2013, 2016). While digitalisation has been accelerating over the past decades, aggregate productivity growth has been slowing down (also known as the productivity paradox) and income inequalities have been increasing. Technological change can affect inequalities through several channels (OECD, 2018). The persistent digital divide in Europe (See Chapter 5.3 – Investments in ICT and digital) limits the potential for less-skilled people, less-digitalised firms and less-connected regions to benefit from this change. At the same time, new technologies affect labour markets, can displace labour and create an upgrading in skills requirements (See Chapter 4.3 – Skills in the digital age) (Bessen, 2015; Ford, 2015; World Economic Forum, 2016). There are also 'winner takes most' dynamics due to the nature of technological change, with firms in sectors characterised by network externalities benefiting from first-mover advantages, strong economies of scale and network effects, which has culminated in the rise of superstar firms (Autor, Dorn et al., 2020).

Figure 3-20: Eurobarometer on the impact of robotisation and artificial intelligence on jobs (2017)



Source: Eurobarometer (2017).
Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-20.xlsx

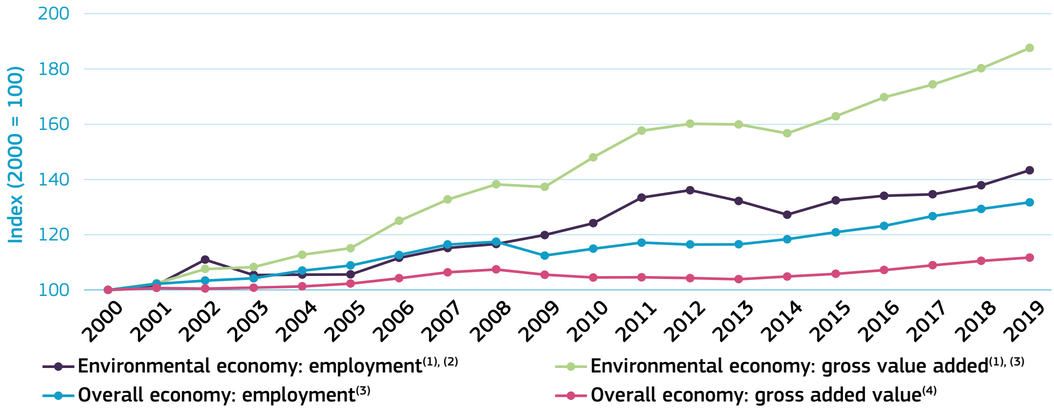
While the consequences of technological progress in the labour market are a concern for Europeans, there are reasons to expect positive developments, as national industries with a higher adoption of robots tend to be more resilient in terms of employment than the rest. Technological change features a creative destruction process, implying that new jobs are created and old ones are destroyed, which can lead to anxiety among workers. Some 72% of respondents to a Eurobarometer survey (Eurobarometer, 2017) agreed with the statement 'robots and artificial intelligence steal peoples' jobs'. With not all jobs being equally exposed to automation, these perceptions can also create concerns in terms of income inequality and social cohesion. It also appears that new technologies have been the main factor explaining the decline in labour's share of national income and increasing inequality, as that income has instead gone to the owners of capital (IMF, 2017; EEA, 2019). However, the history of automation and technological change is not only about the displacement of human labour by automation technologies.

New technologies counterbalance these displacement effects by creating new tasks in which labour has a comparative advantage, reinstating labour into a broader range of tasks and changing the task content of production in favour of labour (Acemoglu and Restrepo, 2018). Recent evidence for Europe also shows that national industries with a higher robot adoption tend to be more resilient in terms of employment than the rest (Klenert et al, 2020).

The transition towards a climate-neutral and environmentally sustainably economy is also expected to significantly impact Europe's labour markets (ESDE 2019). Technical progress and the intended transitions can lead to people losing their jobs in some industries, with heavy social consequences. Policies that aim at achieving a less polluting and more resource efficient economy can be expected to create structural changes in the nature of demand and production processes, affecting businesses and regions, and creating and destroying jobs in different sectors of the economy (OECD, 2017). Hence, making the transition just requires support to affected sectors, adapted labour policies and the right educational frameworks to close occupation shortages and skill gaps (European Commission, 2020). As a tool to ensure that the green transition happens in a fair way, the Just Transition Mechanism provides targeted support to help mobilise around EUR 55 billion over 2021-2027 in the most affected regions to alleviate the socio-economic impact of the transition. Solutions such as those developed by BioeconomyRevier[19] will provide insights to be replicated in other regions throughout Europe.

19 https://www.biooekonomierevier.de/

Figure 3-21: Evolution of employment and gross value added of the EU environmental economy, 2000-2019



Science, Research and Innovation Performance of the EU 2022

Source: Eurostat (online data codes: env_ac_egss1, env_ac_egss2, nama_10_gdp and nama_10_a10_e)

Note: The environmental economy encompasses activities and products that serve either of two purposes: environmental protection – that is, preventing, reducing and eliminating pollution or any other degradation of the environment, or resource management – that is, preserving natural resources and safeguarding them against depletion. (1) Eurostat estimates. (2) In full-time equivalents. (3) Million euro, chain-linked volumes, reference year 2010 (at 2010 exchange rates). (4) Thousands of persons.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-21.xlsx

Net-zero-aligned and circular economy investments can generate jobs quickly and encourage entrepreneurial activity (Unsworth *et al.*, 2020) as they can lead to activities that are both labour-intensive and quick to implement (examples include retrofitting buildings, intensifying broadband and restoring degraded land). While the environmental economy[20] is rather small in Europe (2.2 % of GDP), it has grown rapidly since 2000, outperforming the overall economy (Figure 3.21): the value added and employment of the green economy increased respectively by 80 % and 40 % between 2000 and 2018.

The number of green jobs[21] in the EU was 4.4 million in 2018. The largest increase in green jobs over 2000-2018 was in the domain of renewables and energy-efficiency, with a million full-time equivalent jobs created over the period (from 0.6 to 1.6 million). The second largest contribution to the increase in environmental employment came from waste management from 0.8 to 1.2 million). By contrast, employment related to wastewater management decreased from 0.7 million to 0.5 million over the same period.

20 Encompasses activities and products that serve either of two purposes: environmental protection – that is, preventing, reducing and eliminating pollution or any other degradation of the environment, or resource management – that is, preserving natural resources and safeguarding them against depletion.

21 Jobs in the environmental economy sector, which encompasses activities and products that serve either of two purposes: environmental protection – that is, preventing, reducing and eliminating pollution or any other degradation of the environment, or resource management – that is, preserving natural resources and safeguarding them against depletion.

Figure 3-22: Number of scientific publications[1] in socially-related SDGs (poverty, health and well-being, education, gender, decent work, inequality, peace, justice) – SDGs 1, 3, 4, 5, 8, 10, 16

Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using Scopus database.

Note: [1] The data labels are expressed in thousands of publications and the publications for each SDG are not mutually exclusive. Fractional counting used.

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-22.xlsx

At the same time, R&I is also a crucial factor in supporting the just transition and the social dimension of sustainable development in general. R&I is needed to increase our knowledge about current developments in European societies, and to develop solutions for the future as a means of supporting and improving governance systems, modernising public authorities, reducing inequalities and promoting social justice. Increased R&I activity also goes hand in hand with upskilling and reskilling, and more widely with investments in education, in order to contribute best to a just transition. R&I is an integral part of the EU's response to well-being-related challenges such as an ageing population and healthcare systems under pressure. While the US is a global leader in scientific publications on socially-related SDGs (Figure 3.22), the EU still shows a strong performance in this area, as well as registering steady growth since 2000.

The R&I agenda is becoming more human-centric. As the Lamy report (2015) pointed out, EU innovation policy must be based on a definition of innovation that acknowledges and values all forms of new knowledge – technological, but also business models, financing, governance, regulatory and social – which help generate value for the economy and society and drive systemic transformation. Such considerations are also in line with unleashing the values and potential of the Industry 5.0 agenda, which is characterised

Table 3-3: Percentage of highly cited publications per SDG, by country/region, 2018

	CN	JP	KR	EU	UK	US
SDG 1 – No poverty	12.2	3.9	5.7	9.8	18.6	14.0
SDG 3 – Good health and well-being	13.0	6.9	9.5	11.5	16.0	15.7
SDG 4 – Quality education	10.2	4.2	5.1	10.3	14.8	11.8
SDG 5 – Gender equality	9.3	7.2	4.9	10.0	14.6	13.3
SDG 8 – Decent work and economic growth	16.3	6.4	7.2	12.9	19.9	16.2
SDG 17 – Peace, justice and strong institutions	11.8	3.7	6.4	10.8	13.9	13.2
SDG 10 – Reduced inequalities	12.1	7.1	7.2	9.8	17.4	14.1

Science, Research and Innovation Performance of the EU 2022

Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Science-Metrix using Scopus database.

by a shift of focus from technology-driven progress to a thoroughly human-centric approach (Breque et al., 2021).

New technologies and market-based solutions may not be sufficient in remedying major challenges like climate change, biodiversity loss or growing inequalities (IPCC et al., 2021; UNEP, 2021; EEA, 2021). Emerging technologies, nature-based solutions (EEA, 2021), social innovations and broader shifts in cultural repertoires are highlighted as essential parts of transformative change towards sustainable futures (Folke et al., 2021).

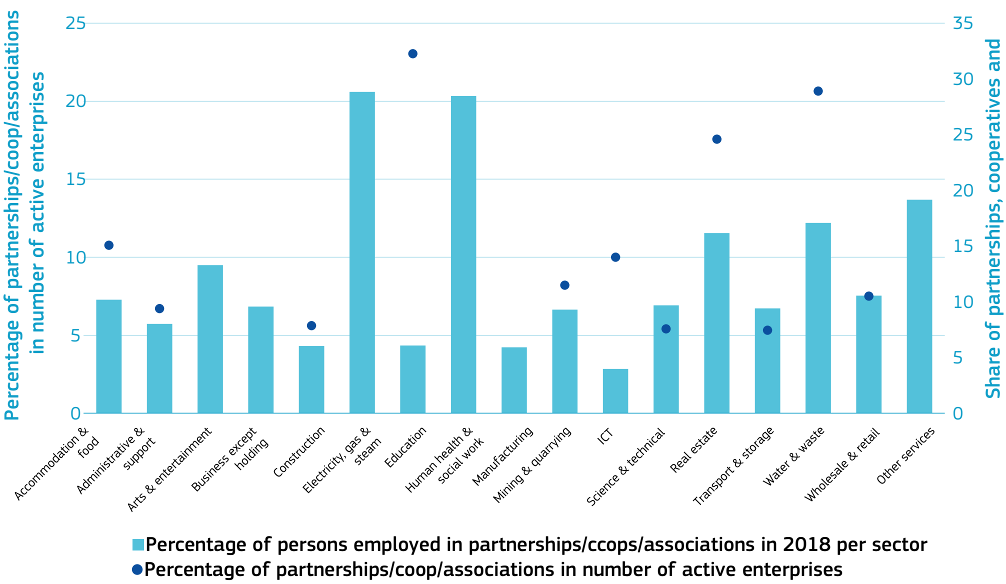
Social innovation has appeared as a successful approach for deep transformation of our systems and practices (EEA, 2021). According to the OECD (2015), social innovation refers to the design and implementation of new solutions that imply conceptual, process, product, or organisational change, which ultimately aim to improve the welfare and wellbeing of individuals and communities. It has the potential to offer novel approaches to contemporary crises that differ from traditional technology-based solutions (Haskell and al., 2021), and would then be complementary to these in achieving the SDGs. Stakeholder engagement, citizen participation, citizen empowerment and cross-sectoral collaboration are key aspects of social innovation (Chatfield and Reddick, 2016). This human dimension is indeed seen as fundamental for transforming our society and for facilitating the design, adoption and diffusion of socially-responsible innovative solutions.

Social economy enterprises, partnerships, cooperatives, public-owned enterprises and associations have proven to be innovative in dealing with socio-economic and environmental problems, while contributing to eco-

nomic development (OECD, 2015) and are often cited as key players for social innovation (European Commission, 2020). There are more than 1.9 million active partnerships, cooperatives and associations across the EU, employing more than 34.8 million persons, about 10.5% of the total workforce in 2018 (Figure 3.23). These actors operate in all sectors of the economy. They are particularly active in education, health care and social work activities and employ 28% of the persons working in those sectors. The European Commission has identified that 3.1 million firms in Europe, composed by 99.9% of SMEs, operate within the proximity, social economy and civil security ecosystem. This ecosystem employs 22.9 million persons across the EU and represents 6.54% of EU value-added (EUR791 billion). As they listen to the motivations and requests of local actors, social economy organisations can indeed act as a catalyst for social creativity by developing innovative services and business models (Social Economy Europe, 2015). At the European level, the European Pillar of Social Rights supports the development of such entities and several funding instruments at the EU level have been designed to target employment, social inclusion, social innovation and training. These include ESIF+ and ERDF e.g. urban innovative actions (URBACT) targeting housing and social infrastructure.

Financial resources are assumed to be critical in the start-up and scaling of social innovation, and often rely on diverse funding sources (Haskell et al., 2017). The lack of funds was described as a constraint for social innovation's long-term success (McCarthy et al., 2014), but more generally for

Figure 3-23: Share of partnerships, cooperatives and associations in the EU, 2018



Source: DG Research and Innovation - Common R&I Strategy and Foresight Service - Chief Economist Unit based on Eurostat (online data code: BD_9AC_L_FORM_R2).

Note: [1]Data on employees in Greece and Austria are provisional, data on the Netherlands, Portugal, Malta, Poland is not available across all sectors, so aggregates have been computed without these.

Data on number of active enterprises are not available in a few sectors (not showcased) – Arts, Education, ICT, Other service acts, human health & social works - //ec.europa.eu/eurostat/web/products-datasets/-/bd_9ac_l_form_r2

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-23.xlsx

sustainable innovation. **At the EU level, the InvestEU Social Window will reduce the risk of investments and improve the institutional capacity of financial intermediaries with the objective to improve access to finance to social stakeholders via a guarantee and an equity instrument**. The Council of Europe Development Bank also issued a EUR 500 million 7-year Social Inclusion Bond in April 2021 (CEB, 2021). The New European Bauhaus, launched in 2020, also has a great potential to accelerate social innovation by creating communities, fora and platforms to discuss, exchange and establish synergies for driving our society towards more resilience and inclusiveness. Finally, through its co-creation process, **Horizon Europe supports directly both collaboration on innovative activities and social innovation**, such as for example the EU-funded PROSPERA project, which will explore new narratives for innovation that would accordingly change and increase the scope of the innovation concept itself in cultural and institutional transformation, and subsequently in social life and social order.

Box 3-4: Does innovation support for the green transition require new action types?

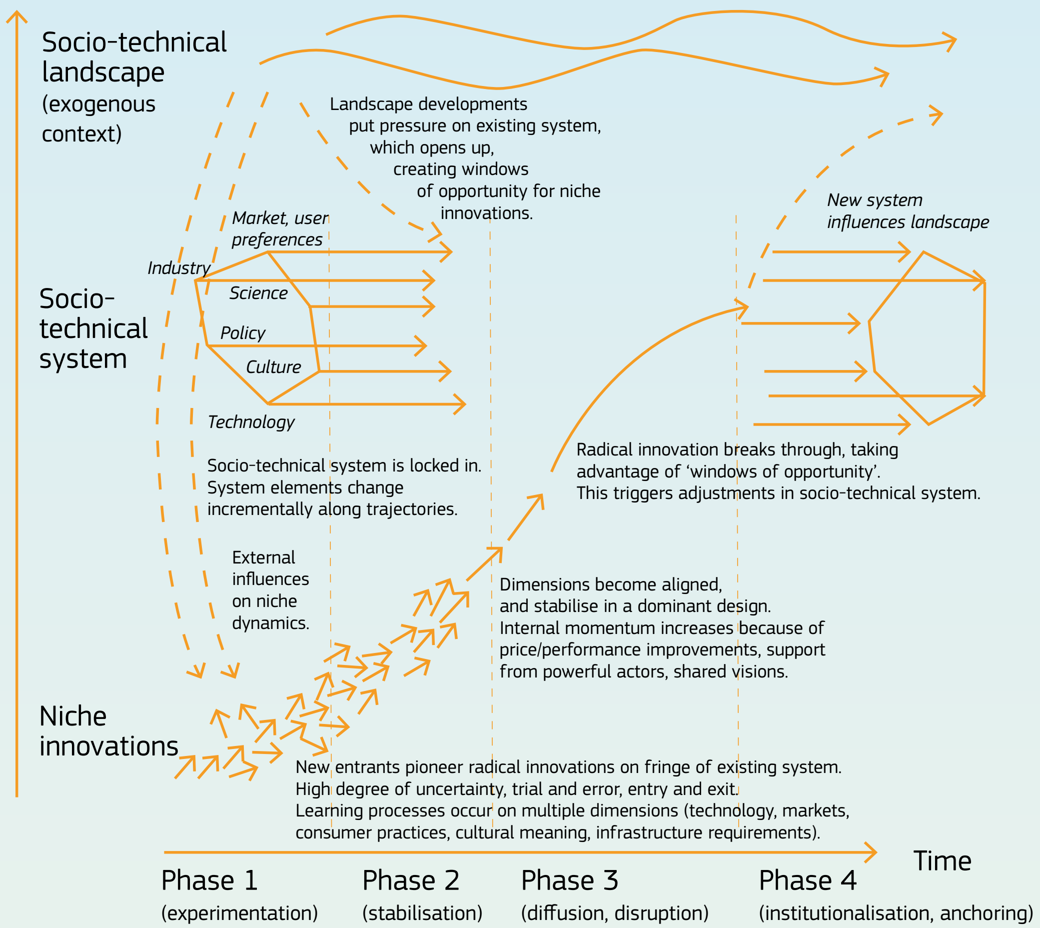
In the SRIP2020[22], Frank Geels described "transformative innovation and socio-technical transitions to address grand challenges". In this more recent framing of innovation policy, the policy rationale is no longer correcting market failures or strengthening interaction between stakeholders, but "*promoting system transformation, which incumbent actors are slow or reluctant to do.*" The key features of the approach are "*nurturing radical innovation and new pathways & shaping the directionality of innovation*".

Large parts of the green transition are not happening in traditional product markets but in public services (i.e. services provided by of entities owned by municipalities, regions or the nation state or by commercial service providers contracted or licensed by authorities); or the transition affects the public good (infrastructure, ecosystems and ecosystem services). This engages quite different stakeholders in innovation processes than for habitual product or service innovation in B2B or B2C markets.

Geels (2020) recognises that a multi-level perspective in socio-cultural transitions should engage different stakeholder networks in different stages of the transition process and (implicit) at different geographic scales. The dimensions of locational and local stakeholder networks are discussed in the regional section (See Chapter 2.2 – Zoom in). Further, the question arises if innovation policy and innovation support for system's transformation requires additions to its policy toolbox. Notably, if the scaling of innovative solutions doesn't happen in traditional B2B or B2C markets but realises in an enlarging physical space and geographic scale.

22 https://ec.europa.eu/info/sites/default/files/srip/2020/rec-19-003_srip_chap-9.pdf

Figure 3-24: Multi-level perspective on socio-technical transitions



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Source: Substantially adapted from Geels, 2002: 1263

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-24.xlsx

Niche creation and 'experimentation' with new approaches will happen locally supported of local authorities that see opportunities. The 'stabilisation' of an innovation will also happen on local scale if the novelty has proven added value and no strong voice speaks against it. Latest in the diffusion and disruption phase that happens in a larger physical space an arising dominant design encounters resistance from incumbent stakeholders. This will delay institutionalisation of the innovation. This happens in B2B and B2C markets as much as in public services. But the administrations' regulatory power is much stronger related to public goods and services as they act not only as contractor ('procurement of innovation') but often as service provider through own economic activities and / or local regulator through by-laws.

In order to foster product and service innovation on established markets, public support should not be provided beyond 'technology readiness level 8' (TRL8), as support at a later stage would distort the market, which would not be in the public interest. But, does this argument of supremacy of non-distorted markets over aspect of public interest still apply if innovation policy asked to provide directionality to future development? Miedzinski et al. (2019)[23] describe this phenomenon as 'tilting the playing field', which aims to create 'targeted demand'.

Research in transitions and their governance goes a step further and emphasises the need for '*innovation arenas*' in niche and transition management (Köhler et al, 2019)[24]. These engage in "*bringing together actors from science, policy, civil society and businesses and develop cooperative rather than competitive relationships between them*".

Innovation policy framed in this way would require a portfolio of action types much broader than what is needed for "*bringing research results to the market*". An innovation arena could include for example a negotiation to abandon technologies, tilt markets accordingly or it could link innovation policy much closer to legislative activities.

In practice first steps in this direction are happening: '*Regulatory testbeds*' and '*innovation deals*' are policy instruments which can be launched at European level in specific contexts. However, they have not yet been translated into project types for the research and innovation framework programme or used in the context of Horizon missions. They could contribute to innovation in the governance of transition processes be creating 'legislative experimentation grounds' and create the above mentioned 'innovation arenas'.

In the context of Horizon Europe internal guidance to topic drafters has been developed on phrasing expectations with respect to 'societal readiness'. The guidance does not follow the same logic as 'technological readiness levels' with respect to market introduction of technologies, but 'societal readiness' shall trigger a reflexion on the phasing of a topic during a socio-technological transition process and on the societal issues at stake during this phase.

'Regulatory testbeds', 'innovation deals' and 'societal readiness' are three novelties that could develop into new action types for Research and innovation support in a green transition as they can engage diverse stakeholders across the physical space from European down to local.

23 Microsoft Word - SDG policy roadmapping framework (final draft 19 June).docx (ucl.ac.uk)

24 Köhler et al, 2019 - An agenda for sustainability transitions research: State of the art and future directions

2. A systemic approach for transformative R&I policies

2.1 Policy context

The adoption of the Sustainable Development Agenda, its 17 SDGs and 169 targets (UN, 2015) **has emphasised the necessity to include social justice and human welfare implications in systemic transformation**. The problems we face today are complex and interconnected, thus requiring solutions from multiple perspectives. Therefore, R&I policies are increasingly expected to provide novel instruments and solutions to interrelated but, often times, conflicting goals (Kanger et al., 2020), implicating different policy domains and levels of governance (regional, national, and European). **Under these circumstances, innovation experts and scholars have put forward a strong claim for policymakers to provide the *directionality* of change**. Namely, policymakers have been strongly encouraged to put forward a harmonised package of policy and regulatory measures tailored specifically to stimulate innovation and focus on well-defined objectives, as well to promote responsible research and innovation (RRI) and adaptive governance (EEA, 2019) to tackle specific societal challenges in a defined timeframe.

R&I policies follow several objectives, such as the twin transitions, which can be compatible or even mutually reinforcing. However, this is not automatic. Evidence at the regional level shows that the digital and green technological transitions are not always mutually compatible in decreasing GHG emissions.

The overall impact of digital technologies is beneficial only for regions above a certain endowment/strength of environmental technologies (Bianchini et al., 2020). There is also evidence of digitalisation being a driver for energy consumption, as it is the case with data hubs) and critical raw materials extraction (EEA, 2019). Besides, **while many sustainability driven technologies promise positive outcomes, technological innovations may have unintended consequences when scaled up to the system level** (e.g. indirect land use change, loss of biodiversity and increased competition for land resulting from bioenergy production or from the use of biomass for contributing to climate mitigation through sustainable bio-based products) (EEA, 2019). The EEA's reports (2001, 2013) give examples of innovations' negative side effects. For example, biofuels during the 1990s and 2000s created competition with food production for land and resulted in land-use change, affecting ecosystems and biodiversity, for example through deforestation or the widespread uptake of bisphenol a with endocrine-disrupting properties without understanding its health implications. Green/climate policies and industrial transition policies need to be coordinated and tailored to specific conditions, including across countries.

The 2021-2027 EU R&I framework programme, **Horizon Europe**, has taken some further steps towards achieving the Green Deal. It **will support research and innovation activities that fully respect climate and environmental standards and priorities of the EU and cause no significant harm to any of them**.

The adoption of the EU's Sustainable Finance Taxonomy Regulation 2020/852 creates a common science-based classification system defining which economic activities can be considered as environmentally sustainable. Research and innovation activities' compliance with the '**do no significant harm**' **(DNSH) principle**[25] will ensure consistency with the European Green Deal objectives and promote the transition to a safe, climate-neutral, climate-resilient, more resource-efficient and circular economy. At the programming stage, work programme preparation guidance and topic screening has been introduced to ensure that the Horizon Europe Work Programme aligns with the European Green Deal's objectives and the DNSH principle. Additionally, while DNSH consideration remains voluntary at the project level, references to the DNSH principle in the work programme and the grant application forms aims to raise researchers' awareness about the environmental risks linked to their research. It is intended as an encouragement for them to design their projects in a way that does not significantly harm environmental objectives and to identify and mitigate potential environmental harms from the outset.

Horizon Europe also includes a new impact-oriented framework programme strengthening evidence informed R&I policymaking. The new data-driven analytical and monitoring systems aims to go beyond tracking input and outputs towards measuring impact, with the introduction of **Key Impact Pathways** to provide deeper analytical insights for medium- and long-term impacts, in addition to the dissemination and exploitation tools (CORDIS[26] and the Horizon Results Platform[27]).

Similarly, the evaluation of the framework programme is being conducted in a holistic approach which does not focus on single instruments or sub-parts of the programmes but looks at the impacts in different thematic areas across the whole framework programme, areas based on Horizon 2020 and Horizon Europe's strategic objectives. Among other dimensions, the analysis will look into the degree to which the framework programme has contributed to a resilient and innovative Europe and the **green, digital and industrial transitions**, using for instance relevant data from technology roadmaps and other efforts in this field.

In the light of these developments, how to determine the right policy mix to induce a deep transformation of our society? The **SRIP report 2020** pointed out that sustainability transitions are directed towards solving specific problems and meeting specific goals. Therefore, **a truly transformative R&I policy is about directionality**. Recent debates about mission-oriented innovation policy emphasise the importance of inspiring visions which provide long-term directionality. Challenging, yet doable, missions with more specific targets (which enable accountability) are accompanied by financial instruments to enable concrete action (Mazzucato, 2018) (SRIP, 2020: 578). EU Missions under Horizon Europe aim to give direction to the EU's R&I policy and support the European Commission's priorities, e.g. the EU Green Deal, by providing concrete and cross-cutting solutions to the most pressing challenges, such as health and climate change.

25 As defined in Articles 17 of Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088

26 CORDIS | European Commission (europa.eu)

27 Funding & tenders (europa.eu)

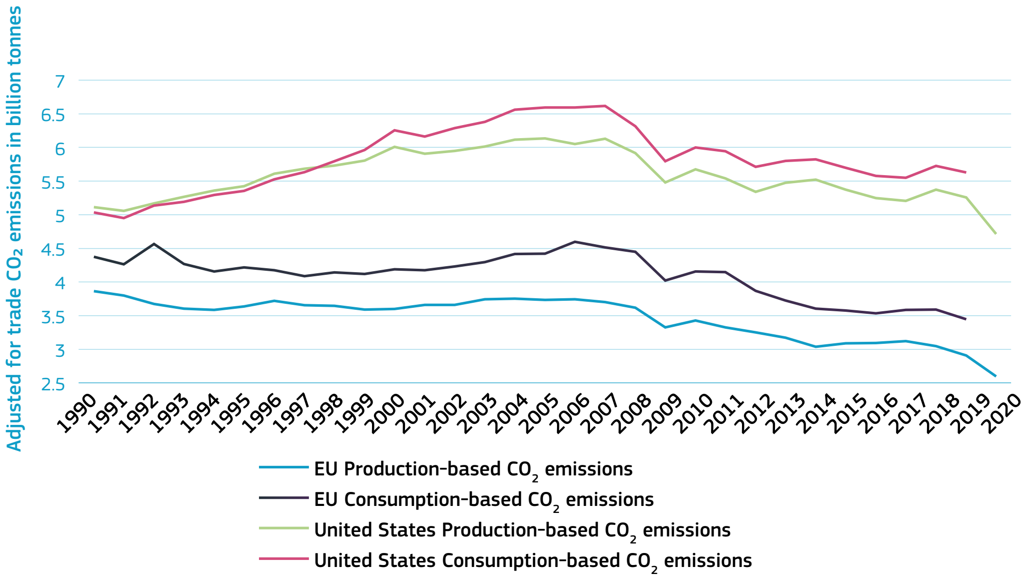
Missions operate across multiple policy domains (e.g. environment, agriculture, health and R&I) seeking to link and coordinate different policy tools, regulations, and funding programmes, while mobilising private and public stakeholders, which includes citizens and public authorities at different levels of government. Missions provide concrete instruments for European society, Member States and regions to navigate the way forward to sustainability and succeed.

At the same time, **the European Commission has called for transformative R&I policy to deliver technological and societal change while ensuring sustainable development for all** (ERA SWD, European Commission, 2020). 'Tackling the grand challenges of our time requires a clear "design" process developed in the public sector, aimed at translating ambitions and aspirations in clear missions and pathways that will channel the allocation of resources.' (p. 22). The emphasis on **'a clear design process'** is in line with scholars' advice to leverage change through policy intervention along the transition processes to enable deep transformations. **Deep transformations require not only R&I policy support to disruptive innovations but also and, most importantly, to diffusion, upscaling and replication**, i.e. when radical innovations are adopted and diffused into markets, businesses, society and the policy environment (SRIP, 2020). In addition, deep transformation requires the understanding the limits and potential in local natural and human capital, and the deployment of tailored transition pathways. In concrete terms, this would first translate into two directions. First, **ex-ante policy experimentation could be more widely incorporated into policymaking processes** (Von Wirth et al. 2019). Second, **policy instruments could be gradually introduced to support the different stages of the change** (from niche adoption of innovations through uptake, upscaling and outscaling), while those that are not needed anymore should be phased out.

Given the complexity of transition and transformation processes (i.e. complex and interrelated socio-technical systems, goals and interests involved), **the structures governing R&I policy processes could be designed for mobilising and supporting such deep transformations across societal and economic systems**. Therefore, a **whole government approach** is needed to ensure coordination and integration among different stakeholders and levels of government, as well as different policy domains. The SRIP report 2020 called for a horizontal policy coordination to better align R&I policies with sector-specific policies (e.g. energy, transport) that are key to provide focus, vision and ad-hoc instruments for deployment and diffusion of innovations (e.g. wind and solar PV, combined heat and power (CHP)). This is also referred to as 'sustainability transitions governance' (Fagerberg, 2018; Turnheim et al., 2020). Some countries, e.g. Finland (Innovation Council) and Norway (i.e. Innovation Norway), have established innovation bodies that involve both public and private actors in setting up the goals and direction of the green and sustainable transitions (Fagerberg, 2018).

Beyond R&I policies, other policies aim at boosting the shift towards more sustainable and resilient systems. Western countries have put in place strict environmental regulations to fulfil such objectives. Such approaches may create incentives for businesses to implement structural changes and upgrade global value chains. But they may also have some side effects. Ben-David et al. (2021), using data on 1970 multinational firms headquartered in 48 countries and their CO_2 emissions in 218 countries during the 2008–2015 period, found that tightening environmental policies in home countries incentivise multinational firms to shift polluting activities abroad (Figure 3.25). At the same time, they discovered that higher foreign emissions levels do not completely outweigh the reduction at home, as they emit less overall CO_2 globally. Both the US and the EU produce more CO_2 if one also considers the CO_2 production of goods made abroad and then imported to be consumed locally. However, both the US and the EU have made significant progress, reducing their production- and consumption-based CO_2 emissions in the last fifteen years. Such outcomes, likely the result of both political will and technological/economic capacity, testify that it is not necessary the case that countries pollute more as they get richer (EEA, 2020b).

Figure 3-25: Evolution of EU and US production- and consumption-based CO_2 emissions, 1990-2020



Source: DG Research and Innovation, Chief Economist – R&I Strategy & Foresight Unit based on Our World In Data and Global Carbon Project (2021).

Note: consumption-based emissions are emissions that have been adjusted for trade (i.e. territorial/production emissions minus emissions embedded in exports, plus emissions embedded in imports).

Stat. link: https://ec.europa.eu/assets/rtd/srip/2022/figure-3-25.xlsx

Besides, **directed R&I policies towards the green transition are more widely accepted politically than environmental regulations**. As an example, policy attempts to increase fuel prices have been met sometimes with fierce opposition by civil society. A key example is the “Gilets Jaunes” movement in France, where an often-cited quote from a protester (‘The elites are talking about the end of the world, while we are talking about the end of the month[28].’ a growing literature demonstrates that, in the context of inequalities and the feeling of neglect, tackling climate change is not a priority for many.

Carbon pricing policies could gain stronger popular support if revenues were distributed across society in ways that are equitable and perceived to be so (Stern and Valero, 2021). It also calls for social policies in the EU and anticipation of the distribution of taxes and transfers resulting from environmental measures.

Read more in Chapter 10 – Part 2 on Research and Innovation Policies for the Green Transition

(Eugénie Dugoua, LSE)

This chapter presents a deeper look into the arguments of a long-standing debate. Should we put research and innovation at the centre of the green transition, or, on the contrary, rely on a cultural shift that changes consumption patterns rather than finding cleaner means of production?

It investigates selected R&I policies that can help foster a transition towards green technologies, considering both supply-side policies, such as R&D funding, and demand-side policies, such as carbon pricing and clean technology standards, explores their complementarities and proposes a few key take-aways: the urgency to invest in the deployment of green technologies, the critical role of both investments in R&D and carbon pricing.

28 Rérolle, 2018. Gilets Jaunes Les élites parlent De Fin Du monde, Quand Nous On Parle De Fin Du Mois(2018)Le Monde

Box 3-5: Transformative R&I for sustainable development: Analysis of SRIP 2020 principles in practice

Andrea Ferrannini, Roberto Martino

The **ambition for European R&I policy is to act as a leverage for transformation in the transition towards sustainable development**, empowering individuals, communities and Member States to meet societal needs and build sustainable and inclusive societies. To realise this ambition, European R&I policy needs to fully embrace the principles underpinning transformative change towards sustainable development – **transformation, directionality, co-creation, diffusion, and uptake** (SRIP, 2020) – and make them operational, going beyond a consolidated narrative.

The following analysis explores how **these principles are reflected and embedded in the design and implementation of EU policies** across different domains, thus contributing to understand how current and future European R&I policy effectively contributes to the sustainability agenda.

This research combines a **state-of-the-art review** of the literature and policy discussions in Europe on transformative R&I with the **analysis of five selected case-studies** of current EU policy interventions. These case-studies were purposively selected – among others – due to their focus on innovation processes and practices across different dimensions of sustainable development. The investigation of each intervention is based on the combination of **extensive desk-based analysis of available public documentation** (e.g., work programmes, regulations, evaluations and assessments, reports and publications, brochures, websites, promotional materials) with the **collection of direct in-depth insights through semi-structured interviews to key informants**, namely internal staff (heads of units and officers) within related European Commission's DGs and Agencies.

The following matrix reports the main findings. The analysis demonstrates **innovation processes are at core of a transformative change towards sustainable development** across different EU policy domains. In particular, the analysed policies promote a combination of radical and incremental innovative solutions to **transform production processes, behaviours, and business/institutional models**. Furthermore, they provide **a clear direction** for the transformative process, bringing together bottom-up solutions with overall priorities while **enabling collective action for a better society** involving a wider set of actors, governance levels and countries. The policies aim at **advancing and disseminating knowledge** across European economies and societies, pushing for **market, institutional and societal uptake of sustainable solutions**, their scale-up and replication.

Notwithstanding relevant spaces for improvement, especially in terms of directionality and uptake, the analysis of these policies shows that R&I objectives, stakeholders, action, resources, and processes contribute to **empowering European individuals, communities, and societies with innovative solutions**, expanding knowledge and information, raising awareness and enhanced capacities to pursue sustainable human development today and in the upcoming future.

Table 3-4: EU policies and transformative principles in practice

Case-study	**European Innovation Eco-systems (EIE)**	**European Digital Innovation Hubs (EDIHs)**	**LIFE Programme**	**European Urban Initiative (EUI)**	**EU Programme for Employment and Social Innovation (EaSI)**
Main conclusion: how does each intervention embrace the transformative R&I principles	It **promotes the development of good practices within and between ecosystems,** favouring **the flow of knowledge and ideas with transformation potential.**	It enables the **uptake of digital technologies at the frontier, involving regional stakeholders in the innovation ecosystem, facilitating the connection of EU-wide actors and the deployment of specialisation strategies.**	It directs **innovation efforts in market-based solutions, policies and public attitudes** towards the transition to a carbon-neutral, circular and sustainable economy.	It fosters the **transformation of policy design in local institutions towards innovative and integrated urban solutions,** leveraging knowledge sharing and uptake.	It enhances **an enabling environment for social policy innovation** to foster a just and socially inclusive transition.
TRANSFORMATION	It sits in the general sustainability framework of **Horizon Europe and the Green Deal.** It promotes mutual learning and linkages between public authorities, start-ups, and funding bodies. It promotes the embedment of **innovation procurement in national and local strategies.**	It aims at transforming private and public entities by identifying, **diffusing, and uptaking the technologies** of the Digital Europe Programme (DEP). It contributes to the twin digital and transitions to make Europe more competitive and just.	It operates to transform **local economies, public governance**, and the general **public's acceptance and behaviours** towards green economy and sustainable development. LIFE projects focus on incremental innovations and close-to-market processes in local contexts.	It enables transformation in local institutions by expanding **in-house capabilities** and a **shared knowledge base** for integrated sustainable urban development. It promotes **new radical innovative proposals** and targets **incremental solutions** fitting the **specificities of local contexts.**	It promotes experimentation and the upscaling of **social innovation to transform policies and institutions** so they can address societal challenges. It fosters the development of **microfinance for micro-enterprises in** support of a sustainable and inclusive **transformation of businesses.**
DIRECTIONALITY	Thematic lines are consistent with **the framework provided by the Green Deal**. The priority setting brings together a **top-down** (Pillar 3 of Horizon Europe) and a **bot-tom-up** (stakehold-ers' engagement) approach. The definition of measurable indi-cators on impact is ongoing. **It complements** the actions carried out by the **Euro-pean Innovation Council (EIC)** and the **European Institute of Tech-nology (EIT).**	Hubs' trajectories depend on **general** priorities (e.g. DEP) and **regional** specificities (e.g. smart specialisation strategies), contributing to the RRF, Cohesion Policy and sectoral policies. It foresees a **detailed set of targets**, in terms of inputs, outputs and impacts. Hubs are expected to support companies by helping them with contacts and access to **financial institutions and intermediaries**, filling information gaps.	It develops a comprehen-sive response to **environment-, energy- and climate-related global challenges**, contributing also to the **SDGs** and to **Horizon Europe's Missions.** It combines **local specific priorities** with **objectives and targets stated in supra-national policy frameworks.** Its implementation strongly relies on **synergies and complementar-ities** with other **EU funding programmes**	It contributes to **Cohesion Policy's vision** of an (urban) Europe that is smarter, greener, more connected, more social and closer to citizens. A **set of potential indicators of outcomes** is under scrutiny for both the overall objective and for each group of actions. Specific goals are set to **maximise complementar-ities with actions under URBACT IV and the European Regional De-velopment Fund (ERDF).**	Its priorities are based on **strong contextual evidence** referring to **weakened economic and employment** performances, **enhanced risks of social exclusion** resulting from the COVID-19 outbreak. It foresees **indicators to monitor** the achievement of its operational objectives. The focus on societal challenges is the link with other ESF+ funding **instruments, InvestEU, Erasmus+, and Horizon Europe.**

CO-CREATION	It complements the top-down strategy with bottom-up contributions. Stakeholders were involved in an **extensive consultation process** at different stages of the policy design, whose outcomes strongly contributed to the definition of the Work Programme. The **EIC Forum** brings together public representatives, experts, and stakeholders, and it contributes to the evolution of its priorities.	Policy implementation embraces a **co-creation** and **participatory** approach, involving both local and international partners. The hubs' embeddedness in the regional ecosystem, the capacity-building approach, and the co-funding mechanisms place the policy at the **crossroads of different policy domains. Cooperation among hubs located in different EU regions** is encouraged to benefit from external knowledge.	The 2021-2027 **programme** is based on both **stakeholders' consultation** and the **participatory assessment** of the 2014-2020 period. A **whole-of-society approach** is ensured by engaging multiple actors **within local communities** in each project. The success of Strategic Integrated Projects and Strategic Nature Projects depends on **close cooperation between national, regional, and local authorities and the non-state actors.**	Its design benefitted from an **extensive consultation process**, including a public consultation, the appointment of an external expert and an Expert Working Group, also drawing from the impact assessment of the predecessor Urban Innovative Action. The policy benefits from the established use of **interactive methods and an online platform** where interested stakeholders may contribute to the working groups.	The annual work programme is informed by **consultation with Member States, a Technical Working Group**, and **strategic dialogues** with key EU-level organisations. The implementation builds on a **shared commitment** and the **strategic composition of partnerships. Networking and capacity-building activities across countries** are key for developing an **integrated EU labour market.**
DIFFUSION	The policy is about the **exchange of talents, competence, knowledge, and technology** (soft side), addressing the bottlenecks in the implementation of R&I policy through the creation of networks among ecosystems and using the EIC Forum. Expected outcomes include improved **flows of innovation resources, knowledge, and talent** between innovation ecosystems at various levels of development.	**The European network of EDIHs** allows local stakeholders to access knowledge, funds, expertise, and innovation opportunities, integrating them in global value chains. Knowledge spill-overs across countries are expected to reinforce the Single Market and reduce the digital divide in the EU. The hubs support local public authorities in the digital transition.	Projects help businesses testing small-scale solutions and supports the sharing of best practices, paving the way for a **large-scale deployment.** The dissemination strategy at European level ensures **open-access to knowledge and practices** relying on a wide and consistent set of tools. Dissemination strategies are also carried out **by Member States** and regions, along with a **continued** monitoring, even after a project's life cycle.	It foresees **sharing mechanisms** to provide local stakeholders with open access to the created knowledge and practices. It enables and encourages the **'reuse of public sector information and the promotion of big, linked and open data'** stemming from the three strands of actions. A single **network of contact points** favours dissemination in Member States and ensures policy support.	**Communication and dissemination** activities are fundamental to assist in the **upscaling, replicating and/or mainstreaming of results** achieved by projects. Strong efforts are devoted to make all produced knowledge and best practices (including all analytical activities) **open and accessible** to institutional and societal actors.
UPTAKE	**Dedicated funding** is allocated to ensure that outcomes from projects are assimilated. **The EIC Forum** is defined as a place to collect feedback from stakeholders concerning **uptake and implementation** and to **transform the policy priorities according to stakeholders needs.**	The European network of EDIHs is itself **facilitating and fostering the uptake of digital technologies by companies.** The activities foreseen in the hubs – including the creation of the European network – are also meant **to contribute to building the digital capacity of public bodies.**	The focus on **ready-to-be implemented solutions favours market uptake.** Institutional uptake of relevant policy actions is fostered by a **national, regional, and local policy framework** on environmental issues. The focus on **awareness** and **acceptance, consumer engagement and behavioural change** fosters societal uptake.	It aims at enabling and nurturing the **systematic uptake** of tested innovative solutions, good practices, and toolkits, using projects' outputs as inputs in the learning and disseminating process. The **implementation rate** of sustainable urban development strategies in cities is among the **outputs indicators** proposed for quantifying the impacts of the policy.	It aims at translating stronger evidence **in policymaking and upscaling, while replicating and/or mainstreaming social experimentation.** Social and institutional uptakes are pursed through a robust **communication and dissemination strategy** and assessed using **outcome indicators.**

Source : Authors' elaboration

2.2 What is needed to enable transformative R&I for sustainability ?

European Missions are an example of R&I policy innovation and hold the potential of enabling deep societal transformations. However, if the sustainable transformation is to be achieved, the policymaking process and policy instruments have to be adapted to the goal. Systems thinking is advocated from multiple sides but putting it into practice is more complicated (e.g. Mazzucato 2018, 2019; ESIR policy brief 2022). Donella Meadows, who was a member of the Club of Rome and a systems thinking apprentice, formalised **a list of leverage points to intervene in a system and provoke change**[29]. Meadows' work can be a guideline for policymakers to navigate and implement change in the policymaking processes. Meadows' leverage points **start with the easiest to implement 'constants, parameters and numbers' (e.g. taxes, subsidies and standards)**, to end with the three most difficult ones to fulfil, but that also hold the greatest potential for transformation. The three deepest leverage points are **changes in goals, mindset and power to transcend the dominant or established paradigms within a system. Paradigms are the sources of a system's** core features, such as goals, mindsets and beliefs, policy instruments, regulatory measures, stakeholders involved and resources employed, market dynamics and so on (Meadows, 1999). These three deepest, leverage points can be exploited by, for instance, introducing formerly excluded stakeholders and visions within policymaking, but also by adopting methods that allow for better understanding complexity and operating in highly complex contexts, and experimenting with new tools and practices.

So how do you change paradigms? [...] In a nutshell, you keep pointing at the anomalies and failures in the old paradigm [...]. [...] you work with active change agents and with the vast middle ground of people who are open-minded. Systems folks would say you change paradigms by modelling a system, which takes you outside the system and forces you to see it whole. We say that because our own paradigms have been changed that way.

(Meadows, 1999: 18).

Future foresight, experimentation, systems methodologies (e.g. system dynamics, Life Cycle Assessment) and co-creation participatory exercises can bring novel ideas into the policymaking and challenge dominant visions. Experimentation, both in the form of co-creation (e.g. niche development, living labs, stakeholders engagement platforms) and ex-ante policy instruments and designs evaluation (test new ideas, see what works and evaluate impacts) is becoming more widely used[30]. Scholars call for governance that is built around 'provisional, flexible, revisable, dynamic and open approaches that include experimentation, learning, reflexivity and reversibility (Kuhlmann & Rip, 2014)' (p. 230). **Experiments can support *upscaling*, through testing and embedding novel technologies in mainstream ways of doing, thinking and organising** (Laakso et al., 2021). Living Labs are an example of these experimental interventions. Living Labs are widely used in urban contexts but there is also an increasing number in rural areas that deal with bioeconomy-related innovations[31]. The Living Labs are sites where a variety of stakeholders come together and design, test, and learn about actual innovations and transition processes.

29 Leverage Points: Places to Intervene in a System - The Donella Meadows Project

30 Nesta | The Innovation Foundation; Research, Consultancy & Education for Transition - DRIFT (eur.nl); Homepage - APRE

31 ULL represent sites in cities that allow stakeholders to design, test and learn from socio-technical innovations in real time. Participation, experimentation and learning are put centre stage.

For example, **Maere Living Lab (green sector – agriculture) and Val Living Lab (blue sector)** in Mid-Norway (Trøndelag) are a network of established farms combined with a unique educational arena where students, researchers, innovators, industrial partners, and farmers participate and find innovative solutions to produce bioproducts and reuse materials in a circular economy approach. **Sustainability transitions practitioners suggest six policy intervention points to support the deep transformation process, from niche development to incumbent structures (European Commission, 2020).** Depending on the directionality and goals of R&I policy design, instruments are best adapted to potential challenges (e.g. strong discontent and resistance from stakeholders, conflicting interests) to mitigate uncertainty while boosting the transition process. The six policy intervention points and examples of related measures are:

- Stimulate different niches to allow for different alternatives of systemic change (e.g. R&D investments, public procurement, foresight and future visions, regulatory shielding, demand-pull subsidies in China);

- Accelerate the niches to support innovations to enter into the market (e.g. creation of innovation platforms, market-based policy instruments, advice systems for small and medium enterprises, provision of venture capital funds);

- Transform the regime, namely incumbent institutional and technological structures, social practices and culture (e.g. taxes, mandatory requirement to replace fossil-fuel energy infrastructure in public buildings in Norway, removing subsidies for certain industries);

- Address the broader repercussions of regime transformation on multiple scales (regional, societal, global) such as economic repercussions on existing industry, adverse environmental effects (e.g. biodiversity degradation), and social conflicts. Responsible Research and Innovation, embedded in the precautionary principle, could prevent unintended consequences of innovation. Examples of measures are information campaigns, financial support to help the industry phasing out older technologies, policies to tackle structural unemployment;

- Provide coordination to multiple regime interaction implies that different but interrelated socio-technical systems in transition mutually influence each other. For example, privately owned gasoline cars and the fossil-based energy infrastructure mutually reinforce CO_2 emissions and over reliance on few sources of energy, thus affecting energy security and societal resilience. Re-balancing this dynamic would entail diversifying the energy technology portfolio (see measures suggested before) and e.g. support car sharing, improve public transport networks, or link the conversion of gasoline to renewable energy.

- Tilt the landscape means to influence global frameworks and agreements towards more sustainable clauses to trigger positive effects on sustainable innovations uptake and upscaling. Examples of such global efforts are the Paris Agreement and the banning of chlorofluorocarbons (CFCs).

Box 3-6. A virtual case study: The transformation from Industry 4.0 to Industry 5.0 as a potential case of transformative R&I policy

The expert group on the economic and societal impact of research and innovation (ESIR) has extensively accompanied the efforts of DG R&I the during the COVID-19 crisis, outlined as an opportunity for change at the economic, societal and policymaking level. With the Policy Brief Industry 5.0: *a Transformative Vision for Europe*[32], ESIR sets up a strong case for R&I policy to accompany the evolution of the European industrial landscape towards sustainability, productivity and well-being.

Industry 5.0 demarcates itself from Industry 4.0 in its paradigm by putting sustainability at the centre as opposed to a focus on enhanced productivity through dematerialisation for the former. From the points outlined in this chapter, ESIR experts drew several policy recommendations illustrating the paradigm shifts upcoming or necessary for the transition from Industry 4.0 to 5.0, as illustrated in the table below. These policy recommendations relate to systemic change. As such, only a partial uptake of these policies is likely to hinder the transition, as mutual interaction across systems is a key aspect of systemic change.

Table 3-5: ESIR policy recommendations illustrating the paradigm shifts upcoming or necessary for the transition from Industry 4.0 to 5.0

Stimulate different niches to allow for different alternatives of systemic change	▸ Make a green and social industrial strategy the cornerstone of the Green Deal to address the challenges of the twin green and digital transitions. ▸ Rethink the role of the public sector in enabling the transition to Industry 5.0 (objectives, instruments, policy coherence, partnerships, interactions). ▸ Encourage a deep transformation of business models where sustainability is a natural component and driver of international competitiveness.
Accelerate the niches to support innovations to enter into the market	▸ A regulatory system that effectively guides accelerated compliance, adoption and best practice. ▸ Create a one-stop shop for companies to interact with the public sector on industrial transformation (streamline and expedite processes, facilitate interaction with different agencies and public sectors. ▸ Encourage more flexible, genuinely experimental and risk-embracing approaches to innovation development and deployment in partnership with industry. ▸ Reduce bureaucracy for SMEs seeking access to R&D support. ▸ Greater incentives for cross-pollination across research and innovation stages and across sectors.

32 https://ec.europa.eu/info/publications/industry-50-transformative-vision-europe_en

Transform the regime, namely incumbent institutional and technological structures, social practices and culture	▸ Full re-orientation of the Better Regulation agenda towards a post-GDP paradigm.
Address the broader repercussions of regime transformation on multiple scales (regional, societal, global) such as economic repercussions on existing industry, other forms of adverse environmental effects, and social conflicts.	▸ Reduced labour taxation (particularly for lower income workers), internalising pollution costs through environmental fiscal reform, considering the role of higher corporate and digital taxation; and discussing the application of a universal basic dividend or income logic.
Provide coordination to multiple regime interaction, as different but interrelated socio-technical systems in transition will mutually influence each other.	▸ A system of due diligence for all value chains that bring their products into the EU Single Market. ▸ Redesign other EU policies on the basis of resiliency principles which could bring mutual influence from agricultural and industrial systems for example. ▸ Put in place a coherent approach between policies covering industrial installations (IED), assets (taxonomy), supply chains (due diligence), products (product policy), materials (CEAP), pricing (ETS, CBAM, environmental fiscal reform), sectors and systems (agriculture, energy, forestry, nutrition, mobility, healthcare and housing and trade).
Tilt the landscape: to influence global frameworks and agreements	▸ Adoption of metrics and indicators that allow for the measurement of progress towards the vision. ▸ Change regulatory frameworks covering eco-design and BREFs (Best Available Technique Reference Documents).

Source : Authors' elaboration

3. Conclusions: for a deep transformation of our systems

The European Green Deal calls for the transformation of entire support systems for human and planet welfare in food, housing, manufacturing, energy infrastructure and transport. It also calls for a much more central role for innovation policy in orchestrating the transformation. Realising this promise requires not only more intensified innovation efforts, but also more extensive actions on innovation that transverse policy portfolios and levels of governance.

The market for nature investment and therefore demand for financing products will remain limited without regulation that obliges investment and/or creates reasonably predictable revenue streams. Natural capital is far from being an established asset class in the sense of depth of market and track-record. For the foreseeable future there will also not be uniformity among end beneficiaries and intermediaries. The Transition Performance Index demonstrates that efforts still need to be made at all levels of governance and across the globe.

In this chapter, we bring insights on **the role, the state of play and trends of research and innovation to preserve natural capital, transit to clean and circular production and consumption systems and adapt them to climate change, and to also achieve inclusiveness and fight inequalities.** The EU leads or is amongst the top international players in both scientific knowledge production and patenting activity related to sustainable development goals, such as biodiversity protection, sustainable cities and communities, responsible consumption and production, clean and smart energy, infrastructures, transport, water, food systems, education, good health and decent work. However, some international trends are worrying, such as the net decline of patenting activity in clean energy from the mid-to-end of the 2010s, or the low rate of circular economy solutions uptake and of technology transfer, most particularly climate change adaptation technologies.

A truly transformative R&I policy is about directionality, which is intended to provide a shared vision. **The European Missions** under Horizon Europe are an example of directed R&I policy innovation which **hold the potential of enabling deep societal transformations and ensuring prosperity within the planet's boundaries.** Emerging technologies, social innovations as well as a diverse portfolio of active stewardships of human actions in support of a resilient biosphere are highlighted as essential parts of such transformations" (Folke et al., 2021). **Future foresight, experimentation, systems methodologies** (e.g. system dynamics, LCA) and co-creation participatory exercises **are critical** as they bring novel ideas into policymaking and challenge dominant perceptions. Climate and biodiversity policies, inclusive policies and industrial transition policies need to be coordinated, including across countries, and tailored to specific conditions.

The integration of the '**do no significant harm' (DNSH) principle** in the EU's R&I framework programme will ensure its consistency with European Green Deal objectives and promote the transition to a safe, climate-neutral, climate-resilient, biodiversity-positive, more resource-efficient and circular economy. Finally, the **new impact-oriented framework** programme, which introduces Key Impact Pathways in the monitoring and evaluation framework will provide deeper analytical insights for medium- and long-term impacts and **facilitate evidence informed R&I policymaking.**

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