Conclusions: Future disruptions and EU R&I policy

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1. Introduction

In a traditional Schumpeterian view, science and technology are an external source of economic disruption through innovation. Gradually, science, technology and innovation came to be seen as internal sources of endogenous economic change. The idea of an R&I policy is founded on the desire for beneficial endogenous change produced by science, technology and innovation systems. Those systems can be national, regional, local or international, organized along the lines or intertwined and increasingly global value chains. Contemporary ideas of transformative innovation policy[130] are based on the view that innovation systems (or R&I systems) can be governed in a way that maximizes social benefit from the disruptions introduced by innovation, either by focussing efforts on specific societal challenges or by strengthening the resilience of society against external disruptions. As Varnai and Simmonds[131] argued the R&I system can be seen as the immune system of society: "a system that remembers the experience of the crisis and improves itself to ensure that future crises are avoided".

Increasingly the R&I system becomes a core concern in the way society governs change and continuity, conservation and progress, knowledge and ignorance, conformity and disruption. The breadth of influences of the R&I system form a challenge for R&I policy, which could address diverse objectives and societal contexts with diverse instruments, making strategic choices over how these are packaged into programming narratives and how success and failure are to be constructed and measured. Future disruptions, expected and unexpected but always surrounded by uncertainty, are an important source of alternative narratives that challenge existing strategy and raise claims for different sets of objectives, policy instruments and social contexts in which R&I activities would be worth policy support. It is not the role of foresight to argue about the correct and legitimate nature (or not) of such claims, but it is the role of foresight to highlight the existence of claims for alternative strategic choices and to seek to illustrate such choices with explorations of alternative futures.

This final chapter provides such a policy analysis drawing on the explorations of potential disruptions in the previous chapters, as well as two additional disruptions explored in a sister project, dealing specifically with the future relationship between society and nature.[132] It first draws interlinkages between the future disruptions explored. Then it proceeds to show how groups of disruptions interact with strategic considerations around policy objectives and instruments and the social context of R&I activities. Following this, it discusses possible normative reorientations of EU R&I policy and their implications for strategic choices of policy instruments and the R&I agendas that could be supported.

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[130] See for example, Weber, K.M. and H Rohracher (2012). Legitimizing research, technology and innovation policies for transformative change: Combining insights from innovation systems and multi-level perspective in a comprehensive 'failures' framework. Research policy, 41(6), pp.1037-1047; Schot, J and W. E Steinmueller (2018) Three frames for innovation policy: R&D, systems of innovation and transformative change, Research Policy,47 (9) pp 1554-1567.

[131] Varnai, P, P Simmonds (2021) The scientific, technological and societal conditions for the end of the COVID-19 crisis, Publications Office of the European Union, https://data.europa.eu/doi/10.2777/293413; p 23.

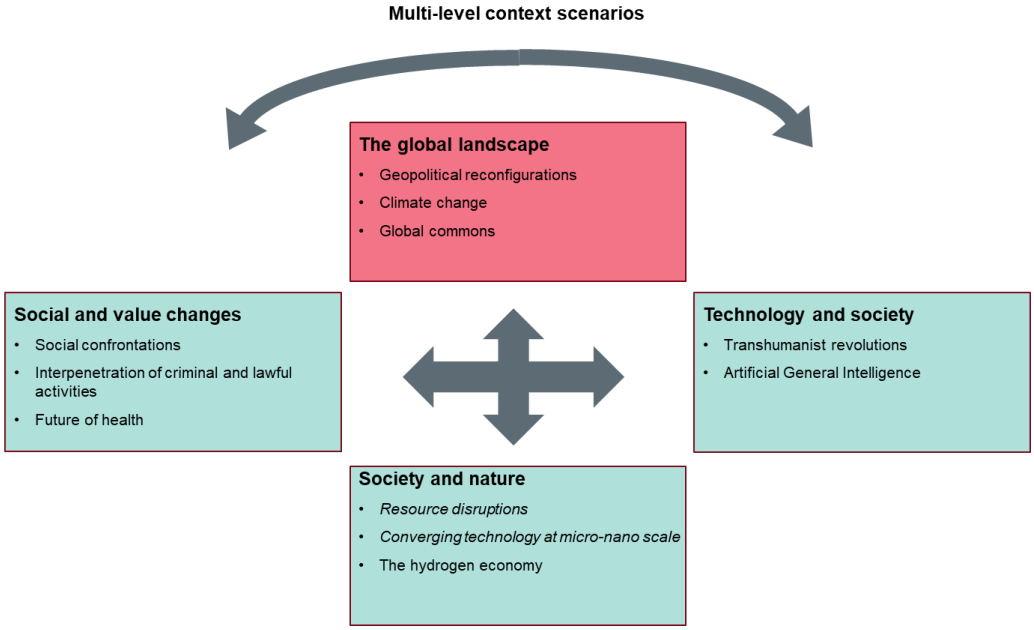
[132] The two disruptive areas "Resource Disruptions" and "Converging Technologies at Micro-Nano Scale" have been explored as part of the project "STI 2050 and ecosystem performance", see for more details www.futures4europe.eu.

2. Domains of influence of disruptive developments

The areas of disruptions that have been explored in the preceding chapters are interlinked in various ways. They influence each other, for instance, through technological interdependencies, social and economic effects, or they could involve shared or mutually reinforcing political goals. The intensity of interlinkages may vary depending on the individual scenarios considered for each of the disruptions.

One way of relating the different disruptions to each other draws on the **domains** they are likely to influence most profoundly. In Figure 1 we propose four domains of influence: i) the global landscape, ii) the relationship between society and nature, iii) the relationship between technology and society, and iv) social and value changes. At even higher level of aggregation, disruptions and domains of influence are embedded in wider contextual developments relating to the collaborative or confrontative nature of the global and European governance contexts, which define the playing field for all areas of disruption. The diversity of future configurations of these playing fields is captured by multi-level context scenarios (cf. Chapter 4 for more details).

Figure 30: Clusters of disruptive areas



From among the eleven disruptive areas, three are directly affecting the **global landscape** of future challenges: geopolitical reconfigurations, climate change, and global commons. Their disruptive potential is huge, and they may lead to tectonic shifts in the patterns of power and influence at global level. If novel ways of addressing the problem of climate change are pursed, from geo-engineering to nature-based solutions, new lines of conflict may emerge among countries that have thus far co-existed peacefully, and these may hamper the ability to counteract the effects of **climate change**. The same holds for global commons; their preservation depends crucially on agreements among bordering countries to manage exploitation of **global commons** in a sustainable way, and on the willingness to attend also to interests that non-bordering countries may have in these commons. Whether or not it will be possible to establish cooperative governance arrangements for global commons and

climate would depend on the emerging **reconfiguration of geopolitical relationships**, which can be conducive or detrimental to collaborative governance arrangements. From a European perspective, the future relationships with the US and the need to join forces – as reflected in the different scenarios – will be decisive for Europe's ability to continue playing an influential role in these governance arrangements.

The disruptive potential of climate change and global commons also has important implications for the relationship between human **society and nature**, domain of potentially major **resource disruptions**, due to growing demand for resources – be it in agriculture and industry, mining or waste disposal and emissions – and more strategic control over access to globally traded resources. Likely consequences include more frequent supply crises and shortages, rising concerns for planetary health, and growing risks of economic, political and even military conflicts arising over the access to scarce resources. A second area of disruption in this domain of influence is related to the enhanced ability to understand and, with the help of converging technologies, **intervene in natural processes at micro and nano scale**. This opens many new possibilities for manipulating nature, ecosystems and species. As is often the case, there are important promises attached to these new possibilities, but they are also associated with major uncertainties and yet unknown consequences. Both disruptive areas are likely to affect profoundly the relationship between society and nature, and they signal a need to rethink and possibly reframe their mutual relationship. The dominant mode of exploiting nature for purposes of improving human and societal performance may need to give way to a framing that ensures paying equal attention to the development of both nature and society, thus calling for strengthened stewardship for nature.[133]

The potential disruptions from the emergence of a **hydrogen-based economy** to replace the fossil fuel-based economy relate to stewardship for nature – given the manifold negative consequences of the fossil age on nature – but also have important repercussions for the global landscape of political and economic power relations. Countries endowed with natural resources needed for a (renewable) hydrogen economy are likely to strengthen their global role, while other countries that have drawn on their fossil resources may need to seek alternative sources of wealth. Still, many challenges associated with the hydrogen economy are poorly understood, and its perspectives will depend less on technology (what is technically feasible) and more on global governance matters and changing patterns of trade enabling a shift towards a hydrogen economy (what is worth doing), which will also be contingent upon a multi-level context scenario that is conducive to a cooperative mode of global governance.

There are two scientific and technological areas of advancement that foreshadow a high disruptive potential for the relationship between **technology and society**. The long-term potential of **artificial general intelligence** (AGI) may yet be perceived as uncertain by many experts, as are its benign and problematic consequences for society, economy and (geo-)politics. Still, recent advances in AI-based tools and solutions are impressive and nurture optimistic as well as dystopian expectations. The race for global supremacy in AI technology has already begun, with yet unclear consequences for the global landscape of power relations. Social tensions may result from novel forms of using AGI in societal and political debates, and they depend on who will have access to AGI or not, and under what conditions. Similar questions arise with regard to emerging technologies underpinning **transhumanist revolutions**. AI will certainly influence the various technological options for enhancing human performance, but there is a multitude of other areas of S&T that will need to be brought

[133] See Kubeczko, K et al (2023) S&T&I FOR 2050: Science, Technology and Innovation for Ecosystem Performance – Accelerating Sustainability Transitions, Publications Office of the European Union, https://data.europa.eu/doi/10.2777/100029.

together, from robotics and human-machine interfaces to cognitive science and genetics. Promises of improving quality of life over an extended lifespan raise profound moral and ethical questions, which may well trigger polarising debates in society and politics. A crucial question in relation to both artificial general intelligence and transhumanist revolutions is whether the further development of these technologies with their uncertain promises and risks would be slowed down and placed under strong social control. Such, is argued, would enable society, in Europe as well as globally, to keep pace, define the institutional conditions for making sure that the uses of these technologies are benign and do not have major undesirable consequences. If not, the competitive race may well lead to a diverse range of benign as well as very problematic applications and forms of use. This is a major regulatory challenge as, what is considered problematic or benign differs across countries and world regions, depending on political values and goals, as well as on the balance between economic and societal opportunities expected from the proliferation of AI and human enhancing technologies.

Such considerations regarding disruptive technologies and their societal implications have already pointed to some of the **social and value-related changes** emerging, which may be disruptive for society. One of the areas, where the developments in AI and human enhancement technologies will be of major importance is the **future of health and health systems**. This is an area of great direct concern for citizens as it offers hope for remedying diseases and improving quality of life. The role that these new possibilities will play depends on the willingness of society to make resources for disruptive health futures available, and to reach agreement on whether broad access to the multitude of new possibilities will be granted and financed, or whether these will remain options for a wealthy minority. This issue could also play an important role in heated **social confrontations** in the future; on their own right an area of rising concern due to growing societal fragmentation and reinforced by the echo chambers of social media and the resulting multiplication of “truths”. Opposing views underpinning social confrontations can be deeply rooted in value conflicts over the societal models to strive for, often forming authoritarian challenges to the liberal democracy model. Such tendencies are leading not only to more fragmentation but – given their roots in value conflicts - also erode the ability to find balanced compromises in political discourse. Controversies, reinforced by fragmented and isolated social ecologies, both online and offline, have the potential to undermine the consensus over fundamental principles on which liberal democracies rest.

Confrontations often get resolved by the establishment of boundaries between the confronting parties, including legal provisions. In an environment of rising social confrontations there is a growing concern with the interpenetration of **criminal and lawful economic activities** and the permeability of boundaries between them. Innovation is inherently about transgressing boundaries and it often enters territories where the dividing lines between lawful and criminal activities are not clear, either because there are no rules in place yet – think of the introduction of cryptocurrencies – or the boundaries between what is considered ethically right or wrong are shifting. However, digitalisation and cybercrime have reinforced the possibilities and accelerated the pace of interpenetration of criminal and lawful activities, up to the point of turning this into a concern for global governance, given the fact that cyber-space transcends national borders and legislations, and what is criminal in one part of the world can well be illegal elsewhere. In this space, there is a continuous race between the perpetrators in organised crime on the one hand and the legislators and regulators on the other hand.

The shaping of the emerging trajectories of these areas of disruption takes place in many different arenas, and whether European interests and voices will be heard depends on the future evolution of the architecture of these arenas. This also affects the role that EU R&I policy can play in influencing these trajectories. The **multi-level context scenarios**

developed represent alternative perspectives on the global and European context of EU R&I policy, and they frame in general terms Europe's future ability to govern and manage conflict and cooperation globally and in Europe, and the room for manoeuvre for R&I policy more specifically. They define the playing field for governing the emerging trajectories of the disruptive areas, and they show that there are many sources of uncertainty and complexity, which could affect the EU, its prospects, power and influence in the world. EU R&I policy is only one of the shaping forces, but – as shown by the context scenarios - its influence depends on the ability to maintain Europe's internal dynamism and ability to act strategically, as well as on the levels of cooperation and conflict in global affairs.

3. Cross-cutting implications for R&I policy

3.1. Strategic approaches to R&I policy for disruptive developments

The different areas of disruption pose challenges for EU policy. They highlight the widening space of future possibilities, the dependency of Europe's future on developments beyond its influence, and the need to reframe Europe's strategic options. This has implications for the strategic priorities of EU R&I policy, as well as for the policy approaches followed and instruments that would best serve the strategic priorities. Disruptions differ in important ways and so do the possibilities for strategic positioning of Europe's R&I policy in relation to them. Three critical dimensions need to be distinguished in this regard:

- **The level of complexity and uncertainty of disruptions**: This refers to the nature of the problem-solution space associated with potential disruptions,[134] i.e. whether the problems and possible solutions ahead are sufficiently well understood to concentrate efforts onto a comprehensive plan to a sustainable future, or whether uncertainty and complexity are so high that a more open, exploratory and adaptive strategy is needed.

- **The level of power and autonomy to shape the future**: This refers to Europe's ability to be the 'master of its own destiny', i.e. whether we are in a position to shape the future of these disruptive areas according to our normative ambitions and will. This has important implications for how openly Europe needs to collaborate with international partners when it comes to finding solutions to the problems associated with disruptions. Global challenges tend to require global collaborative efforts, but even in many other cases we may depend on collaboration, including in R&I, to develop sustainable and just solutions in line with European interests.

- **The level of consensus over the desired future to be pursued**: This reflects to the legitimacy of the problem-solution space and the importance of processes of societal decision-making, whether through market competition or through political and administrative means. Given the evolving European policy-making processes, the consensus on what a challenge is and how to approach a solution should not be taken for granted. The lack of consensus is typical in spaces of high cognitive complexity and uncertainty, but it can also prevail in spaces of relatively uniform understandings of the problem-solution space. Alternatively, consensus can be broad and cohesive in spaces of very high complexity and uncertainty, such as those found around health issues. The

[134] On mission-oriented transformation pathways in the problem-solution space, see Wanzenböck, I., Wesseling, J., Frenken, K., Hekkert, M.P., Weber, K.M. (2020): A framework for mission-oriented innovation policy: Alternative pathways through the problem–solution space, Science and Public Policy, 47(4), 473-489.

pursuit of consensus, and the emphasis placed on the pursuit of consensus is an important part of the strategic response to disruptions.

A number of authors have argued that faced with repeated disruptions, the EU should take decisive, strongly directional coordinated action[135] of the kind that governments take in states of emergency:

> "The EU should embark on deep transformation by seizing the opportunities offered by the current state of emergency" (Dixon-Decleve et al 2023, p 5)[136]

For such action to be meaningful and ultimately successful there needs to be high levels of consensus and low levels of uncertainty about the problem solution space and the desirable future to be pursued. The reference to the "state of emergency" either aims to generate consensus or to bypass the need for consensus altogether like in periods of war. This is why we call this strategic path the "war path". If there are high levels of uncertainty and complexity, the war path will be fraught with peril and strategic challenges are to be expected. Strategic challenges may be overcome by powerful actors, but lack of consensus erodes power, especially in organizations like the European Union in which consensus is a core value and key for legitimating decisions.

Successful implementation of a path would be made easier if the EU had the power of autonomously shaping the relevant futures. Realistically, and recognizing the levels of interdependence of the EU in the global economy, we need to distinguish between paths of "selective cooperation" and "crowd". The first is one in which the EU and a small number of partners are able to shape the world system to make a positive outcome from addressing the disruption. The second is one where a "war against the disruption" can only be successful if the whole (or most) of the international community aligns with the EU goals.

When there is no consensus over the problem-solution space, directional interventions are contested. R&I policy finds itself in the middle of contestations, often about the primacy of technological or social solutions, the trade-offs between them and possible combinations there-of. In such situations, external conditions can constitute an argument for one approach – if for example there is a discernible "crowd path" - or can support fragmentation into constellations that work in selective cooperation with external actors. The relative freedom of policy-makers to decide may be constrained by global institutions, such as trade and other agreements, which guarantee a level of freedom of economic players from government direction. All in all, in the absence of consensus over the problem-solution space, issues of fairness and balance across alternative agendas are the key concerns for R&I policy makers, often taking precedence over directionality, coordination and policy coherence.

How do these strategic considerations apply on the future disruptions that this study has examined? Global context issues are areas where Europe's autonomy and power to act are a function of its size and resources, where "crowd paths" are pursued where possible and where political realism often imposes selective cooperation paths. Of the three global context issues, the one where there seems to be most consensus over the problem-solution space is on the importance of global commons – where the EU advocates strongly a science diplomacy-based approach to issues like climate change and deep-sea mining, and where

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[135] See Mazzucato, M. (2019). Governing missions in the European Union. Publications Office of the European Union, https://data.europa.eu/doi/10.2777/618697.

[136] Dixson-Declève, S., Renda, A., Isaksson, D. et al. (2023), Transformation in the poly-crisis age, Publications Office of the European Union, https://data.europa.eu/doi/10.2777/360282.

the UN tries to forge a crowd path to a safe future. Within Europe, climate change and geopolitical reconfigurations have yet to meet with consensus. In relation to climate change, contestations extend to technological versus social solutions and whether the EU has the authority and the ability to solve the problem anyway. In relation to the emerging geopolitics there is little consensus on the degree of desired autonomy from the US-lead global liberal system, and on the ability of the EU to implement such a strategic autonomy.

The disruptions in the technology-society relations – those driven by technological advances such as AI and transhumanist pursuits, are highly complex. There is considerable consensus about their ability to make important contributions and solve important problems, while there is division about the long-term, structural and indirect effects of their use on society. At a global level there is a perceived need for a crowd path in order to enable society to regulate these effects, but there is also consensus that the predominant form of governance of those technologies is through market mechanisms. The regulatory problem is about how to guarantee responsible progress in public and private settings.

Disruptions of societal and value systems are also complex, characterized by uncertainty and lack of consensus over problems and solutions. Within Europe, governance mechanisms enjoy considerable power but certainly not autonomy to address and resolve societal divisions and value conflicts. Amongst them, the future health threats are by far the most consensual and where there is an understanding of the need for a "crowd path" that involves the whole world. Still preparedness is a challenge, and the economic importance of the pharmaceutical industry is such that autonomy in research and competitiveness in new technology fields remain important concerns. In relation to social confrontations and the interpenetration of criminal and lawful economic activities, there is much less common understanding and consensus over what the problems are and how research could help resolve them, and while values favour selective collaboration paths with like-minded actors, the globalisation of the economy and technology forces a search for global crowd paths.

Finally, disruptions relating to the nexus between society and nature are complex. While uncertainty is decreasing and consensus may be emerging over some aspects of the problem-solution space, huge divides remain over the values that need to be upheld and over the causes and effects of the future challenges. The emerging consensus is around the need to consider the systemic limits of the planet's carrying capacity for pollution in all our interactions with the environment[137]. How these considerations should be translated into individual and collective action and how they should affect historically acquired entitlements and responsibilities, is a matter of important disagreements across the board. Even the case of the hydrogen economy, the most consensual of the three disruptions explored in the study, the distributional effects of different paths forward are widely different and that creates important varieties of R&I and political paths forward.

3.2. Roles of R&I policy for future disruptions

What do these considerations imply for European R&I policy on matters of future disruptions? To start with there is not a one-size-fits-all approach to addressing disruptive areas, but roles of EU policy in general, and of EU R&I policy in particular, need to take into account the types of paths that seem most suitable for each specific disruption. Rather than discussing each individual disruption in this regard (which is done in the individual chapters and reports), and

[137] See: Rockström, Johan; Steffen, Will; Noone, Kevin; Persson, Asa; Chapin, F. Stuart; Lambin, Eric F. et al. (2009): A safe operating space for humanity. In Nature 461 (7263), pp. 472–475. DOI: 10.1038/461472a; Raworth, K. (2017). Doughnut economics: seven ways to think like a 21st-century economist. Chelsea Green Publishing.

given the potential interactions between future disruptions, what follows is an attempt to reflect upon additional R&I policy roles that might be pursued to complement current ones, in order to better cope with disruptive developments.

Since its inception in the 1980s, much of the EU's R&I policy, and in particular its framework programmes for research and innovation, has concentrated on an enabling role for science and technology development, in order to contribute to the strengthening of the competitiveness of European firms and, more lately, help address societal challenges. This enabling role of the EU's R&I policy is also highlighted in the European treaties, and it continues to be very important.

In recent years, and more specifically with the definition of major societal challenges as one of the three pillars of Horizon 2020, the EC has indeed emphasised what could be termed a transformative role of R&I policy. In this, R&I agendas are defined as pursuits of solutions in response to these societal challenges. This was a 'normative turn' which developed momentum over the past decade and involved a rise in ambition of R&I policy to achieve missions. The ambitious narrative often meets with conditions of high complexity, lack of control over the future, and lack of consensus over the intended future. In such conditions there is a risk of over over-stretching the possibilities of R&I policy and under-rating the importance of the broader policy context, including the importance of demand-side sectoral policies for the realisation of transformative changes.

Under such conditions, a more modest take on R&I policy seems appropriate, where instead of a transformative role one could speak of a catalytic role. This does not mean a complete lack of orientation but broad orientations towards an overarching transformative goal would involve flexible and circumspect approaches on the possible transformation pathways, including the nourishing of alternatives and recognizing the importance of uncertainties and potential disruptions. This would typically be also less ambitious in terms of the extent to which R&I policy is expected to contribute to realising transformative change; the key task of R&I policy then consists of testing viable configurations of technological, social, behavioural, organisational and institutional changes, before they can be scaled and taken up more widely.

A final important element that needs to be considered in this context is the role of R&I policy in coalition-building – towards crowd or selective collaboration paths. R&I policy can contribute to widening the range of international partners willing to explore and develop similar configurations as in Europe. Some of the efforts aimed at strengthening Europe's strategic autonomy, underpinned for instance by science diplomacy or a stronger engagement in standardisation bodies, can be interpreted as being in line with this coalition-building role.

3.3. Strategic orientations for EU R&I in the context of future disruptions

Strategic orientation combines the desires for the future with a realistic assessment of the possibilities and limitations for action, seen against the backdrop of a global and European level playing field as captured by the multi-level context scenarios and the different kinds of paths along which the different disruptive areas will unfold.

3.3.1. The crux with leadership in times of disruption

For a long time, normative perspectives as reflected in EC policy documents have emphasised the expectation that R&I policy shall contribute to strengthening technological and industrial leadership of the EU, thereby equally strengthening the competitiveness and growth potential of its industries. In recent years, and reflected in the ambitions that both Horizon 2020 and Horizon Europe, this has been complemented by the goal of addressing major societal challenges. The 'twin' green and digital

transition and the Green Deal are the most recent expressions of this strategic evolution, reflected in the first Strategic Plan of Horizon Europe.

European leadership continues to be an important normative element for R&I policy, current orientations may need to be revisited to strengthen Europe's preparedness for disruptions and Europe's positioning in shifting global power constellations and value chains.

There are also some important caveats to consider with regard to both digital and green leadership. To start with, it needs to be understood that the transitions intended are highly complex, and that the meaning of leadership is not incontestable. At its simplest, the transitions involve the production and use of technologies, and leadership in either of these can be defined, and measured, in numerous different ways. Furthermore, the societal benefit from technology production and use in either transition can be contested. For example, leadership in production of equipment in green technologies may involve unacceptable pollution levels, leadership in the use of digital technology may imply unacceptable social effects and so on.

Then, it is important to recognise that Europe is not in a leadership position in several important technological fields of the digital transition, and in particular in those areas where massive tech investments in the US and some Asian countries have already established impenetrable entry barriers. Examples are Amazon and Google with their sophisticated ecosystems of hardware, software and services, which have created strong path-dependencies. And we can see similar phenomena in areas like micro-processors, where there are strong inter-dependencies between tech firms on different continents, with only some players being based in Europe.

There are some (niche) areas, where Europe still has a leading position, for instance in relation to digital security and production, and in green and digitalised organisational models enabling circularity, agro-food systems, as well as in certain areas of energy technologies. However, leadership in these areas can erode quickly, if it is not backed by massive investments, systemic barriers to entry, a strong reliance on localised skills and knowledge, and overall efficient innovation ecosystems that are supported by sound and reliable rules and regulations.

Future disruptions may well create novel playing fields that offer the opportunity for Europe to position itself in a pioneering and leading role, which – in some areas – may be temporary only, but in others may lead to the consolidation of new and deeply embedded ecosystems in Europe. However, to achieve a leading position will require concentrating efforts in terms of funding, investment and regulation on at least some of these emerging areas of potential disruption.

Given the limited resources available to the European framework programmes, it is a matter of choice whether to prepare for some of the areas of potential disruption that may open up new leadership options for Europe, or whether to focus on catching-up or even in alternative more locally appropriate solutions irrespective of global leadership considerations. When means and resources are limited, European funding may better address areas that promise the highest potential and societal benefits in the future, complementary to national and regional efforts. These areas are not necessarily those that could lead to technological leadership.

Furthermore, for efforts that concentrate on some novel areas, it is important to define the right packages of measures – from R&D funding, upscaling public investments, skills development, a true single market, international collaboration, and smart framework conditions for innovation ecosystems – to succeed in achieving and keeping a leadership position, and to be quick in doing it. In line with the four types of strategic considerations suggested in the previous section, the combination of these measures will differ from case to case.

3.3.2. Beyond leadership: normative ambitions and disruptive areas

Global developments in recent years have demonstrated that next to concerns about leadership, there are several other normative goals in need of pursuing. Next to leading the twin transition, which is currently the overarching guideposts for EU R&I policy, the exploration of the disruptive areas has stressed the importance of taking **further normative orientations** into account; orientations that are equally, if not more vital to our future than the ability to strive for leadership. Some of these orientations have been discussed in recent years already, and they are further strengthened in view of the potential areas of disruption.

3.3.2.1. Improving global governance

Global governance is increasingly necessary and Europe's position in it is increasingly challenged. The necessity to improve global governance originates in the rising interdependency between people and in the concomitant global problems, understanding of which is increasing thanks to a globalizing scientific effort. The erosion in the position of Europe originates in the rising of populations, economic weight and military power outside Europe's borders.

The importance of science for good global governance is beyond doubt. Science is an important global commons in which Europe is competing for global leadership. Its position in global science enables Europe to play an important role in global negotiations for addressing global challenges – such as climate change, as well as for safeguarding other important global commons – such as the negotiations for Deep Sea Mining or outer space exploration.

However, Europe's performance in races for technological leadership is not commensurate to its scientific standing, and this places Europe at less advantageous positions in global negotiations about regulating technology – from existential threats from artificial general intelligence to cutting-edge transhumanist pursuits. Further to that, there is a concern that erosions in Europe's technological standing will undermine its scientific performance, competitiveness and security. In the evolving geopolitical reconfigurations, there is a concern about the rise of security concerns and that Europe's scientific performance may need to be more tightly coupled to security. Balancing appropriately the global commons character of science, the contributions of EU science to the governance of other global commons and the concerns with Europe's security and competitiveness is likely to become a more intensely felt challenge in EU R&I policy.

3.3.2.2. Resilience to crises

It is commonplace to say that the 21st century has been but a series of crises. Our exploration of disruptions indicates that the succession of crises is unlikely to stop. In each crisis there is an important role played by a mismatch between the complexity of the problem and the relevant governance mechanisms. As global populations and their interdependence grow this mismatch is found in more and more areas, and so, in all likelihood, efforts to evolve governance to catch up with the problems will have to coexist with efforts to be better prepared for, and cope with, crises.

Resilience is likely to continue to be an important issue whether crises originate in climate change, environmental and resource issues, geopolitical competition, runaway technology, social rifts and confrontations, evolving health threats or combinations thereof. For government as well as for society at large, preparedness and agility are important to contain and prevent crises from growing and spreading. Intelligence and rapid response capabilities as well as stability of supply and reliability of value chains gain in importance as opposed to opportunism and short-term optimisation.

In the evolution of governance, science, technology, research and innovation are of prime importance in ensuring that democratic principles are adhered to while the complexity of emerging challenges does not prevent speedy identification and response. Of particular importance here is the need to address potential social confrontations arising in the intersection of social disparities with the digital transition. Populism, radicalisation, disinformation, and fragmentation of society amplify social tensions and undermine resilience. The response to such threats must involve scientifically informed, principled public debate, and having spaces and practices for such debate in a very important foundation for resilience.

3.3.2.3. Reflexivity towards new frontiers

Where research into science and technology increasingly breach new frontiers and create new capabilities to shape living beings, society, the environment and the planet, developments are contested, uncertain and potentially highly impactful. Climate engineering, transhumanism and human enhancement and Artificial General Intelligence are but some such areas that require broad societal deliberation around the pursuits and conditions for public research, as well as about responsibilities and liabilities for direct and indirect effects of using emerging technologies. Such broad societal deliberation needs to be early and needs to find an appropriate balance between the need for precaution and the importance of risk taking and innovation. Reflexivity is not an easy path, but it is a necessary one.

3.3.2.4. Reframing the relationship between nature and society

It is increasingly understood that human life, individually, and society collectively, affect nature in ways that influence the prospects of other species to flourish, and through this process human society exposes natural ecosystems to major risks. The pervasiveness of human interference in nature, from nanoscale all the way to the global level makes the identification and containment of crises, and the governance of environmental impacts, particularly challenging. There are important pressures to broaden the way nature is viewed, from a resource to individual humans, to a common good or even as an ecology in which humans exist in partnership with other beings. In this context, resource crises are not only opportunities for technological change but also for broader civilizational shifts that could turn people from exploiters or nature into its stewards. There are important R&I agendas associated with different ways of valuing nature and humans influences that need to be represented in public R&I programmes alongside the technological priorities of nature exploiting industries.

3.4. Towards more differentiated R&I policy instruments and programming

Beyond the reframing of strategic objectives, the potential for disruptions raises issues about the suitability of the current programmes and instruments of European R&I policy. Put simply, future disruptions increase the turbulence R&I policy needs to face, and to which it needs to respond with more flexible and diverse policy mixes. Disruptions – we argue – will require the smart use of instruments and programmes that allow choosing between, and possibly combining the R&I policy roles elaborated above (enabling, catalytic and transformative) in a flexible manner, geared towards the specificities of the different disruptive areas in question.

Several areas of disruption suggest a need to transform existing systems of provision, production and consumption, related for instance to concerns about having to adapt to climate change, or prevent the exploitation of global commons in an unjust and environmentally damaging way. For such transformations to happen, however, European R&I policy on its own can play a limited role only, for instance by experimenting with and piloting new socio-technical configurations. Given the complexity of such configurations, the

experimental approach needs to go beyond established technological pilot projects and include regulatory and behavioural changes as well. Whether or not such comprehensive experimental solutions will scale-up and generalise depends often on sectoral policies and the rules that govern market and other coordination mechanisms, not least to ensure the breaking of historically grown structural path-dependencies and the phasing out of established technologies and systems.

EU missions are an attempt to respond to, and even channel, potentially disruptive developments in the medium to longer term. They aim to enhance the impact of R&I policy and align with other policy areas. The uncertain and complex nature of disruptive system transformations and lack of consensus on the nature of transformation sought can challenge EU missions, calling for a variety of alternatives to be pursued. So, while the ambitions behind EU missions are comparable in terms of their scope to some of the systemic disruptions explored, the latter require a more open, flexible and catalytic role of EU R&I policy, than a very targeted transformative role.

Other areas of disruption – such as in the case of artificial general intelligence, human enhancement or converging micro-nano scale technologies – are driven by very fast technological developments. They are characterised by extremely high uncertainty, and they open up entirely new horizons and future worlds, which implies that a more open approach to R&I policy is needed in order to explore a variety of possible directions and scale them quickly. This is rather similar to the ambition currently pursued by the European Innovation Council with its emphasis on the fast scaling of deep-tech start-ups. The disruptive scenarios developed point to further mechanisms of scaling and generalisation beyond start-up/scale-ups (e.g. place-based replication) and the importance of additional reflexive elements in order to address societal and ethical issues that developments in quickly emerging disruptive technology areas may raise.

What this suggests is a flexible combination of enabling, catalytic and transformative roles of R&I policy, which is both ambitious and realistic when addressing the dynamics and challenges associated with disruptions, and the necessary instruments to fulfil these roles. Does the EU have the right instruments for these roles?

Box 1: Instruments for different R&I policy roles

In order to be able to play on the enabling, catalytic and transformative roles, EU R&I policy needs to have the right instruments in place.

To assume an **enabling** role, the following elements are needed:

- Research programming with a focus on *capacity building*, including an important bottom-up component (similar to ERC).
- Programming areas aiming to develop capacities in specific areas that are potentially important and not supported by bottom-up funding (which reflects current instruments in the Societal Challenges pillar of Horizon Europe, but also the COST model).
- In the EU, the *cross-national cooperation* would be important as well as the establishment of *inter-institutional linkages* (see European partnerships) in order to bring the best competencies and capabilities together (e.g. an extended MSCA scheme, including scholarships to industry).
- *Public engagement in the agenda setting process* as an important element for the legitimacy of the policy choices.

To play a **catalytic** role, R&I policy requires some additional elements:

- Research *networking and engagement* of the respective stakeholders, supported by community building activities (e.g. through investments in networking infrastructures and in community building projects).
- Improve the *alignment* of R&I policy with other, often sectoral, policy areas. This implies building interfaces and exchange processes (while not over-burdening it with too ambitious objectives) and ensuring that the insights from R&I are made available to sectoral policies (which may require involving sectoral policies in the design of R&I programmes).
- In addition, *policy experimentation* should become an area of common interest for both R&I and sectoral policies (e.g. through living labs and regulatory experimenting).

To be **transformative** a very demanding set of instruments needs to be put in place in addition:

- Mixing the instruments of the other two with strong elements of *demand-side policies* (ie., public procurement and regulation), in a proactive "industry policy" which exercises some degree of political direction on the economy be it for public utility sectors (e.g. transport), simply demand-driven policy (e.g. farming) or regulation-driven (e.g. in some disruptive high-tech industries).
- Pursuing *consensus-building across various stakeholder communities* implies a major effort of wide-ranging societal engagement in the process of priority setting.
- *International cooperation* becomes a strategic choice between crowd paths and selective paths, depending on the nature of the disruptive challenge addressed. Strategic knowledge management issues apply differently to different areas – depending also on Europe's strengths and weaknesses.
- *Strategizing* is at the heart of aiming to be transformative. Political strategizing in the economy involves important risks in terms of the fairness and legitimacy of the governance regime within which the strategy is applied. Transformative policies potentially involve contradictions with the principles of free trade and free markets that underpin the current rules-based international order.

3.4.1. R&I programming for disruptions

Considering the above discussion of R&I policy roles and instruments there are some key issues that need to be addressed in R&I programming if EU R&I policy shall be put in a position to better address disruptions:

3.4.1.1. The need for more open instruments

All disruptive areas considered are characterised by significant levels of uncertainty and complexity, even if to a varying extent. This has consequences for the ability and need to formulate objectives and directions for R&I, and thus for the contribution that R&I policy could make. It is therefore important to provide space for different views of the "problem-solution" space in the programmes, and this needs to be recognised not only in the exploratory frontier research in pillar 1 of the Horizon Europe framework programme, but also in its targeted parts on the grand challenges in pillar 2.

The need for more openness concerns programme governance and definition of the R&I agenda, as well as flexibility in the implementation of that agenda. In all disruptive areas many different actor

groups have important roles to play in shaping the future. These can be societal actor groups with a say on ethical and societal consequences of disruptive technologies (e.g., transhumanism) or on the societal tensions that a major change in one of the key disrupted systems may entail (e.g., in relation to the future of health, social confrontations). Some disruptions will depend greatly on future processes of global collaboration and governance (e.g., global commons, hydrogen economy, artificial general intelligence).

Shaping the agenda does not necessarily mean that all new actor groups will need to be partners in collaborative R&I projects. While we see a greater need to broaden further the scope for novel types of participants – in the economy, policy, public administration and broader society - the need for collaboration varies between areas. One important parameter is the type of R&I activity. There are differences between basic research on the one hand and applied research, demonstration activities and piloting on the other. In the former, the range of actors involved in research may well be restricted to specialists, with other actors being involved only in wider agenda-setting roles. This even holds for quite fundamental research on emerging and disruptive technologies like artificial general intelligence or human enhancement, where the early involvement of societal stakeholders is increasingly important in order to take ethical and societal concerns into account before path-dependencies have been created that would make any substantial re-orientation impossible.

3.4.1.2. The criticality of time

Speed and timeliness are key in addressing disruptive areas. The pace of change in several of the explored areas of disruption is very high, and so is the need to keep pace for public policy in general, and for R&I policy in particular. This has been recognised in the current Horizon Europe framework programme by the emphasis put on scaling in the EIC, which applies primarily to deep tech areas, where the fast growth of start-ups is regarded as the key mechanism. What is missing, however, are corrective reflexive mechanisms. Thus, often disruptions form the targets of R&I programming activity after they have occurred (e.g., Ebola, COVID, migration, defence – following the invasion in Ukraine) and programming finds it hard to adapt to insights into critical and contested societal and ethical implications.

The challenge is also present in disruptive areas that unfold more slowly (e.g. climate change, hydrogen economy or global commons), but where in view of inertia, uncertainty and complexity of their impacts on society, economy and the environment, there is a continuous need for monitoring progress and incorporating new insights into the understanding of the challenges and potential of new options, and adapting policies and programmes to them. In other words, they equally require flexibility, reflexivity and learning, in addition to long term directional commitments.

3.4.1.3. Global collaboration vs. preferential international collaboration

In most disruptive areas, the future is shaped in arenas well beyond Europe. If R&I is to pave the way forward, international, if not global collaboration is very important. In several of the areas studied, the key choices are made at a global level, where the influence and control of EU policy is limited by its (declining) economic weight and – in several areas – its receding technological leadership. The extent to which EU positions can be brought to bear often hinges upon collaboration with selected partners sharing similar concerns and values (e.g., the US, Japan, and some Latin American countries). For instance, in relation to the hydrogen economy – according to our scenarios – collaboration with the US plays a crucial role. In artificial general intelligence there is a tension between a competitive race between major blocks on the one hand and the benefits of common global rules on the other hand. In other disruptive areas, truly global collaboration is needed to establish common rules, e.g., in relation to climate change, global commons or – as indicated – in artificial general intelligence.

This diversity underlines the need for a more differentiated approach when it comes to establishing collaborative ties with non-European partners in emerging areas of disruption. It may be that some general rules and principles will be sufficient in the longer-term, i.e. when there is higher likelihood that they would be respected by member states, but currently, and also in the short- to medium-term, this seems rather unlikely, which is why a thorough analysis and mapping as well as a political discussion of common European and corresponding national interests in the different areas of disruption should underpin the international collaboration strategy.

3.4.1.4. Programming capacities and capabilities

In order to be able to address the challenges associated with openness, time and balance between broad and closed collaboration, programme management requires appropriate capabilities and capacities. This would imply going far beyond allocating and spending grants, and rather become an active part of the shaping of EU science and technology capacities and institutions. The EU programming machine needs to be highly sensitive to alternative agendas and to have highly open deliberation processes that address them, if it is to be able to enable and catalyse change, and to organise the levels of consensus required for launching transformative policies in particular.

Europe's ability to be prepared and to respond appropriately to disruption-related challenges and opportunities depends on making best use of capacities that exist in all Member States across the European Research Area. This adds an additional level of complexity to programme management for disruptions. Strategic planning at the EU level should be an integral part of strategic programming across the European Research Area.

The role and influence of EU R&I policy at global level also depends on the ability to form common positions within the EU and promote them at international and global level. For the EU to play an influential role in addressing potentially disruptive developments in accordance with its values and interests, it needs to speak with one voice. Reaching consensus in Europe over strategically important areas is very challenging, in particular given the often value-related character of disruptive areas (e.g., regarding social confrontations, transhumanist revolutions) and the – at times - strong partial interest of individual member states (as opposed to widely shared common European interests). This challenge is further enhanced by the uncertainties associated with disruptions: Neither the constituencies and stakeholders, nor their interests and positions are clearly defined at the early stages of potentially disruptive developments.

What these issues suggest is that the perspective on EU R&I policy instruments and programming needs to evolve. The disruptive areas indicate that more flexibility is needed in order to address them appropriately, and that EU R&I policy needs to embrace new actor groups and constituencies well beyond the traditional players and engage them in processes of forming common European positions. This is imperative if R&I policy wants to play a significant role in society in general, both in Europe and beyond, and in relation to particular areas of disruption. A first step in this direction is to identify alternative ideas for addressing the disruptive challenges ahead of us. This is what the next section is about.

3.5. Future disruptions and candidate priorities for EU R&I policy

The insights from the foresight work on future disruptions points to a number of areas that deserve consideration in the further development of the 2nd Strategic Plan of Horizon Europe, but also in the upcoming debates about the purpose and the overarching orientations of the next framework programme. For each disruption examined in this exercise there are explicit R&I policy implications including specific research and innovation agendas that could be pursued, that were developed in chapters 5 – 13. In addition to those, the study carried out

an expert survey in which experts were shown a summary of the scenarios developed and were asked to identify potential R&I priority topics for the 2nd Strategic Plan of Horizon Europe. Tables 1 to 4 give an overview of these topics in the respective disruptive areas.

Table 31: Foresight expert survey priority areas of R&I – The global landscape

Geopolitical reconfigurations
• evolution of critical dependencies in energy, food and trade, • circular economy and material-recycling systems with reduced import dependence, • sustainable, secure and resilient food supply systems (e.g. agroecology, aquaculture, fisheries), • development of global natural resource governance (see UN International Resource Panel reports), • engagement of autocracies in a win–win dialogue, • societal and geopolitical impacts of climate change, • global governance models for biosecurity.
Global commons
• alternative forms of governance and ownership models to manage global/local commons, • science and scientific knowledge as global commons, • substitutes and alternative sources of materials to combat over-exploitation of global commons, • ways to abandon the dominant framing of goods as private (market) or public (state) and instead recognise their value as common goods, • upscaling from local to global governance of commons: infrastructures & management systems.
Climate change
• biodiversity and climate change, • nature-based solutions, • circular design and material use in climate technologies, • integration of climate impacts in environmental impact assessments, • behavioural change and ways to increase people's capacity to react to climate change.

Table 32: Foresight expert survey priority areas of R&I – Social and value changes

Social confrontations
• sources of social fragmentation and tensions, and the role of social media, • effective methods for sociocultural integration and tolerance of diversity, • pilot of new mechanisms for managing and resolving conflict in society (new forms of mediation on major decisions of public interest), • development of cross-cultural communication and governance, • evidence-based and normatively informed policy advice, • new forms of public–private community governance.

Criminal and lawful economic activities
• crimes against nature, • social innovation for community security, • ways of detecting and detecting new forms of crime, • technological traceability, • monitoring systems for new types of illegitimate activities, • ethics and law – new tendencies, • design for radical transparency, • new forensic technology and methods.
Future of health
• understanding of health and its value, • extension of personalised medicine to self-diagnosis and self-medication/treatment, • new testing modes and models – speeding up medicine approval without compromising safety, • early detection of non-communicable diseases, • interlinkage between health (humans, animals and the environment) and climate change, • real-world evidence-based health system strengthening through implementation science, • non-antibiotic treatments for bacterial infections.

Table 33: Foresight expert survey priority areas of R&I – Technology and Society

General artificial intelligence
• AI improvements for specific applications, • the nature of AI and human intelligence, • AI in medical applications, • understanding of cooperation between humans and general AI systems, • ethical standards and AI regulatory sandboxes, • pilot of rule sets for general AI applications in specific areas of application, • understanding of threats and opportunities associated with general AI, • AI supporting continuous learning and collaborative problem-solving, • interpretable AI.
Transhumanist revolutions
• Understanding ageing and disease, • rigorous criteria to assess, and regulate, the impact of technologies on humans considering both psychological and physical health, • ethical aspects in the context of digitalization - industry of the future, • the psychological consequences of immersive worlds, • productive caring communities in connected spaces, • molecular anti-ageing therapies.

Table 34: Foresight expert survey priority areas of R&I – Society and nature

Resource disruptions
• nature-based solutions, • use of high tech in recycling and material decomposition (including the design and manufacturing stage), • laws for nature (legal status and representation of nature, for example animals, plants, landscapes), • sustainable soil management practices, in line with agroecological principles, • resource management – environmental and social baseline data acquisition.
Converging technologies at micro-nano scale
• big data, environmental modelling and simulations, web applications and tools for decision-making, • environmental impact assessment procedures for micro- and nano-level interventions, • monitoring techniques for the micro, nano and virtual cosmos, • biocentric/geocentric ethics, • safety and testing regulation for nanotechnologies and micro technologies.
Hydrogen economy
• opportunities and challenges of an increasing variety of energy options, • resilience, security and vulnerability of the new energy system, • large-scale storage systems for hydrogen, • upscaling of H2 production technologies, including the process of synfuel production (e.g. binding H2 to C or N, yielding methanol or ammonia), • hydrogen as a fuel for long-range transport (e.g. ships, trains, planes, rockets).