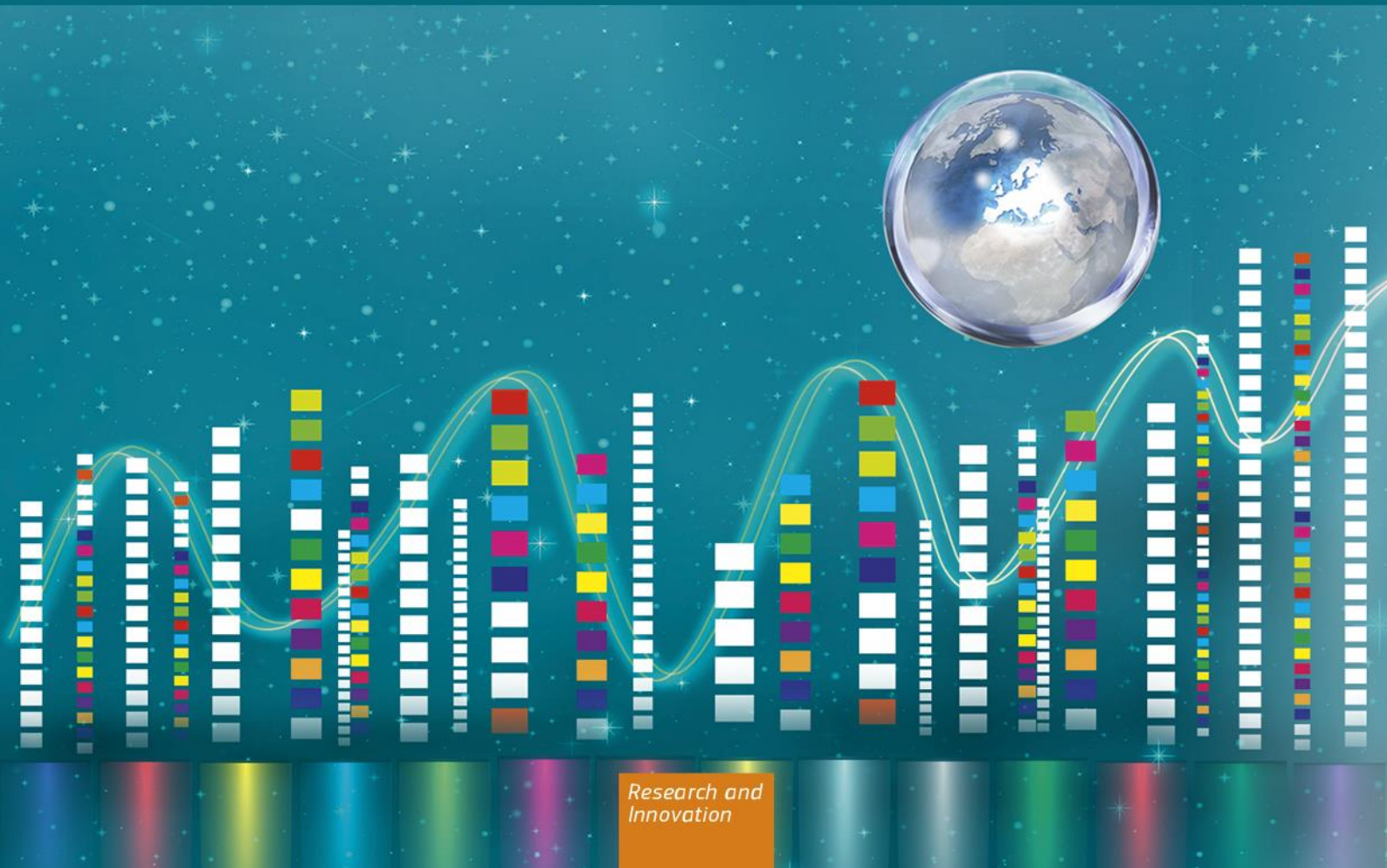




Foresight

Transitions on the Horizon:

**Perspectives for the European Union's
future research and innovation policies**



Research and
Innovation

Transitions on the Horizon:

Perspectives for the European Union's future research and innovation policies

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EUROPEAN COMMISSION

Transitions on the Horizon:

Perspectives for the European Union's future research and innovation policies

Final report from project BOHEMIA

Beyond the horizon: Foresight in support of the EU's future research and innovation policy

(Contract no. PP-03021-2015)

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All views expressed are those of the authors and do not necessarily reflect the views of the European Commission

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FOREWORD

Research and innovation is at the core of the Commission's vision for a more united, stronger and democratic Union. Our budgetary proposals for the period 2021-2027 include the largest absolute increase ever to the European Union's investment in research and innovation to € 100bn. Horizon Europe, the next framework programme for research and innovation (2021-2027) is the main vehicle that will bring the investment to bear on Europe's ability to shape the future.



Foresight has been a key ingredient of the Commission's preparations for Horizon Europe. It was more than two years ago that we launched a foresight study to support future EU policy in research and innovation: the BOHEMIA study. The study has accompanied the preparations of our proposals ever since.

Its first report, published in June 2017, described broad scenarios about the evolution of the context of EU research and innovation based on the Sustainable Development Goals and on the role of the European Union in the world. Those scenarios helped shape the recommendations of the High Level Group on maximising the impact of EU research and innovation programmes, chaired by Pascal Lamy, as well as the Commission's reflection on global challenges.

Its second report, published in December 2017, made public the data from a Delphi survey investigating future trends in science, technology, the economy, society and in research and innovation systems. This data has been very helpful for our reflections on a mission-oriented approach.

This final report of the BOHEMIA study involves scenarios and recommendations that broaden our strategic intelligence and allow us to reflect on new important emerging areas, risks and opportunities, and on new ways to stimulate important transitions. It provides an information base and a reflection that advances the debate on Horizon Europe and how to maximise its impact for a better Europe in a better world.

It is often said that the future cannot be predicted. It cannot be read in a book. The future is created by purposeful strategies and actions. Foresight provides a conversation space in which purposeful strategies and actions can take shape. I hope that readers of the BOHEMIA report will be inspired to join the Commission, the Member States, stakeholders and citizens in deliberating on the future and shaping it through research and innovation.

Carlos MOEDAS

Commissioner for Research, Science and Innovation,
European Commission

A handwritten signature in blue ink, appearing to read 'Carlos Moedas', on a white background.

SUMMARY AND RECOMMENDATIONS

BOHEMIA aims to support ongoing debates about future European R&I policy by providing a view of needs and opportunities for R&I in Europe from a future perspective, with a time horizon to 2035-2040, and highlighting their implications for EU R&I priorities in the 9th framework programme.

The challenge: making transformative change in Europe through EU R&I policy

Recommendation: Make EU R&I policy transformative

Trends in R&I activities, practices and organizational models combined with a highly volatile global context posing unprecedented challenges, call for a transformative EU R&I policy.

The approach: Towards a new mode of European R&I policy

Recommendation: Step up the ambitions of European R&I policy to become the engine of European and global transitions

For the EU to maintain a strong economic and political role in the world and to be able to co-shape “the future Europeans want”, EU R&I policy needs to simultaneously address four transitions that will move the world towards the Sustainable Development Goals. The transitions concern:

- Social needs: Providing for the needs of people;
- The biosphere: Safeguarding a hospitable planet;
- Innovation: Harnessing the forces of change;
- Governance: Joining forces for a better world.

Recommendation: Put preparedness at the heart of EU R&I policy

Preparing for the future must include exploring a diversity of research options through cutting-edge research and scientific excellence in order to advance the frontiers of knowledge. It must also include strategic focus on areas where scientific curiosity may be lacking and potential policy and commercial benefits can be accrued. Strategic preparedness involves foresight (the disciplined exploration of alternative futures) as well as broader anticipatory governance structures that can respond to the insights developed.

Recommendation: Accelerate market creation, by providing space for policy experimentation

It is increasingly apparent that the challenges facing Europe and the world are substantial and not fully understood. Yet, postponing actions until we fully understand the context can have dire consequences. Policy experiments can drastically improve understanding of problems and potential solutions. They create the space for markets to emerge, for accelerating the realisation and scaling of new solutions, and for mutual learning between innovators, users and policy makers.

Recommendation: Improve the alignment of R&I and sectoral policies through the innovation principle and policy coordination

Solving real world social, economic and policy problems – achieving socially relevant missions- requires R&I and other forms of policy actions (e.g. regulation, standards, procurement). The increasing complexity of real world problems is combined with a lack of recipes about how to successfully combine policies. Improvement in policy alignment is an important area of experimentation that should be supported by EU R&I.

Recommendation: Strengthen the productivity and impact of R&I, by better connecting supply and demand of innovation

Strong interactions between supply and demand for innovation is an often over-looked feature of successful innovation ecosystems, which should be reinforced by future R&I policy measures to promote a wider spread of innovation capacity.

Recommendation: Promote a sense of ownership through new forms of citizens engagement in agenda-setting and R&I

Citizens' engagement in research, from setting objectives, missions and agendas to implementation, is increasingly demanded by citizens. This is an opportunity for the EU to improve the productivity of EU funded R&I, and to strengthen the profile of Union institutions amongst EU citizens.

The priorities: Towards a thematic agenda

Recommendation: Prioritise European R&I of relevance to the four transitions

The four transitions provide a frame of reference and focusing device for the ambitions and possible priorities in future EU R&I policy.

Recommendation: Follow the top R&I directions recommended by the public consultation in view of likely future disruptive scenarios

BOHEMIA developed 19 targeted scenarios of likely disruptive futures, and carried out a public consultation on the EU R&I policy implications of these scenarios. Some of those recommendations got overwhelming support and should be considered in the planning of FP9, irrespective of its strategic positioning towards the scenario they come from.

Overview of top priority R&I directions for the 19 targeted scenarios

Targeted scenario	Top priority R&I directions
Assisted Living	E-health solutions including tele-medicine, measuring health data and transfer
	Research on assistive technologies and the impacts of their application
The Bio-economy	Developing and testing new circular bio-economic processes
Cheap Renewable Energy	Methods, practices and solutions to promote energy saving and reduction of energy consumption
	Exploration of energy storage solutions, beyond batteries
Continuous Cyberwar	Tools for monitoring, evaluation and responding to threats
Ubiquitous Expert Systems	Development of better machine-learning algorithms
Defeating Communicable Diseases	Effective public health education about communicable diseases, incl. Prevention, treatments, hygienic questions, disinfection
Emotional Intelligence Online	Developing standards and codes of behaviour concerning the use of individuals' emotions for commercial and public purposes, as well as for emotional data sharing and privacy
	Research and development in cybersecurity, particularly in relation to the

	online sharing and use of information about individuals' emotions
Human Organ Replacement	Breeding of tissues and organs (theory and practice)
ICT-Based Security and Defence	Understanding the roots causes of security challenges
Low Carbon Economy	Exploitation of new business models for circular economy and promotion of sustainable lifestyles
Material Resource Efficiency	Environmental impact assessment
Nano-to-Macro Integral Manufacturing	Understanding the impact of 3D printing on individual health and safety and on the environment, across various industries
Nature Valued	Building models for a sustainable circular economy based on renewable resources and renewable energy
Precision Medicine	Making use of biotechnologies for personalised medicine
Reframing Work	Research on new variants of entrepreneurship through collaborative research
Smart Sustainable Mobility	Research on battery efficiency, energy storage and recovery technologies
The Electrosphere of Sensors	Development of new sensors based on a better understanding of the relation between sensing and knowing
Towards a More Diverse Food Supply System	Understanding and managing systems of sustainable agriculture and aquaculture
Towards a New Knowledge System	Adapting educational techniques to online environments, and piloting various solutions (e.g., distributed online courses with tutoring, navigating through the stock of knowledge)
	Understanding the neural basis of knowledge acquisition, and the relation of cognition to experience more generally
	Devising intellectual property models and practices in open knowledge systems, and experimenting with new forms of IP sharing

1 INTRODUCTION

Project BOHEMIA aims to support ongoing debates about future European R&I policy by providing a long-term view on the requirements and opportunities for research and innovation in Europe, and for the next framework programme in particular. It complements other preparatory activities, in particular the interim evaluation of Horizon 2020¹ and the modelling efforts to demonstrate the economic impact of R&I, and has fed into the Lamy Report². Its contribution focusses on exploring the future potential areas of research and innovation on which Europe could concentrate its efforts.

It usually takes five, ten or even more years for research results to diffuse widely and achieve their full impact in society and economy. While lead-times are getting shorter, especially in some sectors, they are still a significant factor in planning of R&I policies and activities. Pursuing relevance across a wide range of fields and policies, BOHEMIA started from socio-economic and global challenges at a time horizon of 2035 to 2040. What will the world look like by then? Will the needs, aspirations and challenges be similar to today's or rather look substantially different? Providing orientation with regard to these questions is essential for guiding research and innovation activities that respond to future requirements.

One fundamental set of changes to be considered relates to the nature and the scope of R&I activities, practices and organizational models. Part of the trend is the increasing emphasis placed on openness and on the participation of a wider range of actors and stakeholders in the design and implementation of R&I agendas. This takes place in a highly volatile global and socio-economic context, which Europe can at best influence to some extent.

These requirements translate more specifically into the following three objectives, which are addressed respectively in the three phases of the BOHEMIA project:

- Explore possible alternative futures in terms of societal, economic and political conditions and boundaries for EU R&I policy;
- Assess the likelihood and importance of the possible future evolution of socio-economic as well as of scientific and technological challenges, needs and opportunities;
- Recommend potential priority areas and policy approaches for addressing them.

As BOHEMIA has piloted a novel methodology which was designed specifically to support the preparation of the next framework programme, the next chapter (Chapter 2) outlines the approach and the methods used, in order to ensure transparency about the process of generating insight and allow the assessment of their validity.

Chapter 3 briefly outlines four transitions that the EU Framework Programme needs to support. The transitions represent clusters of UN Sustainable Development Goals (SDGs) that respond to sets of challenges posed by the superposition of global megatrends. Inspired by the BOHEMIA scenarios report³, the transitions outline areas where major transformative changes – at global, European, national, and sub-national levels – are needed and/or are likely to arise in the next 20+ years.

Chapter 4 provides the core analytical findings of the project. It presents and discusses briefly the 19 targeted scenarios that resulted from the analysis of the BOHEMIA Delphi

¹ EC (2017c)

² EC (2017b)

³ Ricci et al (2017)

survey⁴. The full targeted scenarios were used in a public consultation that enquired about their implications for EU R&I policy. Chapter 4 provides the broad analysis of the consultation, while the complete scenarios with their implications, as resulting from the public consultation, are presented in separate documents.

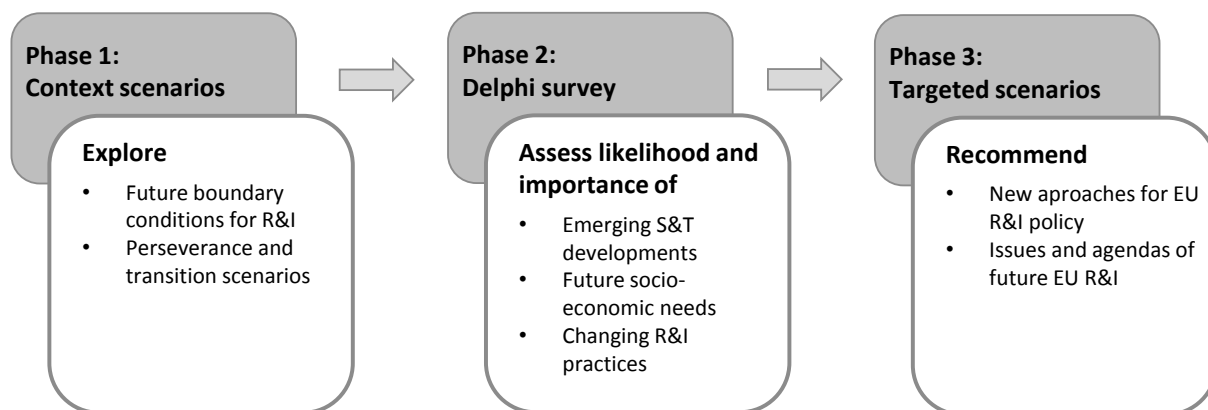
The final section (Chapter 5) brings together the recommendations from the whole project for future EU R&I policy, including the list of future directions for EU R&I policy that were most supported in the public consultation.

⁴ Gheorghiu et al (2017)

2 APPROACH: POLITICAL AMBITIONS IN AN AGE OF UNCERTAINTY

Project BOHEMIA addresses developments both in the context of R&I and in the field of R&I to devise new possible approaches and issues for EU R&I policy. Figure 1 below presents the three phases of the BOHEMIA project and how each of them contributes to the project's objectives.

Figure 1: Objectives and corresponding phases of the BOHEMIA project



2.1 Phase 1: Context scenarios

R&I policy does not take place in a vacuum, but is embedded in a wider socio-political and economic context. In order to explore boundary conditions set by this context, BOHEMIA has developed two contrasting context scenarios for each of the following seven domains⁵: global political and socio-economic context, climate and energy, environment and ecosystem resources and services, health, security and resilience, accelerating innovation, and towards a world of cities.

In each of the seven domains, a pair of context scenarios was developed, in order to capture the variability of the future in a simple and clear-cut manner. The pair included a 'perseverance scenario' and a 'transition scenario' (see Box 1).

Box 1: BOHEMIA Context scenarios

Transition scenarios represent ambitious structural and institutional change process, which in many cases will alter of the 'rules of the game' in the seven domains. As such, they focus on areas where major changes are necessary and/or likely. They define the requirements and opportunities for future R&I, but also point to important implications for other policy areas and strategies of stakeholders.

However, transition scenarios cannot be taken for granted. Overcoming historically grown path-dependencies and switching to a different trajectory is very difficult. Therefore, it is necessary to be also prepared for **perseverance scenarios**, in which the fundamental structural and institutional conditions persist by and large as they are today.

The transition scenarios would enable the EU to meet both sets of ambitions simultaneously: to maintain or even strengthen its global role, at least in selected areas, and at the same time contribute to the fulfilment of the SDGs.

⁵ Ricci et al (2017)

These transitions cannot be achieved by R&I alone, but require complementary actions in other policy areas and by other actors and stakeholders if the ambitious agendas are to be realised. To manage longer-term transitions there is a need for new forms of governance.

2.2 Phase 2: Delphi process

Emerging developments in science, technology and innovation (including social innovation!) are essential forces that could help realise the transition scenarios, or pose barriers and risks for the transition processes. The second phase of BOHEMIA examined the likelihood and significance of certain emerging trends in science, society, the economy and policy, and in R&I practices.

Box 2: The BOHEMIA Delphi survey

Delphi is a survey technique for collecting expert and stakeholder opinions on statements about the future. Delphi surveys typically build on a process of participants' revisiting their assessments in light of interim survey results. In the past Delphi questionnaires were circulated in multiple 'rounds'; today online questionnaires allow revisiting interim results in real time. The BOHEMIA Delphi survey was a real-time online survey, in which participants were able to revisit their initial assessments - the second assessment could be made under the influence of own and other judgements, which were provided in a visualised form.

Moreover, BOHEMIA employed a Dynamic Argumentative Delphi (DAD) technique, asking participants to also propose and rate arguments underpinning their responses to the Delphi statements. The goal of DAD is to enable inter-active online Delphi consultations with a large number of participants (in the hundreds or more), while adding an 'argumentative' (i.e., justification-based) dimension to it. This argumentative dimension allows understanding the reasons behind the assessments made.

The BOHEMIA Delphi survey contained 147 statements; concerning future states of affairs with presumed relevance for R&I policy in Europe. The statements were formulated in a precise and concise way, based on a combination of sources: interviews, scanning of internet sources scientific literature and foresight studies, the BOHEMIA context scenarios, a media analysis, a project team workshop, and a scoping workshop with the EC Foresight Correspondents' Network. As a result, the final set of statements is well balanced and its scope is wide ranging, although, of course, there is no such thing as a perfectly balanced and fully exhaustive set.

The survey was implemented between 5 May 2017 and 18 June 2017. Invitations were sent to approximately 15,500 individuals, with reminders dispatched up to three times. Eventually, the number of registered participants (~ 1500) exceeded initial expectations by a substantial margin. About half of the participants went through the entire survey for one or more fields of knowledge, and ca. 18% of these also revisited their initial assessments and arguments. More than 10% of the participants originated from a country outside the EU, and the participation from EU member countries was reasonably balanced, though – as expected – with a comparatively strong participation from the home countries of consortium partners (Austria, Germany, Italy, and Romania).

2.3 Phase 3: Targeted scenarios

The results of the Delphi survey were analysed as to the degree of expert consensus on their likelihood within the timeframe addressed in the study and on their significance for EU R&I policy. Starting from likely to materialize statements, the results were synthesized into 19 targeted scenarios. The process involved clustering of Delphi results into draft targeted scenarios, a workshop with the foresight correspondents' network and an online consultation with a wider audience of stakeholders.

With the growing significance that the notion of 'missions' has acquired recently in the context of both European and national R&I policy, BOHEMIA has strived to generate results that are at a comparable level of granularity, thus serving as a source of inspiration for upcoming political debates about priorities for the next European framework programme (see Box 3).

Box 3: Making sense out of Delphi results with the help of targeted scenarios

The Delphi results provided the foundation for the formulation of more targeted scenarios, which in turn suggest possible orientations for future EU R&I policy. Based on the assessment of the Delphi statements in terms of likelihood and significance, a first set of targeted scenarios was developed following a clustering exercise of related statements. The targeted scenarios varied in terms of level of abstraction, but followed a common template:

- A **summary** of the essence of the targeted scenario
- A brief description of the actual scenario, formulated as a **visionary outlook** on ambitions and challenges with a time horizon of 2035 to 2040
- A set of arguments addressing the **relevance** of the targeted scenario at global level (i.e., their contribution to tackling SDGs) and at European level (i.e., why is it important for the EU)
- A section on **implications for EU policy** areas adjacent to R&I policy, in order to point to framework conditions and demand-side policy issues that will need to be addressed if the targeted scenarios are, or need to be, realized.
- A specific section on the **EU R&I policy implications** of the targeted scenarios, distinguishing between understanding-oriented research, regulatory science and policy-knowledge, solutions-oriented research, and scaling-up experiments, demonstration and social innovation.

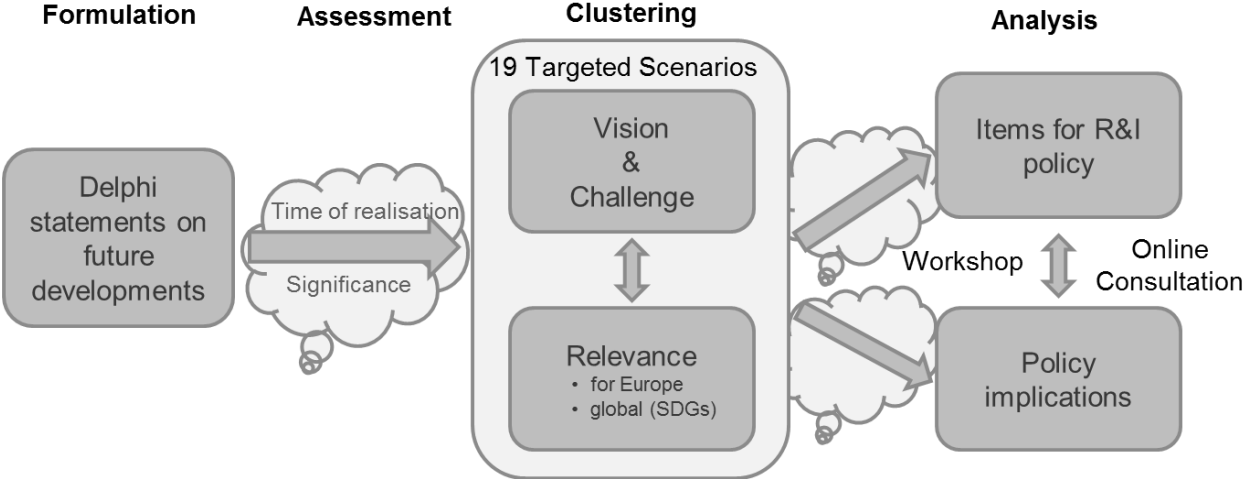
The targeted scenarios were validated and refined in a workshop with the EC Foresight Correspondents' Network, and subsequently were placed to a final online consultation, which centred on their importance for EU R&I policy and on their implications for future EU R&I policy directions. In total, about 1250 participants registered for the consultation, and finally almost 750 finished responding to at least one field of knowledge.

The consultation delivered an overall assessment of the perceived relevance of the targeted scenarios for EU R&I policy, and an amended and ranked list of possible future directions for EU R&I policy perceived as priorities within each of the targeted scenarios.

These results were further refined by a process of shortlisting key R&I directions, taking into account the total number of votes received as well as their share, and aggregating duplicates into clusters⁶. Finally, the resulting clusters were slightly rephrased in order to better reflect the essence of the prioritised key R&I directions. Figure 2 below illustrates the process of sense-making from the formulation of Delphi statements to the analysis of targeted scenarios.

⁶ See Annex 2 for further details.

Figure 2: From the Delphi statements to future directions for EU R&I policy



3 FOUR KEY TRANSITIONS

3.1 Framing a transitions agenda

In the scenarios report⁷, we have argued that, in spite of the fundamental openness of the future as reflected in the pairs of perseverance and transition scenarios,⁸ the transition scenarios represent the future Europe should aim for. The scenarios were selective, covering only parts of the future space, composed of four major domains of change.⁹ The domain of social needs, for instance, was represented by the scenario pairs on 'Security and Resilience' and on 'Health', while other social needs, such as food supply or inequality, were addressed only indirectly, as part of other scenario pairs. Moreover, the seven scenarios spaces are not independent but inter-penetrate each other. This is probably most pronounced in the scenario pair on 'Towards a World of Cities'. Cities represent the spaces where most of the scenarios interact. In spite of the overlaps and inter-relations, the four main domains, to which the scenarios were assigned, showed a degree of coherence and distinctness. This inspired us to re-frame them as key transition goals.

The purpose of this chapter is to sketch these four distinct transition domains and highlight their distinctive features. From a global perspective, the four key transitions can be tied to the 17 Sustainable Development Goals (see Figure 3). From a European perspective, the transitions sketch pathways that would allow the EU to maintain and possibly strengthen its global role, while at the same time moving towards the Sustainable Development Goals. The four domains of key transitions are:

- **Social needs: Providing for the needs of people**, to ensure a better life for all;
- **The biosphere: Safeguarding a hospitable planet**, to ensure the survival of the species;
- **Innovation: Harnessing the forces of change**, to improve change and the mechanisms that bring change;
- **Governance: Joining forces for a better world**, to establish the conditions for successfully managing transitions.

The realization of key transitions requires more than just evolutionary adjustments to current institutions. Significant organizational and institutional changes are necessary to stimulate and manage such transitions, both in the EU and globally. Yet, continuing along established institutional and structural paths would lead to a downward spiral with sub-optimal outcomes in terms of both SDGs and Europe's ability to play a significant role in shaping global futures.

⁷ Ricci et al. (2017)

⁸ The seven pairs were addressing the following areas: 1) Security and Resilience, 2) Health, 3) Climate and Energy, 4) Environment and Ecosystem Resources and Services, 5) Towards a World of Cities, 6) Accelerating Innovation: People and Tech Convergence, 7) Global Political and Social Context.

⁹ In the scenario space, the four domains were called 1) Social Needs, 2) Biosphere, 3) Drivers of Change, and 4) Governance. As the delimitation of these domains has evolved in the course of the BOHEMIA project, they have been re-named as four transitions: 1) Social Needs: Providing for the Needs of People, 2) The Biosphere: Safeguarding a Hospitable Planet, 3) Innovation: Harnessing the Forces of Change, and 4) Governance: Joining Forces for a Better World.

Box 4: Transitions and Transition Management

Over the past twenty years, an extensive body of scientific literature on transitions has been produced, focusing in particular on sustainability and energy matters¹⁰. Transitions can be defined as the simultaneous occurrence of far-reaching institutional, organizational, technical, social and political changes in and of socio-technical systems.¹¹ Apart from stressing the importance of devising longer-term transformative strategies in order to guide the necessary changes in a smooth, rather than in an uncontrolled and disruptive manner, emphasis is put on principles of reflexive governance and deliberative politics procedures for managing transitions¹². Transitions are too complex and uncertain to be managed within traditional blueprints of a command-and-control planning paradigm, but require a continuous adjustment and learning process along the transition path at multiple levels of action, from local to global, and across different fields of action and policy.

Much of past research has focused on more sustainable modes of consumption and production, in particular in areas like transportation, energy supply, water management or housing. It is now well understood how transitions arise. However, turning this understanding into sound advice on how to better manage present and future transitions is still a major challenge.

More recently, sustainability transitions have triggered debate about the need for a new R&I policy, associated with transformative change, stressing the necessity to open up R&I policy to the demand side and pursue more ambitious goals tied to societal challenges¹³. This kind of reasoning has also attracted interest in policy circles including UN, EEA and OECD¹⁴, but also national governments that have embarked on transition strategies in selected areas¹⁵.

The concept has been applied to different kinds of transformative change processes, in which the unintended disruptive effects of transformations are contained by deliberate efforts of governing change in a systematic and coordinated way involving stakeholders ('transition management').¹⁶ The lessons learned from these first experiences support the argument that reflexivity, continuous adaptation, and coordination across levels and action fields are crucial ingredients for governing transitions. This is a significant departure from current governance practices, requiring an opening up of existing policy silos.

¹⁰ See the journal *Environmental Innovation and Sustainability Transitions*, and regular International Sustainability Transitions conferences, and some highly cited publications such as Geels and Schot (2007), Markard et al. (2012), Fischer-Kowalski and Rotmans (2009), and others.

¹¹ Adapted from Markard et al. (2012).

¹² See Voss and Kemp (2006).

¹³ See for instance Schot and Steinmuller (2016); Edler and Nowotny (2015) or Weber and Rohracher (2012).

¹⁴ UNDP has established its approach to transition planning for developing and emerging countries (<http://www.undp-globalfund-capacitydevelopment.org/en/transition/>). OECD has shown a growing interest in system innovations and their governance (OECD 2016). The EEA in its most recent flagship publication "State of the Environment Report" refers explicitly to the need for an environmental transition (EEA 2015).

¹⁵ See, for instance, the Dutch energy transition and the current German *Energiewende*.

¹⁶ For the concept of transition management see Rotmans et al. (2001). However, 'transition governance' is more appropriate a term and will be used in this report.

Figure 3: Main areas of transitions



3.2 Transition 'Social Needs: Providing for the needs of people'

This first transition concerns the changes that are necessary to improve the quality of people's lives, to provide access to fundamental public services and to substantially reduce inequalities of various kinds. This transition depends on a combination of technological, institutional, organisational and social innovations, which – taken together – represent a complex challenge. Distinctive for this transition area is the key role played by basic, often public, services, including guarantees for access to food, lodging, health systems, water supply, safety/security, social security, infrastructure, etc. One characteristic of those needs is that they are personal and perceived by individual people. Accordingly their fulfilment is strongly dependent on behavioural changes at the individual level.

In the BOHEMIA scenarios report, the transitions in the two areas of health and security were elaborated in more detail¹⁷. The main challenges in the health area are resulting from demographic trends on the one hand, in particular related to the ageing of the population and migration, and on the other hand from new technological opportunities. Together they could give rise to major tensions in terms of who has access to the new opportunities arising from new technology, and how the balance is struck between a preventative and a curative approach to healthcare. The visionary outlook proposed in the scenarios report puts priority on promoting healthy lifestyles, preventing illness and curing promptly while supporting vulnerable people, enabling social participation and equitable access to health services and treatments¹⁸. Citizens are encouraged and empowered to move towards healthy lifestyles, also enabled by digital health solutions¹⁹ to manage, track and potentially improve their own health, and supported by information and continuous public monitoring. This shift represents a major challenge for health

¹⁷ Ricci et al. (2017)

¹⁸ See National Institute for Public Health and the Environment (RIVM) (2014)

¹⁹ See Sonnier (2016): <http://storyofdigitalhealth.com/>

systems and health policies, which could be tackled as part of a package of major reforms of social security systems.

A similar paradigmatic shift takes place in relation to security matters. It recognises that the rise in insecurity experienced in Europe around the middle of the 2010s was partly due to problems of inequality and lack of social integration in Europe itself, and partly to crises in other regions of the world that could have been avoided. In response, a movement for a broader approach to societal security gains momentum. Going beyond an 'end of the pipeline' mind-set, security policies have also started to address the deeper causes of insecurity – in combination with active policies in other areas to mitigate social and environmental challenges - and not only the effects. As a consequence, emphasis is put on system level 'security by design' and resilience-centric initiatives in relation to essential (infrastructure) systems, involving users in participatory processes co-designing security solutions in a consistent way as well as pre-emptive measures, such as smart design of cities and localities in order to strengthen the (real and perceived) level of security. Overall, this shift in security policies has led to a significant widening of its scope, and addresses broader concerns about equality, employment, education (training) and resource security.

While health and security are two very important social needs involved in this transition area, which have been examined extensively in this study, there are a number of other social needs that are just as important: guarantees of basic human rights, fairness and equality, access to food and sanitation, employment and fulfilling lives, all combine public services with personal necessities and aspirations. Many of these issues are strongly related to the other transition areas, as some depend on the provisions of the biosphere, some relate to governance and agreed forms of social organization, and of course they all aspire to improvements that become possible through innovation. Yet, they are important for the human condition, strongly dependent on public services and guarantees, and felt as needs by all individuals in society.

3.3 Transition 'The Biosphere: Safeguarding a hospitable planet'

This second transition has its roots in the debates about the environmental sustainability of our economic model, which builds on the (over-)exploitation of natural resources and seriously damages our natural environment. At its core, the paradigmatic change involved in this transition is reflected in changing basic principles of our economic systems in order to provide the incentives and create the structures necessary to respect the ecological boundaries of our planet and in order to ensure the possibility of living in a hospitable world also in the future. In particular, a shift towards an effective internalization of the long-term and external costs of economic activities, and the stringent application of the 'users pay' principle are important triggers to fight climate change and environmental over-exploitation effectively. They enable combinations of technological and organisational innovations (e.g. in the context of a circular economy or regenerative bio-economy). One of the main barriers to this transition is the absence of a global system of common rules, principles and commitments, in order to help overcome global price competition at the cost of the environment.

In the BOHEMIA scenarios report, the nexus of energy, climate, and the area of environment and ecosystems resources and services covers the transition related to the biosphere. The economic argument about the long-term costs of climate change is a strong driver of the transition towards safeguarding a hospitable planet, but it is not alone. Stringent mitigation programmes, such as those for renewable and low-carbon electricity supply (from 30% in 2015 towards a target of more than 80% for the year

2050), may have some impact on climate change, but alone they are not enough. While major technological advances are essential, organizational, behavioural and institutional changes are equally needed (e.g. in relation to mobility). Furthermore, in spite of these advances, major adaptation measures are necessary to cope with extreme weather events, raising the importance of adaptation capabilities and resilience across the globe.

Climate change is also part of the concern with the environment and life- and prosperity-enhancing ecosystems resources and services. Ecosystem resources and services are fundamental for a number of important social needs, such as food and personal health. The bio-economy, the circular economy, on land and in water, and bio-diversity and land management are all important parts of the transition to safeguard a hospitable planet. An important contribution to this transition can be made through regulatory processes that factor external dis-economies into the prices of goods and services. However, this is extremely challenging to implement, and on its own not sufficient for the transition. Innovations in design, manufacture and organisation are needed that build on the potential restorative powers of natural systems, combined with strategies to reduce overall demand for resources²⁰. This move in both OECD and non-OECD countries towards a resource-efficient economy and the decoupling of material consumption from economic growth²¹ is further supported by networked service provision at 'zero marginal cost', advanced automation and new materials contributing to new consumption and production models (including e.g. sharing models)²² and the emergence of new services and business models for repair, re-use, re-distribution, re-manufacture and recycling of products, and sustainable finance models such as impact investments and valuation of natural capital. 'Green' approaches benefit from advances in nanotechnology, biotechnology, advance materials and information- and communication technologies, as well as from improvements of extraction technologies for those resources that cannot be fully supplied through circular material flows.

3.4 Transition 'Innovation: Harnessing the forces of change'

This third transition is about a fundamental change in how societies relate to innovation. Individuals, organisations and society at large increasingly accumulate and use knowledge to introduce purposeful change. The resulting acceleration in science, technology and innovation challenges social, economic and political institutions, and creates contradictions that result in loss of control, crises and stark ethical dilemmas. Recent examples are digitalisation and automation, with their consequences for labour and work, the perception that artificial intelligence is taking over, or the emerging possibilities and risks associated to synthetic biology. The challenge lies with the ambivalence of these developments, which offer an enormous potential, but at the same time entail social (e.g. in terms of inequality), economic (e.g. in terms of dependence on single global players) and ethical (e.g. in terms of privacy) challenges. There is a strong need to learn how to harness these dynamics of change and devise processes to quickly learn how to best exploit their potential to the benefit of society.

²⁰ See Perez et al (2016). There is a huge competitive opportunity for Europe to ride this 'green' trajectory and turn environmental problems into solutions for promoting investment and jobs. Such a green direction implies the use of technological capacities (which the EU has) in order to drastically increase the productivity of energy and material resources (which the EU only has in limited quantities). New 'green' lifestyles are creating new markets domestically and will gradually entice the new millions joining the middle classes across the world.

²¹ Economic modelling results suggest that resource productivity improvements of around 2% to 2.5% pa can be achieved with net positive impacts on EU28 GDP. It is estimated that resource efficiency improvements all along the value chains could reduce material inputs needs by 17%-24% by 2030.

²² See Rifkin (2014) or Mason (2015).

The BOHEMIA scenarios explored partly the dynamics behind the acceleration of innovation, with a particular emphasis on digital technologies and cities as spaces where these dynamics are particularly strong. The 2020's may witness further acceleration of innovation. The data-driven digital economy, automation and artificial intelligence could drive this development disrupting further established businesses and markets. Education is of paramount importance for creating and harnessing innovation, and at the same time its institutions are challenged by innovation across Europe and around the world. Industry is at the heart of change, the force introducing much of the innovation in people's lives. At the same time industry is challenged by the volatility introduced by the pace of change. They are creating new economic activities, and new types of jobs are emerging alongside with new forms of entrepreneurial activity. Change is perceived as a threat and at the same time as an improvement. This is particularly true for European energy-intensive industries (e.g. chemicals and steel) that need technological breakthroughs to face the challenge of global competitiveness and 'hospitable planet'.

The EU can embrace the innovation revolution, by nurturing research and social as well as technological innovation. An open system for science and innovation across Europe makes it possible that all actors can become active in that system. Openness in this broad sense contributes to empowering European citizens in relation to R&I activities. Accelerating innovation and openness entails uncertainty, and Europe needs to provide appropriate regulatory and institutional frames. This is an important 'bet' for Europe in relation to the future. Intelligent regulation can spur technological developments into sustainable directions and give competitive advantages. Appropriate institutional frames need to be timely and flexible, and to steer efforts in the right direction. In such an environment, fast growing European start-ups could out-compete American and Chinese companies in key global sectors. Misplaced regulatory frameworks could be massive burdens for Europe's innovators. It is urgent to find appropriate governance models for innovation, and this cannot be a piecemeal exercise. Experimentation is paramount.

Economic success in the emerging competitive environment of accelerating change brings massive, though ephemeral, rewards. Losses of failure can be amortized by a system of insurance and transfers. Through an effective grounding of Responsible Research and Innovation (RRI) practices paired with responsible investments, a shared ownership of the innovation revolution can be achieved in the EU. Collective fostering of innovation can bring economic benefits, better services and products, and the social benefit of more cohesion, where citizens are able to shape the future of rapid change together. Emphasis on inclusiveness cooperation and solidarity could include promoting continuous education, training and skills development, while addressing the risks of volatility and inequality in earnings in labour markets through social and tax policies.

Cities are the hubs where the different ingredients of innovation come together to unleash social and economic dynamics. They are also important laboratories to harness the forces of change and to learn how to establish new collective learning mechanisms in face of fast and disruptive change. Such truly 'smart' cities can build on advances in sensors and their connectivity through high-performance computing and the Internet of Things. But smartness is not restricted to technology. It is primarily driven by processes of collective learning and inclusive planning. These help to rethink the way the cities are built, managed, and provide the living environment for an increasing share of the European urbanised population. Truly smart cities can become laboratories for the study of new models of urban development. as well as for innovation and for harnessing the forces of change through drawing together cooperation with committed partners, relevant stakeholders, and urban actors at all levels, including industry, knowledge institutions and government.

3.5 Transition 'Governance: Joining forces for a better world'

The three previous transitions depend to a significant extent on the ability to build global governance systems through which common rules are established to frame the change processes ahead. The core of this transition is to move from a governance system that builds on the pursuit of national and organisational interests to a system where cooperation and collective global values effectively underpin major political choices. This takes place in an environment of shifting global tectonics, where power spreads towards the south and the east, and from state actors to a much broader variety of actors and stakeholders. The main ambition of this transition is to tackle truly global challenges that require coordinated action, such as climate change, economic disparities and under-development, military and security conflicts, and global diseases.

If the overarching global ambition of reaching the SDGs were to be largely achieved in the course of the 2030s, this success would require coherence of actors' strategies at different scales from global to local level, in a context of major global socio-economic and political shifts. Nation states and international institutions are joined by a range of new types of players that shape the global governance arenas. Next to already established multi-nationals, NGOs and philanthropists, digital platforms and networks constitute new entities that reach beyond traditional regulatory and governance arrangements. The transition to a better world needs a transition to better governance, based on a global system that best fits the sustainability visions and targets.

The EU could be core regional actor on the global governance scene. It could lead in setting the standards in environmental and social performance worldwide, whilst building its economic, technological, political and cultural leadership on the advantages offered by living sustainably. Progress down the path of SDGs involves a lessening of the differences between Europe and other parts of the world, creating the conditions for a more open EU in a more open world (or, to say it differently, a less fragmented EU in a less fragmented world). The path involves changes in living standards, technologies, infrastructures and a host of other conditions, which, in order to take place, requires economic activities, investment, production, consumption, and opportunities for innovation, competitiveness, benefit and income. A now strong EU leadership will safeguard the long term prosperity of EU citizens, providing important economic opportunities for European players in the world economy.

Policies should not be about quick fixes and ad hoc solutions but should be based on reflexive, participatory and anticipatory governance models. Part of the recipe is to understand that policy alone is not enough to achieve the transformation required. A truly new system requires changes in individuals' behaviour and preferences, which are beyond the control of policy-makers. Political leaders, economic actors and societies must understand the need to share the planet. New purpose-based business models and economic principles that consider the longer term should become profitable. Sustainable and inclusive globalization management needs to lead to widespread opportunities and benefits. The financial system needs to become more sustainable with a strong focus on the long-term and with investments supporting transitions. People empowerment and social safety nets could be building blocks for the co-created future human society. This new mode of governance of complex global challenges can be supported by a wise use of powerful artificial intelligence tools, allowing better modelling of complex phenomena to join other evidence that feed into political decision-making. The appropriate governance of complex global challenges is a key framework condition for the other three transitions to be realised.

4 TARGETED SCENARIOS

4.1 Overview

The four transitions outlined in the previous section jointly represent ‘the future we want’. They are not necessarily likely or easy to realize by 2030 or even by 2040, but they serve as a positive frame of reference for the ambitions of EU R&I policy. The 19 targeted scenarios developed from the results of the Delphi survey of BOHEMIA can be qualified as likely futures because they were based on Delphi statements that had obtained high ratings in terms of their realisation by 2040. Their content (see table 1 for summaries) expresses either, aspirations and visions we are aiming at, or – in some cases - threats. As likely and important futures, the targeted scenarios are part and parcel of the envisaged transitions, and can thus be frames of reference for possible specific missions of EU R&I policy. In figure 4 the targeted scenarios are positioned in the context of the four transitions to which they are most relevant. As reflected in the figure, several of the targeted scenarios are related to more than one transition.

Figure 4: Positioning targeted scenarios in the transition frames

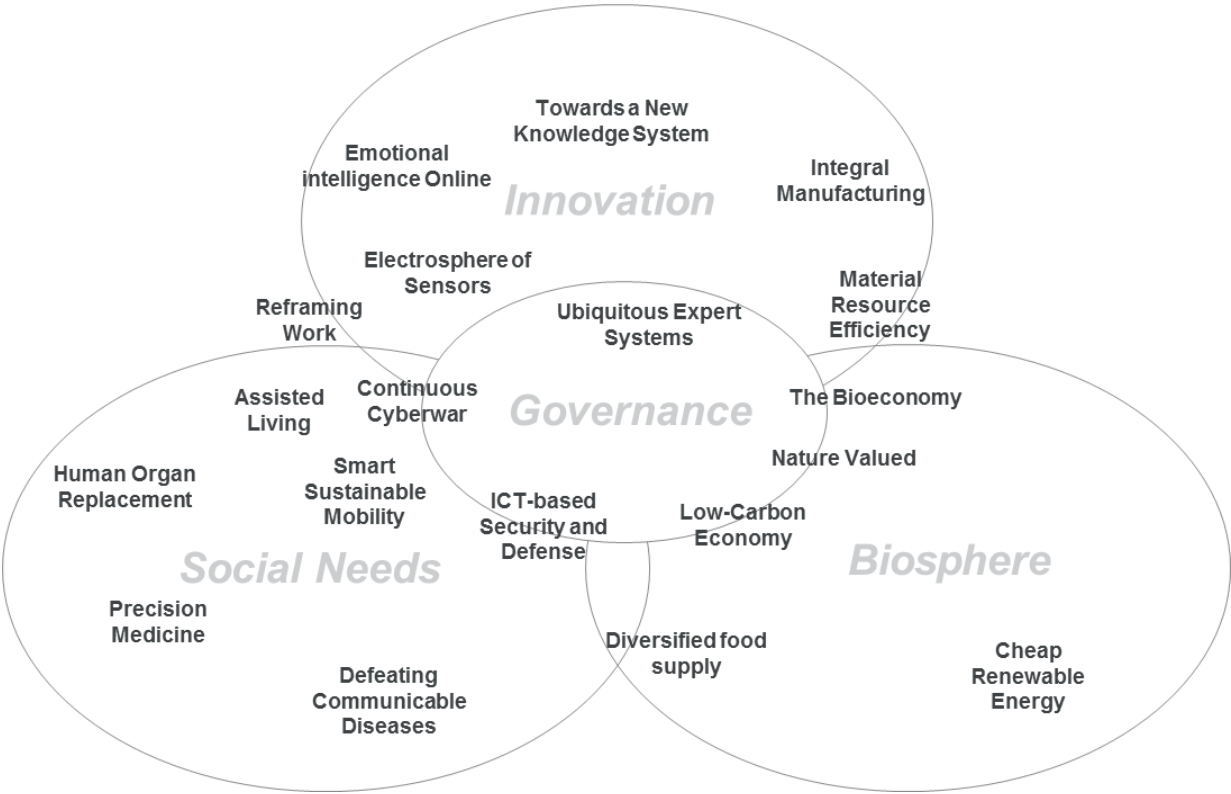


Table 1: Targeted (2040) scenarios in a nutshell

Targeted Scenario	Summary	It is now 2040.....
Assisted Living	In the ageing populations of Europe, but also abroad, the demand for assistance in daily living has more than tripled over the last 25 years. New service concepts combining automation, robotic assistance, digital helpers, virtual trainers and small exoskeletons have transformed care, assistance and the relevant industries.	
The Bio-economy	The Bio-economy promises to be a major contributor to European economic growth and re-invention with impacts on all sectors. Technological advances are set out to replace finite resources and conventional industrial processes, with processes and components that are biologically derived. In the long term, Bio-economy will be a major contributor to climate mitigation and to the transition to a circular economy.	
Cheap Renewable Energy	Renewable Energy is available at competitive prices. More than half the electricity used for transport, housing and industry comes from renewable sources. A pan-European smart grid coupled with local micro-grids, with adequate storage facilities, ensures reliability of electricity supply. Hydrogen and biofuels complement the system. The sector is expanding to novel cultivations, such as algae and bacteria.	
Continuous Cyberwar	With the rapid growth of Internet of Things, cybersecurity hacks proliferate, putting citizens and infrastructures at risk. EU governments strengthen collaboration with citizens and industries to build up a response based on both social participation and cutting-edge technologies.	
Ubiquitous Expert Systems	There is an abundance of advice based on collected experience, using simulations, data analytics and learning systems. With just-in-time data available all around, expert systems are used routinely in the prediction and management of complex situations, as well as for organizational and individual activity.	
Defeating Communicable Diseases	Communicable Diseases (viral infections as well as biotic diseases) that reduce the quality of life of people and cause huge economic losses are being defeated. The number of people dying from Communicable Diseases is steadily decreasing. New approaches, including replacing antibiotics and ways to avoid infections have been developed in international collaboration.	
Emotional Intelligence Online	With emotional markers from diverse sources widely available, and 'emotionally transparent generation' has been ushered in. The flow of emotions is woven into the social, economic and political fabric. Governments aim to learn continuously from feedback gathered from the flow of emotions – as do corporations and individuals. Techno-pessimistic and techno-optimistic ideologies clash around the question of the future prospects of the 'emotional generation'.	
Human Organ Replacement	Most human organs and tissues can be replaced. The majority of organs and tissues are bio-printed, produced by additive manufacturing or breeding (e.g. organoids). Human organ or tissue replacement is accessible and affordable for all European citizens so that the average life expectancy increases.	
ICT-Based Security and Defence	Globalisation and ICT solutions have changed the nature of threats faced by the EU. A combination of preventive and response measures are implemented in coordination by security and defence forces with the aid of computers. The role of the anticipatory crime units is rising, together with the diffusion of unmanned aerial vehicles and military robots with Artificial Intelligence features. These are used in external military actions as well as to secure national territories in cooperation with security units.	
Low Carbon Economy	The EU has slashed the release of greenhouse gases in the atmosphere, invested heavily in carbon sinks and has become carbon neutral including for energy intensive industries like steelmaking. Energy and transport sectors have radically changed through low carbon electricity, cities' sustainable mobility and CO2 storage opportunities. Carbon capture technologies, together with renewed environmental actions, enlarge artificial and natural carbon sink, reversing carbon emission trends.	

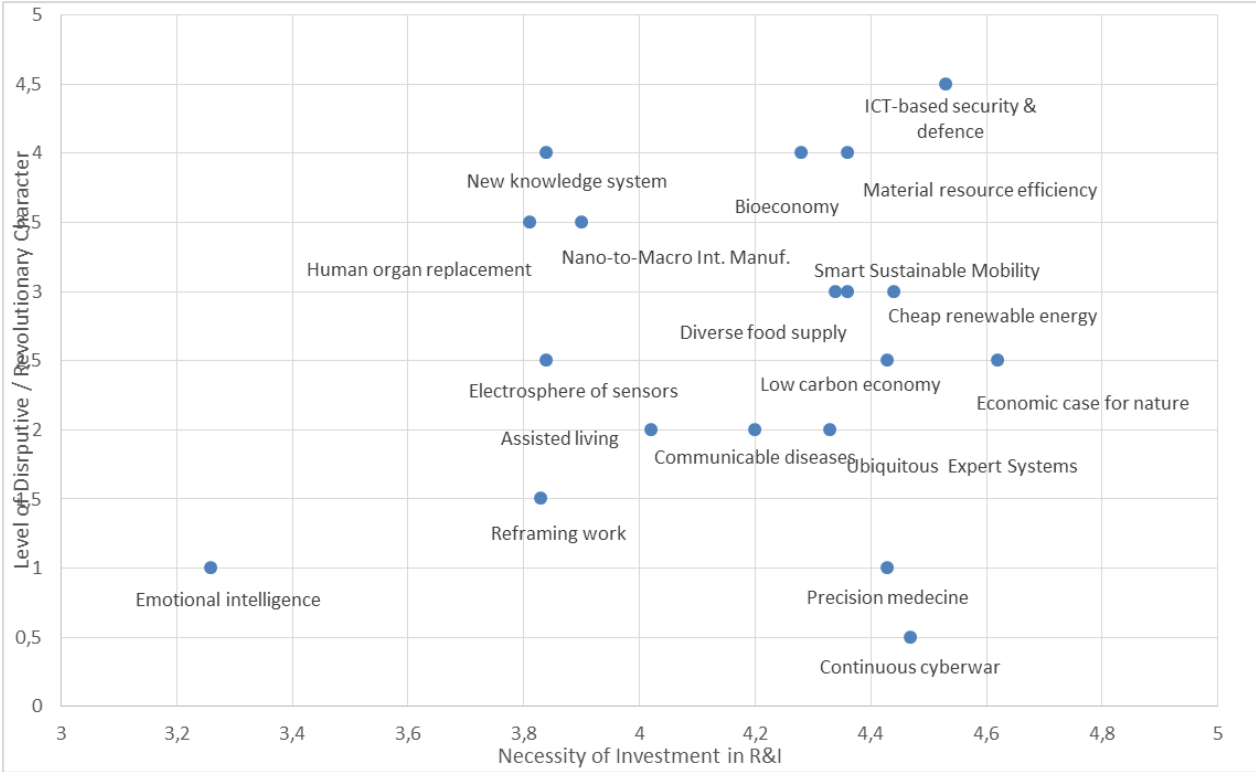
Material Resource Efficiency	Sustainable consumption patterns, truly circular production-consumption networks, and shifts to less harmful, often renewable resources have made Europe less dependent on natural resources, more self-sufficient and more competitive in its industries. In addition, environmental degradation has been reversed.
Nano-to-Macro Integral Manufacturing	Mature 3D printing technologies have become one of the main modes of production of finished goods. Aided by advances in nanotechnology, additive manufacturing has entered many high-value added markets. Changes in product design have rendered it possible for whole products to be made with fewer or no intermediate goods. As a result, traditional global value chains have been disrupted in terms of both geographic span and density.
Nature Valued	Overexploitation of natural environments, intensive agriculture, and climate change have triggered further declines in wildlife with dramatic impacts on biodiversity, while also causing pollution, erosion and other forms of harm. In response, there was a change in the economic policy paradigm promoting sustainable business and consumption patterns that respect planetary boundaries, and more generally makes a case for the importance of biodiversity and nature-based solutions.
Precision Medicine	Individualized precision medicine combining mass data analyses, genetic engineering, epigenetics, and knowledge about the personal microbiome and the biotic environments helps anticipate and cure illnesses. Human enhancement is an issue of ethical and regulatory concern.
Reframing Work	Digitalisation has turned our understanding of work all around. Full time paid jobs are the exception rather than the norm. Working time, family time, education time, social time and leisure are all mixed. Work is framed as purposeful activity, and people work for the sense of purpose it brings. Basic income guarantees satisfy essential human needs. Retirement age is by and large flexible and self-defined.
Smart Sustainable Mobility	A new cultural and business model has emerged: half of EU citizens do not own a car but rely on seamless intermodal mobility services. Passenger vehicles are increasingly automated and run on electricity, while freight transport also benefits from automation, with a massive use of drones for last-mile delivery, and high-performance power storage systems for trucks.
The Electro sphere of Sensors	As energy-harvesting technology makes substantial leaps and sensors are further miniaturized, self-sufficient micro-sensors flood public spaces as well as individual and corporate premises. Valuable data are constantly generated, but personal and organizational environments are exposed to predatory information-gathering practices.
Towards a More Diverse Food Supply System	Major efforts during the 2020s succeed in making our food supply systems more sustainable, secure, efficient, healthy and inclusive. Still in view of a growing world population and environmental pressures on land and water, these efforts are not sufficient. A second pillar of food supply, based on a range of novel types of food production methods, complements the prevailing food supply system in the course of the 2030s.
Towards a New Knowledge System	Ubiquitous digitalisation has transformed science, technology, research and education to a new integrated knowledge system. Abundant data, real-time and historical, are easily accessible through AI devices. Education makes extensive use of the digital tools. It empowers young and older people to make effective use of data, information and knowledge for social and economic ends. As knowledge becomes pervasive people lead more productive fulfilling lives. But established institutions are challenged to adapt.

4.2 The portfolio of targeted scenarios

The scenario descriptions include the basic storyline, their relevance for Europe and in regard to Sustainable Development Goals and Europe’s position in the world, their relevance to EU policies in general and their implications for EU R&I policy. The implications for EU R&I policy come from the public consultation. Respondents were asked to rate the importance of the scenario for EU R&I policy and investment, and to express, in the light of the scenario, what are important EU R&I policy directions. In their recommendations for policy directions, respondents were asked to consider the need for ‘solutions oriented R&I’, ‘Regulatory science and policy knowledge’, ‘Scaling up solutions and social innovation’ and ‘Understanding-oriented R&I’.

Despite the common structure, targeted scenarios differ in several regards. Some are more systemic (e.g. low-carbon economy, bio-economy), others are more specific. Some project current agendas into the future (e.g. low-carbon economy, cheap renewable energy), while others depart quite radically from current thinking (e.g. emotional intelligence online, building an economic case for nature). This diversity affects also the results from the online consultation. All targeted scenarios received high ratings in terms of necessity of EU R&I investment. Most were rated between 3.8 and 4.6 on a 5-point scale, with ‘Nature valued’ in the lead. There was one outlier at a rating of 3.25 (‘emotional intelligence online’). However, ‘emotional intelligence online’ is also a scenario with a high dispersion of ratings, thus reflecting the divergence of opinions about and emotional reservations against it. Figure 5 maps the portfolio of targeted scenarios in two dimensions: the necessity of EU R&I investment and the disruptive/revolutionary character of the targeted scenario.

Figure 5: Targeted scenarios in terms of disruptive / revolutionary character and necessity of R&I investment



In the online consultation, participants were asked to vote for their priority directions and to add directions they regarded as missing. In all cases, a very small number of between one and three items stand out as receiving a very high number of votes from the

participants of the online consultation and can thus be regarded as 'top' priorities.²³ In the 'Cheap Renewable Energy' scenario, for instance, the two items 'methods, practices and solutions to promote energy saving and reduction of energy consumption' and 'exploration of energy storage solutions, beyond batteries' clearly ranked on top of the list of proposed directions. And in the case of the scenario 'Towards a More Diverse Food Supply System', there is one (albeit rather general) clearly top-ranked item, namely 'sustainable agriculture and aquaculture practices'.

Next to these top-ranked items, there is usually a fairly broad range of directions for EU R&I policy that receive substantial support from the participants in the consultation. This observation indicates that there are usually several directions that seem worth pursuing in order to maintain a diversity of future options, which are expected to have a good potential. In the case of 'Cheap Renewable Energy', for instance, energy efficiency measures, the development of renewables-friendly regulatory frameworks, or research on artificial photosynthesis. Finally, there is also a group of EU R&I directions that received very limited support. Each scenario description (published separately) lists the top-ranked EU R&I policy directions and those receiving substantial support in the consultation.

The R&I directions retained after the online consultation are often composed of a mix of scientific-technological issues (either of a fundamental nature to better understand phenomena, or in need of scaling and experimentation to move towards operational solutions), social/organisational ones, and R&I directions that are geared towards supporting regulation and policy. Overall, the picture is quite heterogeneous. There are several targeted scenarios, where regulatory or social/organisational directions show up very prominently. In the case of 'Material Resource Efficiency', for instance, environmental impact assessment is a top priority direction for EU R&I policy. Similarly, in the targeted scenario 'Towards a More Diverse Food Supply System', social/organisational innovation and environmental impact assessment rank on fifth and third position. In the case of 'Emotional Intelligence Online', the top third R&I items is about the rights and obligations of sensor owners. In some other targeted scenarios, scientific-technological directions, either on fundamental understanding or in search of novel solutions, dominate the list of priorities, for instance in the case of 'Cheap Renewable Energy', but this applies to a minority among the scenarios only.

For the purposes of the BOHEMIA consultation we distinguished between solutions oriented R&I, understanding oriented R&I²⁴, regulatory science and policy knowledge, and scaling up solutions and social innovation. While there are overlaps between the four categories, they nonetheless describe endeavours of different purposes. The EU R&I policy directions needed in relation to each scenario vary in composition. In the targeted scenario 'Towards a More Diverse Food Supply System', for example, the top five R&I items include understanding- as well as solutions-oriented R&I ('Understanding and managing systems of sustainable agriculture and aquaculture'), but also regulatory science ('Environmental impact assessment of agricultural practices') and social innovations ('Organisational and social innovations for optimising food supply systems from farming to consumption'). In 'Nano-to-Macro Integral Manufacturing', technological improvements and applications or the understanding of impacts figure most prominently among the priority items. It is important to note that in all scenarios there was substantial support for at least three different categories of recommended EU R&I policy directions.

²³ The list of top priorities is provided in the chapter on conclusions and policy recommendations.

²⁴ Fundamental and basic research is often driven by the interest of people to understand; understanding-oriented research does not need to rely on the curiosity of scientists, but can be driven by policy concerns.

There are two points here. The first is the heterogeneity of needs across the scenarios. The second is the transformative nature of the scenarios, and the awareness of the community that an intelligent combination of different types of R&I directions (fundamental understanding, solutions-oriented research, regulatory science, social/organisational innovations and scaling) will be needed.

5 CONCLUSIONS AND POLICY RECOMMENDATIONS

We live in a time when Europe and the world are confronted with new and unprecedented challenges. What is needed is no less than a new pact between science, society and policy. There are two parts in this new pact. The first part is that R&I should contribute to the tackling of major societal challenges ahead. The second part is that R&I should take place under conditions of openness that favour innovation. R&I activities need to open up to new stakeholders, and citizens in particular. Horizon 2020 did focus on societal challenges and has been accompanied by policies favouring open science, open innovation and openness to the world as well as responsible research and innovation. However, Horizon 2020 has yet to be transformative, enabling Europe to lead the world in the transition towards the Sustainable Development Goals, by maximising its potential and linking appropriately with citizens and other policies.

To maximise the transformative potential of the next Framework Programme the BOHEMIA study provides two sets of policy recommendations. The first set is associated with the ambition of EU R&I policy to play a key role in helping Europe achieve its global ambitions, both in terms of determining its own future, and in terms of leading the world towards the achievement of the UN Sustainable Development Goals. The second set of recommendations is about specific R&I agendas and actions associated with the disruptive revolutionary futures explored in the 19 topical scenarios. These recommendations carry the extra weight of a public consultation.

5.1 Towards a new mode of European R&I policy

Step up the ambitions of European R&I policy to become the engine of European and global transitions

The BOHEMIA scenarios report²⁵ stressed the importance for Europe of aspiring for ambitious transitions in a range of key domains, closely tied to the UN Sustainable Development Goals, to which not only the EU but also Member States have subscribed. This complements the long-standing concerns about how to maintain a Europe's strong economic and political role in the world, in order to be able to co-shape "the future Europeans want".

The EU R&I policy can be at the heart of Europe's strategy, with appropriate levels and forms of investment, appropriate structural interventions in Europe's innovation system, and appropriate forms of alignment between the objectives and modes of operation of EU R&I policy and of other EU policies. R&I can become a driving force in a change-oriented policy agenda that will change prevailing development trajectories and embrace fair and inclusive transformative change.

Put preparedness at the heart of EU R&I policy

R&I provide options that enable strategic responses to challenges and opportunities. Exploring options creates preparedness for using them – skills, knowledge, tools and infrastructures. Preparing for the future must include exploring a diversity of research options through cutting-edge research and scientific excellence in order to advance the frontiers of knowledge. Options can also be explored strategically, for example in areas where scientific curiosity may be lacking and potential policy and commercial benefits can be accrued. Strategic preparedness involves foresight, - i.e. the disciplined exploration of

²⁵ Ricci et al (2017)

alternative futures, but it also involves broader anticipatory governance structures that can respond to the insights developed.

The 19 BOHEMIA targeted scenarios make the case for some candidate priority directions for future EU R&I policy, but uncertainty and contingency will continue to prevail. This is very obvious, for instance, in the targeted scenario on ICT-based security and safety, where we have a sense of the challenge ahead, but still a limited understanding of the R&I options that could be pursued. This situation means that selecting one avenue for developing cybersecurity would entail substantial risks. It is important to explore and develop different options before crises strike.

Accelerate market creation, by providing space for policy experimentation

It is increasingly apparent, and in the BOHEMIA context it is made very clear, that the challenges facing Europe and the world are substantial and not fully understood. Yet, postponing actions until we fully understand the context can have dire consequences. Each policy attempt to solve a problem is an experiment from which lessons can be learned. Multiple policy experiments can drastically improve understanding of problems and potential solutions. Policies create the space for markets to emerge, and European policies shape Europe-wide markets.

For markets to emerge and to accelerate the realisation and uptake of new solutions, there is a need for mutual learning between innovators, users and policy makers. Beyond the need for more experimentation, rapid prototyping and scaling of new solutions, there is a need for a more experimental approach to policy making, involving R&I as well as sectoral policies, in order to promote and support real-world purposeful innovation.²⁶

Improve the alignment of R&I and sectoral policies through the innovation principle and policy coordination

An important part of the experimental approach proposed relates to the alignment of R&I policy and sectoral policies. In fact, conditions for uptake of new solutions and the realisation of targeted scenarios are often defined by sectoral policies (e.g. regulation, standards, procurement), and it is through alignment between sectoral and R&I policies that change can be accelerated. The 'innovation principle' frames all Commission policies in terms of their importance of promoting innovation, removing barriers to innovation and stimulating market creation by supportive policies.²⁷ Similarly, an earlier involvement of sectoral policy in defining the goals of R&I policy would help ensure the relevance of R&I agendas to long-term future-oriented sectoral policy strategies.

Some sectoral policies are strongly shaped at European level, while others may fall under the competence of Member States. Therefore, the alignment with national policies and national ecosystem will become more important than ever. Already now, we can observe a growing number of platforms of actors from public, private and third sector (PPPs, P2Ps) taking care of Europe-wide agendas, involving national communities from R&I policy, sectoral policies, and other stakeholder groups.

²⁶ This emphasis on policy experimentation is in with the broadened understanding of openness as suggested by the RISE group advising Commissioner Moedas (see EC 2017a). The book argues that the realization and upscaling of new solutions can be accelerated by strengthening openness in three dimensions: 1) openness as a tool addressing the grand societal challenges of our time, 2) openness as a tool to strengthen the inclusiveness of R&I, and 3) openness in relation to experimentation for market creation (i.e. including regulatory experimentation).

²⁷ The Innovation Principle was suggested by the Innovation Policy Management High-Level Group, see IPM (2016).

Strengthen the productivity and impact of R&I, by better connecting supply and demand of innovation

Fostering the productivity of research in terms of its impact on innovation and change in society and economy is crucial for strengthening Europe's competitive position in the world and ensuring its influence on global agendas. The productivity of R&I is to a considerable extent dependent on the structures of national and regional innovation ecosystems across the EU. Structural interventions that improve the productivity of R&I include support to national reform programmes, the improvement of R&I infrastructures, the development of more Europe wide competition for R&I, including a stronger and more integrated Europe-wide system for financing innovation.

Structural interventions also include the creation of links between supply and demand for innovation and measures to promote a wider spread of innovation capacity.

Promote a new sense of ownership through new forms of citizens engagement in agenda-setting and R&I

There is ample evidence that citizens' engagement contributes to research, accelerates market creation and facilitates closure of ethical debates on science and technology related issues. There is also ample evidence that individual citizens (and non-citizens) demand – and will increasingly demand - to engage with scientific and technological issues and place hopes and expectations on science and technology. This is an opportunity for EU policy to build on citizens' engagement to improve the productivity of EU funded R&I, and to use its R&I policy to strengthen the profile of the Union institutions amongst EU citizens.

It is important to mention here the large proportion of respondents to the BOHEMIA consultation who expressed positive sentiments for the consultation method. In particular, the explicit use of concise scenarios was mentioned several times as a useful and thought-provoking element of the consultation, which helps elicit expectations about emerging R&I needs and opportunities and establish key R&I directions for the European Union.

5.2 Prioritising for future European R&I policy

Prioritise future European R&I by focusing on areas of relevance to the four transitions

The four transitions framework developed in BOHEMIA can act as a focussing device as well as a framework for priority selection in EU R&I policy. We can imagine the four transition domains as an evaluation grid that enables the European Commission to screen each proposed area of research in terms of its potential impact on one or more transitions. We can also imagine programmes on each of the four transitions, following different organizing principles, appropriate for the transition in question. A programme on harnessing the forces of change would place emphasis on fast technological innovation, strengthening innovation capacities and creativity across the board. A programme on safeguarding a hospitable planet, would place emphasis on the planetary boundaries and their implications for R&I. A programme on the needs of people would place emphasis on R&I that enables understanding and solutions for social problems, and a programme on governance would place emphasis on the information needs of managing transitions. These organizing principles would be programmatic, rather than thematic. This means that each discipline or thematic area could be appropriate in each of the four programmes. It would be the considerations and criteria for selection and evaluation that

would be different. Another difference between the transitions would be the extent to which they require solutions oriented R&I, understanding oriented R&I,²⁸ regulatory science and policy knowledge, and scaling up solutions and social innovation, in the same way that the 19 targeted scenarios required different combinations of R&I types.

Follow the top R&I directions recommended by the public consultation in view of likely future disruptive scenarios

For each of the 19 topical scenarios a small number of recommended policy directions got overwhelming support²⁹. We recommend to the Commission to include these policy directions in its planning, irrespective of the strategic positioning it would decide to take towards the scenarios they come from. The recommended directions and the scenario they come from are presented in table 2:

Table 2: Overview of top priority R&I items for the 19 targeted scenarios

Top priority items	Related Targeted scenario
E-health solutions including tele-medicine, measuring health data and transfer	Assisted Living
Research on assistive technologies and the impacts of their application	Assisted Living
Developing and testing new circular bio-economic processes	The Bio-economy
Methods, practices and solutions to promote energy saving and reduction of energy consumption	Cheap Renewable Energy
Exploration of energy storage solutions, beyond batteries	Cheap Renewable Energy
Tools for monitoring, evaluation and responding to threats	Continuous Cyberwar
Development of better machine-learning algorithms	Ubiquitous Expert Systems
Effective public health education about communicable diseases, incl. Prevention, treatments, hygienic questions, disinfection	Defeating Communicable Diseases
Developing standards and codes of behaviour concerning the use of individuals' emotions for commercial and public purposes, as well as for emotional data sharing and privacy	Emotional Intelligence Online
Research and development in cybersecurity, particularly in relation to the online sharing and use of information about individuals' emotions	Emotional Intelligence Online
Breeding of tissues and organs (theory and practice)	Human Organ Replacement
Understanding the roots causes of security challenges	ICT-Based Security and Defence
Exploitation of new business models for circular economy and promotion of sustainable lifestyles	Low Carbon Economy

²⁸ While fundamental or basic research is often driven by the need of people to understand, understanding oriented research does not need to rely on the curiosity of scientists, but can be driven by policy concerns and considerations.

²⁹ This selection of top priorities is based on three criteria: 1. More than 50% of participants indicated this item as priority, OR 2. It is the top-listed item, OR 3. If the difference between the top-listed item and the subsequent item is less than 5%, both are included.

Environmental impact assessment	Material Resource Efficiency
Understanding the impact of 3D printing on individual health and safety and on the environment, across various industries	Nano-to-Macro Integral Manufacturing
Building models for a sustainable circular economy based on renewable resources and renewable energy	Nature Valued
Making use of biotechnologies for personalized medicine	Precision Medicine
Research on new variants of entrepreneurship through collaborative research	Reframing Work
Research on battery efficiency, energy storage and recovery technologies	Smart Sustainable Mobility
Development of new sensors based on a better understanding of the relation between sensing and knowing	The Electro-sphere of Sensors
Understanding and managing systems of sustainable agriculture and aquaculture	Towards a More Diverse Food Supply System
Adapting educational techniques to online environments, and piloting various solutions (e.g., distributed online courses with tutoring, navigating through the stock of knowledge)	Towards a New Knowledge System
Understanding the neural basis of knowledge acquisition, and the relation of cognition to experience more generally	Towards a New Knowledge System
Devising intellectual property models and practices in open knowledge systems, and experimenting with new forms of IP sharing	Towards a New Knowledge System

This list of top priorities is complemented by several other R&I directions that also received substantial support in the online consultation. Whether the scenarios are desirable – possible missions to be realized through EU R&I, or undesirable – where missions could be formed with the aim to avoid their realization or mitigate their consequences – the R&I directions supported by the public consultation can bring EU R&I agendas closer to the citizens, and the method of involving citizens followed by the BOHEMIA project can help the Commission bring citizens closer to EU R&I agendas.

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Europe will be facing unprecedented changes in the coming twenty years. Global trends, combined with inertia in Europe's economies and societies and their chronic underinvestment in research and innovation, are likely to result in serious challenges. The changes will also harbour opportunities which are to be found in disruptive scientific and technological developments, as well as in growing demands for societal participation in research and innovation activities.

If the European Union wants to maintain its position in the world and take a leading role in tackling Sustainable Development Goals, it needs to initiate major transitions in the ways social needs are addressed, the biosphere is cared for, the forces of innovation are promoted and harnessed, and the affairs of the world are governed.

The next European framework programme for research and innovation is expected to make a difference, generating innovation that enables the transitions and shaping Europe's future capabilities. Based on a foresight processes involving scenario development, a Delphi survey and an online consultation, this study puts forward policy recommendations for the next framework programme. These include the identification of 19 likely future scenarios with disruptive implications and associated priority directions for EU research and innovation.

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