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TECHNOLOGY FORESIGHT FOR PUBLIC FUNDING OF INNOVATION

Methods and best practices

EU Policy Lab

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EMERGING TECHNOLOGIES

DISRUPTIVE INNOVATION

STRATEGIC FORESIGHT

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TECHNOLOGY FORESIGHT FOR PUBLIC FUNDING OF INNOVATION

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This report is a part of the project 'Anticipation and monitoring of emerging technologies and disruptive innovation' (ANTICIPINNOV), a collaboration between the European Commission Joint Research Centre and the European Innovation Council (EIC).

The EIC is Europe's flagship innovation programme to identify, develop and scale up emerging technologies and disruptive innovations.

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Abstract

In times of growing uncertainties and complexities, anticipatory thinking is essential for policymakers. Technology foresight explores the longer-term futures of Science, Technology and Innovation. It can be used as a tool to create effective policy responses, including in technology and innovation policies, and to shape technological change.

In this report we present six anticipatory and technology foresight methods that can contribute to anticipatory intelligence in terms of public funding of innovation:

- the Delphi survey,
- Genius forecasting,
- Technology roadmapping,
- Large language models used in foresight,
- Horizon scanning and
- Scenario planning.

Each chapter provides a brief overview of the method with case studies and recommendations.

The insights from this report show that only by combining different anticipatory viewpoints and approaches to spotting, understanding and shaping emergent technologies, can public funders such as the European Innovation Council improve their proactive approaches to supporting ground-breaking technologies. In this way, they will help innovation ecosystems to develop.

Executive summary

Technology foresight can be framed as a systematic and holistic approach to exploring the long-term futures of Science, Technology and Innovation (STI), and to dealing with uncertainties and complexities where anticipatory thinking is key. Technology foresight can be used to identify breakthrough technologies and game-changing innovations with the potential to address societal challenges, position players internationally and boost economic leadership. In this specific context, it can and should be used as a tool to define effective policy responses, including shaping technological change through targeted STI policies.

Many anticipatory and technology foresight methods and tools have emerged in past several decades. In this report we present six methods: the Delphi survey, genius forecasting, technology roadmapping, the use of Large Language Models, horizon scanning and scenario planning. The selection of these methods took into the account their potential application in the specific context of the European Innovation Council (EIC) in the short term, but it also reflected their possible use by other EU services in the STI sector and related public funding organisations in EU countries. No selection is without flaws, however, as many other methods and approaches could have been included. As such, a follow-up to this report is surely needed and we invite all interested stakeholders, from policymakers to academia, to join us in developing the next iteration.

The six methods and approaches included can be briefly described as follows:

- The **Delphi survey** is a surveying method that relies on expert judgement through one or more rounds, which aims to reach a consensus about future developments.
- **Genius forecasting** is a set of processes where individual strategies and creativity are combined with insights from the field, to create future visions.
- **Technology roadmapping** is a strategic visual planning tool that can inform decision-making about near, mid and long-term research, development and demonstration needs for specific technologies.
- **Large language models (LLMs)**: rather than a method itself, LLMs recently entered the public space with discussions on AI, and could

help to identify knowledge gaps and new areas for research with increased speed via the automated use of large amounts of data.

- **Horizon scanning** is a methodology aimed at the early discovery of novelty by collecting and assessing topics, usually classified as signals, and whose potential is not yet widely recognised by most experts, decision makers or the general public.
- **Scenario planning with stress testing** is an anticipatory framework where the comparative use of distinct future scenarios makes it possible to stress test strategy assumptions against plausible events for better priority-setting and decision-making.

Specific recommendations for applying each of these methods, are highlighted in this report. They are relevant as regards the work of organisations such as the EIC. Briefly:

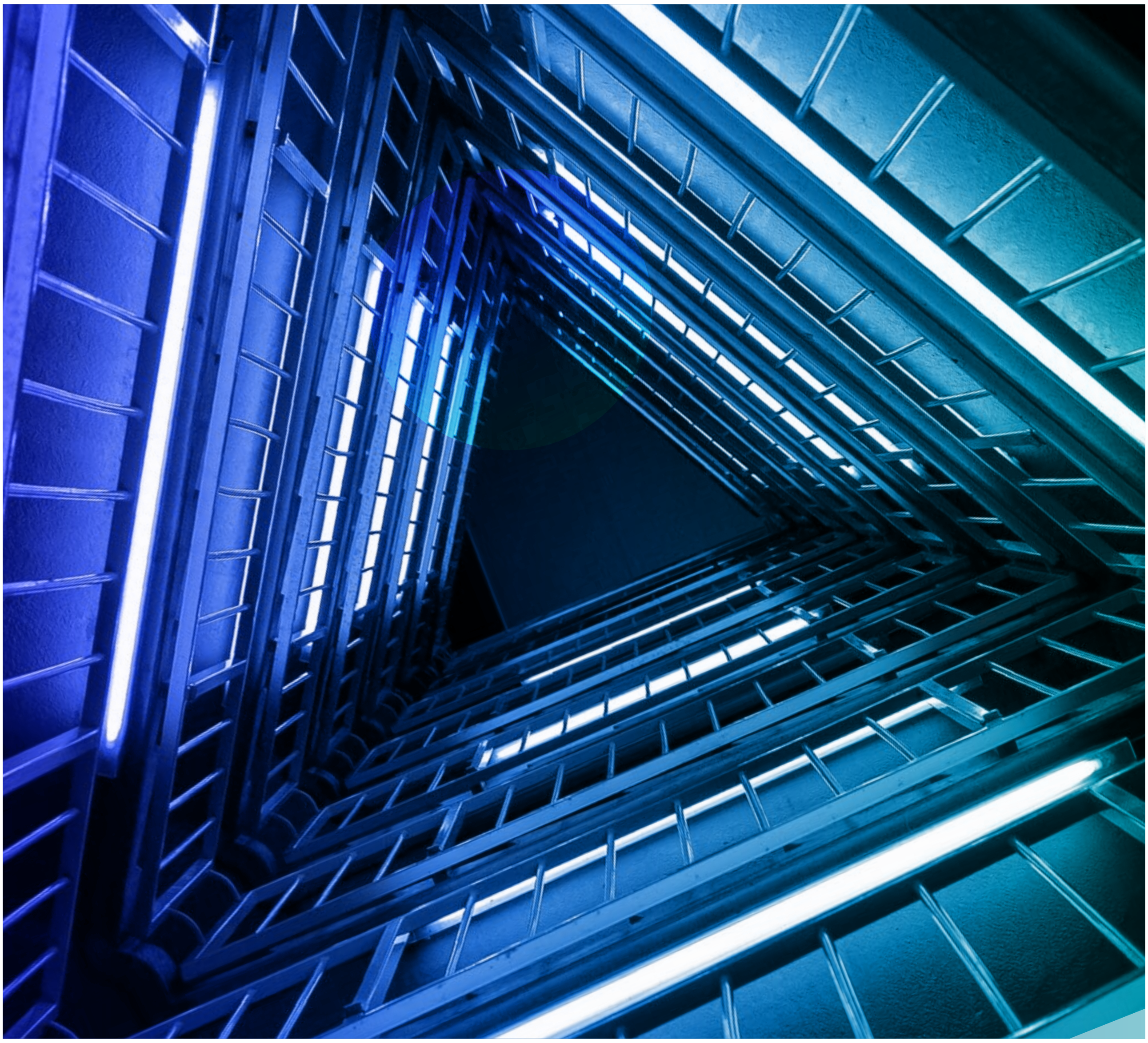
- **The Delphi survey** – having clear and distinct roles, a professional team to carry out the survey and a careful selection of the panel of experts are key to obtaining robust results.
- **Genius forecasting** - integrate the intuition of individual 'geniuses' consistently across an organisation by recognising their individual values, charisma and contributions together, while focusing on the longer-term futures and engaging external experts.
- **Technology roadmapping** - it might be necessary to change the organisational culture to start planning on the basis of roadmaps. The actual use of developed roadmaps is important for the long-term sustainability of this method.
- **Large language models (LLMs)** - pilot projects using strategic intelligence and foresight to evaluate the effectiveness of LLMs should be conducted with an open and experimental dataset. Human judgement and expertise should be combined with LLM-generated insights, but should not be fully replaced by them.
- **Horizon scanning** - web-based knowledge management platforms can facilitate the gathering of anticipatory intelligence and support its systematic mapping. Cross-disciplinary teams should focus on mapping innovations according to strengths, opportunities, weaknesses and threats to navigating through possible disruptions.
- **Scenario planning and stress testing** - skilled facilitators are needed to implement this method, especially for stress testing. Internal pilots can improve familiarity with stress testing across the organisation. Different kinds of stakeholders should be involved to collect a diversity of ideas and create co-ownership.

We can find certain commonalities in all of these methods, which we can highlight as follows:

- they can all be used to identify breakthrough technologies and game-changing innovations that have the potential to scale up internationally and become market leaders;
- they can be integrated into an organisation and ongoing work to anticipate and monitor opportunities effectively;
- they can provide information on the timeframe of future social challenges and opportunities generated by developments in science and technology; and
- they all benefit from developments in internal capabilities of organisations to implement the results of their anticipatory processes.

Additionally, only by combining these and other methods and approaches, can the EIC and other similar organisations properly improve their anticipatory capacity. How, when and where this might happen should be further explored in any future iterations of this report. Nevertheless, we wish to highlight a balanced approach in five dialectical dimensions:

- implementing participatory processes involving external multi-stakeholder expertise (e.g. through Horizon Scanning, Delphi surveys and Scenario planning) and relying on the vision



of individualistic genius forecasters (e.g. programme managers);

- using 3 horizons framework (Curry and Hodgson, 2008), by looking at horizon 2 and 3 (e.g. by exploring weak signals of emerging and little-known technological breakthroughs) and pursuing incremental innovation (horizon 1) opportunities;
- exploring the potential of LLMs to analyse large and diverse amounts of data and relying on human judgement and capacities to assess which breakthroughs are really innovative;
- deep dive into specific technologies or technology groups (e.g. through roadmapping and theme-driven horizon scanning) and assessing the general context of society and technology adoption;
- implementing recurrent technology foresight exercises to feed the launch of cyclical funding calls for proposals and developing less-frequent long-term future-oriented outputs such as visions and scenarios.

Introduction

By: Lucia Vesnic-Alujevic, João Farinha and Alexandre Pólvora

Lucia Vesnic-Alujevic *is a policy analyst and researcher at the Joint Research Centre. She has worked on the intersection of policy and research for more than 10 years. She developed projects and (co-)authored papers in the area of futures studies, Science and Technology Studies, political science and communication science.*

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Alexandre Pólvora *is a policy adviser on Foresight and Strategic Intelligence at the European Innovation Council. He has coordinated award-winning research and development projects with measurable impacts from high-level policy making to grassroots communities and has authored multiple publications from social and public innovation to the anticipation and governance of emerging technologies.*

1.1 Technology Foresight

In recent decades, we have witnessed significant advances in the development and adoption of technology, namely in complex and novel technologies that impact almost every economic and social aspect of human activity (JRC Megatrends Hub, 2022). This brings both challenges and opportunities, with policymakers and decision makers requiring forward-looking thinking.

Technology foresight is understood as 'a systematic exercise aimed at looking into the longer-term future of science, technology and innovation in order to make better-informed policy decisions' (Pietrobelli and Pupato, 2016). It has an important role to play in enabling a better understanding of the complexity of technology developments and applications, as well as related societal and other impacts (Warnke and Heimericks, 2008) and can impact and shape potential technological change in the future (Pietrobelli and Pupato, 2016).

Therefore, technology foresight could become one of the key policy tools used to define effective policy responses in R&I, including technology and innovation policies and potential investments (Miles, 2010, Andersen and Andersen, 2014). In the context of the EU, technology foresight can help EU policymakers become more anticipatory and deal with complex issues.

Many technology foresight and other similar anticipatory tools and methods have emerged in past several decades. In the beginning, many of these methods were developed and used in the military, for example the development of the scenario planning method or Delphi by the RAND corporation. They were used to provide a framework for innovation and generate knowledge and insights that can give an advantage in the military realm or in technology leadership. Large corporations such as Shell quickly saw their added value and started using and further developing these methods to maximise profits in competitive markets. Over the years, these methods were translated from the for-profit and defence domains into the public sector. For some time, the European Commission and the Joint Research Centre have been at the centre of this development, with the Institute for Prospective Technological Studies, and the development of conceptual empirical frameworks such as future-oriented technology assessment (FTA).

Due to the growing volatility, uncertainty, complexity and ambiguity in the world we in live today[1], but also in priority setting and decision-making processes, it is increasingly challenging to achieve robust policy design or implementation. In such circumstances, anticipatory thinking is of utmost importance (Burrows and Gnad, 2020). The forward-looking frameworks, such as technology foresight, offer a structured, systematic and systemic path to gaining valuable insights on mid- to long-term futures. They also open up spaces in which present assumptions and established paradigms can be challenged in an actionable way (Kaivo-Oja and Lauraeus, 2018). This is why, today, many national governments around the world use foresight (e.g. Singapore, Canada or Finland). It has also been used at the EU level by almost all the EU institutions and many EU agencies, as well as at regional and local levels of governance. Similarly, it has been used by some innovation agencies (e.g. the Danish Agency for Science, Technology and Innovation or the European Network of Leading Innovation Agencies - Taftie) and public research institutes that support policymaking (e.g. TNO or Fraunhofer).

A better understanding of future challenges and opportunities can be created by combining established methods that have been widely used with new or innovative ones in the same toolbox. Driven by participatory, stakeholder-centric models, a diverse range of viewpoints can be captured. Participatory exercises can lead to more robust results and more effective scanning of a broader spectrum of new patterns. Collective intelligence also contributes to better decision-making and prioritising of issues that are important for the future about which we lack evidence.

Therefore, broader responses anchored in anticipatory insights can strengthen the EU institutions by enabling them to create more future-ready strategies for policy design and implementation across several policy fields (Strategic Foresight Report, 2020).

1.2 Innovation in the EU and the European Innovation Council

Technological sovereignty is at the core of the notion of and debate on open strategic autonomy in EU policymaking. It is considered to be ‘a means to achieving the central objectives of innovation policy - sustaining national competitiveness and building capacities for transformative policies’ (Edler et al, 2023). It creates the possibility for the EU to act independently and foster innovation that is able to help it deal with pressing societal challenges (Cagnin et al, 2021). European leadership in this area is one of the EU’s current priorities, because it is strategically important for our competitiveness, (cyber)security and strategic autonomy, as well as for climate change and people’s well-being.

1 The acronym VUCA was first used by Bennis and Nanus (1987) to describe the world at the end of 1980s, related to the collapse of the USSR and end of Cold war by US Army War College. However, its use increased in the last 20 decades and its use is quite common in foresight and futures studies. An alternative acronym is TUNA (Turbulant, Uncertain, Novel and Ambiguous

The New European Innovation Agenda (European Commission, 2022) aims to support deep tech and breakthrough innovations and help bring them to market. Horizon Europe and its predecessor framework programmes have been some of the EU's biggest innovation funding mechanisms. In Pillar III of Horizon Europe, 'Innovative Europe', the basis for a pan-European innovation ecosystem, bringing together regional innovation ecosystems across the EU, has been set up. Many other initiatives are ongoing to strengthen research and innovation in the EU by developing and scaling up technologies (e.g. the Quantum Technologies Flagship Initiative, the European Tech Champions Initiative).

As set out in the Horizon Europe legislation, the mission of the EIC is to identify and support technology, innovation and the actors behind them with the potential to scale up and lead markets internationally, while meeting real world needs with Europe's resilience and strategic autonomy at the centre. This mission has now been translated into the continuum between the EIC Pathfinder, Transition, and Accelerator funding programmes, as well as other EIC instruments such as the Innovation Fund and the EIC Prizes, or support mechanisms such as the EIC Business Acceleration Services.

The knowledge generated through anticipatory approaches allows for future-driven exploration and future readiness in different choices. Their integrated management ensures that such choices are evaluated with a wider lens to guarantee a more impactful investment in tomorrow's assets.

In the context of the EIC, the anticipatory approach can help to scan for, identify and monitor novel science and deep technology, new innovators and entrepreneurs, research and technical organisations, startups, scale-ups, and potential unicorns or other players working on breakthrough ventures to be ahead of the curve. It can speed up new ideas, products, services, or businesses, to disrupt or shape markets and drive the resilient and strategically autonomous growth that is the ambition of the EU.

1.3 ANTICIPINNOV project

An integrated use of technology foresight can be a game-changer in how EU funding is designed and distributed, as well as a transformational element in how such foresight process is able to inform both institutional strategies and policy frameworks at different levels. This can help to counter common perceptions of public investment as excessively slow in spotting and backing emerging technologies, or unable to ensure that support from public institutions reaches disruptive innovators at the right time.

In 2022, the JRC and the EIC began working together on the project ANTICIPINNOV (Anticipation and monitoring of emerging technologies and disruptive innovation), which aims to address these opportunities and related challenges at European level.

This report[2] is one of the outputs of this collaboration. Its primary goal is to further support the EIC's strategic intelligence capacity by exploring different potential anticipatory approaches. This report does not aim to prescribe a final roadmap for the development and implementation of such approaches, but rather to explore potential avenues to strengthen the EIC's anticipatory capacities.

1.4 Structure of the report

This report explores six methods from the area of technology foresight and anticipation as regards their potential application in funding agencies such as the EIC.

Four chapters (2, 4, 6 and 7) examine well-established future-oriented methods to support innovation systems and the work of the EIC and similar organisations that fund innovation. Chapter 3 describes a method that relies heavily on the creativity and intuition of an individual. Chapter 5 offers an additional outlook on an emerging method that is increasingly used in technological innovation and foresight and which also has a potential application in funding innovation. For this report, we collaborated with six experts in the area of technology foresight, and we present their views

2 Farinha et al, 2023a and Farinha et al, 2023b

on how different methods and approaches could support innovation and organisations such as the EIC.

In Chapter 2, Per Dannemand Anderson explores the **Delphi survey**, one of the participatory expert-based methods**.** The Delphi method, which relies on expert judgment in the context of uncertainty, has been widely used in technology foresight, in particular to support decision-making in science, technology and innovation policies. Four use cases are analysed to show a variety of recent projects using the Delphi approach which are relevant to the EIC and similar private and public organisations. When using the Delphi survey, it is important to construct statements well, test and refine them, and carefully choose the experts participating in the survey.

In Chapter 3, Marco Bevolo examines the possibilities that arise from applying **genius forecasting**. The author describes how individual intuition and creativity, combined with insights from the field, can help create visions of the future. The author discusses the advantages of applying this method, through two case studies. He explains how these approaches were integrated in two quite different settings, and how the approach might be useful for the EIC, especially considering the role of programme managers in the organisation.

Imoh Ilevbare discusses **technology roadmapping** and its application through a number of case studies in chapter 4. Technology roadmapping is an important tool for informing decision makers about possible future options, including in technological development, and for creating visual pathways useful for strategic planning. In this chapter the author shows the relevance of roadmapping for strategy, foresight and policy-making for both industry and government. The chapter ends with a presentation of the benefits of applying roadmapping, which can be done either on a centralised basis or via a step-by-step approach, and of using roadmaps to support decisions on funding and investment, including for organisations such as the EIC. This section also discusses the importance of change in organisational culture and management techniques.

Chapter 5, authored by Eirini Malliaraki, discusses **large language models** (LLMs) and their application, especially in Research and Innovation, through identifying knowledge gaps, supporting bottleneck analysis and technology foresight more broadly. While the application of LLMs and artificial intelligence (AI) shows significant promise in different domains, such as increased transparency and collaboration across society, there are still many legal and ethical uncertainties. The author recommends continuous research and development on this approach with pilot projects to further evaluate the efficiency of LLMs.

The next chapter 6, authored by Rafael Popper, describes **horizon scanning** and how it can be used by the EIC. Horizon scanning is a method that looks at the 'weak' signals of change and at detecting and assessing potential technological developments. Taking the example of four cases, this chapter shows the relevance of this method for anticipating emerging technologies for funding purposes within the European context. It highlights the importance of horizon scanning in shaping policy and funding strategies in Science, Technology and Innovation (STI) to promote breakthrough advancements in Europe's innovation landscape. The chapter concludes with recommendations, showing that when this approach is oriented towards emerging technologies and disruptive innovations, the focus is on transformational changes, including socio-technical system transitions.

The report concludes with **scenario planning,** one of the oldest (technology) foresight methods, which has been used since the end of the 1940s, in chapter 7. The scenarios describe a set of plausible future contexts and help encourage strategic discussions about how we should act in the present. In this chapter Matthew Jon Spaniol presents scenario-based stress testing that can be used as an analytical tool to assess strategic options and take decisions on innovation portfolios. The chapter provides examples of scenario use and stress testing that can be used to prioritise innovations in the context of uncertainty. They show how scenarios can be used as an engagement tool to get input or, later on, to shed light on emerging issues and strategy or for maintaining the required innovation portfolio. It concludes with recommendations on how investment portfolio managers and strategists could use scenarios to inform their selection of innovations.

1.5 Concluding remarks

The ANTICIPINNOV project is a first systemic step in integrating technology foresight in the EIC's funding priorities pipeline. The project results, which were obtained through desk research (Farinha et al, 2023a), horizon scanning (Farinha et al, 2023b), the data and text mining of databases of patents, scientific publications and EIC data (Eulaerts et al, 2023), have provided trends and signals of emergent technologies and disruptive innovations that are of interest to EIC programme managers and other stakeholders inside and outside the EIC. While demonstrating the importance of such practices, it was also evident that their impact is limited if they are applied in isolation. Therefore, the EIC could benefit from and between these methods, as well as customised approaches, synergies and complementarities with other policies.

This report provides an overview of the state of the art of these and other foresight methods, and how they could be further developed to meet the specific needs and uses of an innovation funding agency such as the EIC. It makes several proposals on how to move this organisation into the next stage of maturity in the use of technology foresight, by pursuing a balanced approach in five dialectical dimensions:

- supporting the process by using participatory methods and external multi-stakeholder expertise (e.g. through horizon scanning, Delphi surveys and scenarios) and by relying on the vision of individualistic genius forecasters (e.g. programme managers);
- adopting risky portfolio approaches with 3 horizons frameworks (Curry and Hodgson, 2008), in horizon 2 and 3 topics (e.g. by exploring weak signals from emerging and little-known technological breakthroughs) and pursuing incremental innovation opportunities and addressing gaps in the technology development chain;
- integrating digital technologies in foresight approaches and exploring their potential to analyse large and diverse amounts of data (e.g. integration of LLMs in horizon scanning and technology assessment) and relying on human judgement and capacity to bring together different sources and their inherent perspectives while assessing which breakthroughs are really innovative;
- performing thematic analyses that deep dive into specific technologies or technology groups (e.g. through roadmapping and thematic-driven horizon scanning) and assessing the general context of society and technology adoption, while exploring different contexts in which specific technologies might excel (e.g. through scenarios and wind-tunnelling);
- performing periodic technology foresight exercises that are aligned with the cyclical EIC challenge launches, and engaging in occasional, stable and long-term future-oriented analyses such as vision building and scenario planning.

Only by intelligently combining different viewpoints and approaches to spotting, understanding and shaping emergent technologies, can the EIC strengthen its proactive approach to supporting ground-breaking innovations and continue to play an important role in the EU's entrepreneurial deep tech ecosystem.

The detailed insights of this report, together with this summary, should be analysed by the EIC's board and programme managers, and support further integration of foresight into the agency's strategic intelligence framework.

In addition, the report can be used by policymakers dealing with innovation and national innovation agencies who seek to implement technology foresight in their organisations and promote an anticipatory culture for priority setting and decision making.

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Potential uses of the Delphi method in innovation funding institutions

CHAPTER 2

By Per Dannemand Andersen

Per Dannemand Andersen is a professor of Technology Foresight and Innovation at the Technical University of Denmark. Since the 1990s, his research interests have focused on technology foresight, strategy processes in industrial sectors and technological innovation. Dr Andersen has been involved in and led numerous research and advisory projects in Danish, Nordic, European and international contexts. He has taught foresight at the executive and doctoral levels. He has published in journals such as Technological Forecasting and Social Change, Futures, Foresight, Technology Analysis & Strategic Management, Futures & Foresight Science, *and* Renewable & Sustainable Energy Reviews.

2.1 Introduction

The Delphi method was developed in the 1950s by Ted Gordon, Olaf Helmer and Norman Dalkey in the American institution the Rand Corporation and in collaboration with the US Air Force. The method is used worldwide as a tool to support decision-making and priority-setting in science, technology and innovation (STI) policymaking. This chapter contains a short introduction to the method followed by four recent use cases that have been selected to present varieties of the Delphi approach relevant to the EIC and other similar private and public organisations. Against this background, the chapter considers how the method can be useful for the EIC and concludes with six recommendations for implementing the method.

2.2 The state of the art

The Delphi method has been defined as 'a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem' (Linstone and Turoff, 1975, p3). The method can guide participants through an iterative and systematic process of debating different futures and challenging participants' assumptions, expectations and understandings. The key features of the method are: the elicitation of expert knowledge, judgements and viewpoints through a highly structured questionnaire; the anonymity of the participants; and iterations (often two rounds) with feedback.

For policymaking within STI, the Delphi method can help build consensus - or clarify disagreements - among experts about future developments, the possible negative or positive economic or societal effects of these developments, and policy instruments to promote a desired development. The Delphi method can be combined with other prospective methods, e.g. horizon scanning, trend analysis and scenarios.

Carrying out a Delphi project involves several types of actors. A sponsor, funder or project owner is responsible for the overall framework (e.g. an innovation council or similar organisation). A steering committee represents the sponsor and acts as the executive board for the project. A project team (of two to six people) carries out the project and should preferably include solid methodological skills and experience in the subject areas of the project. A panel of experts is composed of persons with knowledge of particular relevance to the topic of the project.

The panel of experts can be selected in several ways. One of the most common ways is the 'snowball' or co-nomination process, where a small group of experts is asked to nominate additional experts according to a set of criteria such as expertise in the topic and variation in gender, age, nationality or personal interests etc. One of the key issues in selecting participants is avoiding biases in the final group of participants. Biases and the concept of over-optimism of experts is well documented (Tversky and Kahneman, 1974; Tichy, 2004). Such biases can be mitigated by ensuring a variety of expertise and backgrounds among the experts (Bonaccorsi, Apreda and Fantoni, 2020).

The Delphi method often has three core phases: topic or idea generation, priority setting and consolidation. Before the core phases, an initial phase is carried out that includes scoping of the study, overall design of the investigation within a given budget and timeframe, selection of participants/experts, desk research on the topic of the study, initial interviews with selected participants/experts and decisions on technical issues such as an online survey platform. In addition, a follow-up phase to the core phases addresses issues such as dissemination and implementation of the findings and documentation of possible learning results from both the topic and the process.

When first devised, the Delphi method used the postal service to collect participants' input. Today, researchers and practitioners use a variety of online survey platforms such as SurveyMonkey, Qualtrics, Google Forms, and LimeSurvey. Large international consultancies provide tools for idea generation and management or collective intelligence processes. These include the Delphi survey platform ExpertLens™ provided by RAND[3] and Insight2Action™ supplied by Deloitte[4]. Among other platforms are the Global Futures Intelligence System provided by the Millennium Project[5] and eDelphi supplied by the Finnish firm Metodix[6]. In addition, many small and large consultancies offer commercial solutions for collective and crowd intelligence, including Delphi surveys.

Besides the Delphi method, there are other approaches to eliciting experts' judgement on issues characterised by high uncertainty and long-term horizons (Morgan, 2014). In projects aiming to estimate the future cost and performance of water electrolysis and at prioritising international agriculture research investments, expert views were sought on the basis of a combination of expert surveys (questionnaire), workshops, interviews and experts' reviews of other experts' working papers (Schmidt et al., 2017; Pemsl et al., 2022).

2.3 Use cases

The Delphi method is frequently used to support decision-making on STI policies. The following section examines four use cases. The criteria

3 https://www.rand.org/pubs/tools/expertlens.html
4 https://action.deloitte.com/
5 https://www.millennium-project.org/projects/global-futures-intelligence-system/
6 https://www.edelphi.org/

for selecting the cases were: (1) recent cases published in 2022 and 2023; (2) variety in size from large national foresight projects with over 2000 participants to industry-level cases with a few participants; (3) variety in geographical scope from international and national to regional level cases; (4) variety in timescale from short-term to long-term; (5) variety in scope from setting priorities among emerging technologies to fostering innovation in general; and (6) whether information was publicly available in English.

2.3.1 Korean national science and technology foresight

The project was carried out by a team in the Korean Ministry of Science and ICT in collaboration with the Korean Institute of Science and Technology Evaluation and Planning (KISTEP) and a range of other Korean authorities (KISTEP, 2022)[7]. It aimed to forecast and analyse developments in science, technology and society over the next 24 years (i.e. until 2045).

The project had three overarching aims. First, to predict both the future society and the future technologies expected to appear in this future society. Second, to contribute to the government's science and technology planning and policies in response to the needs of the predicted future society. Third, to predict tipping points for new technologies, in terms of when new technologies become socially widespread and have an impact on people's lives.

The Korean science and technology foresight project followed the same overall methodological approach as previous large national foresight exercises in Japan, Germany, the UK and other advanced industrial nations.

In the first phase, 241 future technologies were identified (e.g. 'Hybrid power generation system integrating hydrogen fuel cell and gas turbine'). In a two-round Delphi survey, these technologies were assessed according to three criteria: their importance, year the technology is realised, and the government policies that are necessary. Large panels of experts from the identified areas of science and technology carried out the assessment. In total, 2 147 experts responded in the first round and 1 617 in the second round.

The project identified future technologies to address the major societal needs expected to arise in the next 25 years. The project also identified promising fields of research that can improve the understanding and utilization of future technologies. According to the final report, the findings are expected to be helpful in three ways: (1) helping researchers to identify new research ideas; (2) helping policymakers to plan systematically for the future; (3) encouraging the public to be interested in the future and to prepare for it.

2.3.2 Future innovation in the agri-food industry

The study aimed to 'generate a consensus among experts on a definition of food innovations and forecast an overview of food innovations that are likely to be available to consumers in the next five years' (Zickafoose, Lu and Baker, 2022, p3)[8]. The study was carried out by a team of researchers at Texas A&M University.

A panel of experts was selected through a snowball sampling method. An initial list of 61 experts were identified from the private and public sectors. Thirteen of the identified experts were willing to participate in the process, and they had expertise in relevant topics such as food policy, animal science, agriculture communication, the poultry industry, the beef industry, soil and crop sciences, natural resources, food technology and public health.

The project followed a traditional three-phase Delphi approach. The study was carried out relatively quickly from November 2021 to February 2022. The experts were asked to rate their level of agreement with some definitions of food innovation

7 The case is based on the official Korean report on the 6th Science and Technology Foresight (KISTEP, 2022).
8 The case is based on an article in the journal Foods (Zickafoose, Lu and Baker, 2022).

and the likelihood of the availability to consumers of each of the 29 specific food innovations. The surveys were conducted using the Qualtrics commercial survey tool, and the experts were given two weeks to complete the questionnaire in both phases.

The project concluded that 'food industry experts, researchers, practitioners and government officials can use the identified food innovations to capitalise on food innovation research and development' (Zickafoose, Lu and Baker, 2022, p9). In addition, the project resulted in: (1) an overview of expected food innovations over the following five years and insight into current and developing agri-food research; (2) suggestions for future research, including an investigation of consumer acceptance of the future innovations; and (3) the revealing of two divergent viewpoints among the experts on how to improve the future food system - a technology-based and a nature-based approach.

2.3.4 Regional innovation policy for the Centro region of Portugal

The aim of this project was 'to understand the relevant pre-conditions and barriers for territorial innovation behind the Research and Innovation Strategies for Smart Specialisation (RIS3) of a lagging European Union (EU) region' (Silva *et al.*, 2022). The study was carried out by a team of researchers from two Portuguese Universities: the University of Coimbra and the University of Aveiro. The study was funded by a research programme under the *Programa Operacional Regional do Centro* (a program funded by the Directorate-General for EU regional and urban policy) and *Fundação para a Ciência e a Tecnologia* (the Portuguese Foundation for Science and Technology) [9].

The panel of experts was selected from experts already involved in the RIS3 activities in Centro since they were assessed to have the necessary background and practical expertise on regional innovation strategies. The project followed a traditional three-phase Delphi approach. The study was carried out between January 2020 to October 2020.

In the first round of the Delphi survey, replies were received from 22 experts with various backgrounds in municipalities, higher education institutions, business associations and other associations, together with some private individuals. Ten were female, and twelve were male. In the second round, nine experts replied.

The surveys were conducted using LimeSurvey's free and open-source online statistical survey platform. The results were analysed using the commercial SPSS Statistics software. The surveys revealed both issues of consensus and disagreements between the panel experts.

The study resulted in an overview of the experts' views on: (1) existing knowledge bases and key actors in the regional innovation system (e.g. government and central administration, large businesses, SMEs, higher education institutions); (2) determinants of regional innovation (e.g. human capital, R&D investments, science and education infrastructure); and (3) barriers to innovation in the region (e.g. a high degree of bureaucracy, lack of qualified human capital, low innovative capacities of firms).

2.3.5 Prioritisation of public health investments – Asian Development Bank

This project aimed to 'reach consensus on a "menu" of priority COVID-19 response interventions' (Osewe and Peters, 2022, p137). The study addressed the need for support to decision-making in international financing institutions and multilateral development banks like the Asian Development Bank, which have committed $230 billion to respond to and recover from the COVID-19 crisis (Osewe and Peters, 2022, p138)[10]. The project was carried out by a team affiliated with the Asian Development Bank in Manila, Philippines.

9 The case is based on an article in the journal Urban Research and Practice (Silva *et al.*, 2022).
10 The case is based on an article in the journal Health Security (Osewe and Peters, 2022)

An initial panel of 30 experts in global health security was identified, based on authorship of influential publications and participation in professional working groups. In addition, the diversity of organisations represented (multilateral organisations, governments, non-governmental organisations (NGOs) and academia) was also considered. 25 experts responded in the first Delphi round, and 19 responded in the second round.

The Delphi study was carried out in a very short timeframe between 2 April and 15 May 2020.

The initial phase comprised a literature review and stakeholder consultations (Asian Development Bank, WHO, the World Bank and the International Monetary Fund). It resulted in the identification of 11 technical areas and 37 potential interventions distributed across the 11 technical areas.

The experts were asked to rate each of the technical areas and interventions from the viewpoint of their importance for a country's ability to prevent, detect and respond to COVID-19 and similar diseases. In addition, the panel was asked if any area or intervention was missing in the questionnaire. As a follow-up, a teleconference was arranged with 24 experts to review and refine the findings.

The Asian Development Bank used the project results to inform project development and build resilient healthcare systems in Asia and the Pacific. The results could guide future health investments, indicate research priorities and secure continued dedication from the public health community in Asia and the Pacific. In addition, feedback from the participating experts on the process and the opportunity to learn from each other was overwhelmingly positive.

2.4 Use of Delphi for funding innovations

Since the late 1960s, the Japanese Science and Technology Agency has used the Delphi method to inform its national STI policy. Japan has carried out Delphi-based science and technology foresight exercises regularly, on average every five years. During the 1980s and 1990s, several large industrial nations, including the UK, France and Germany, ran their Delphi-based technology foresight projects based on the Japanese experiences. The use of the Delphi method in large national-level foresight exercises prevails in countries such as Japan, China and South Korea. In Europe, the method is frequently used to inform policymaking and priority-setting on new technologies and in regional innovation policy.

The Delphi method can be useful in various ways for the EIC and other private and public organisations funding innovation:

- Expert judgement on topics with a high level of uncertainty: first, the Delphi method can provide a highly structured approach to elicit insights and judgements from a group of experts on issues with a high level of uncertainty. The method can provide detailed insights and perspectives on specific areas of technology and innovation where information cannot be found in publicly available (published) material.
- Identification and overview of potential breakthrough technologies and game-changing innovations: this method can assist the EIC in its core aim of identifying future research possibilities and investments. Three of the cases also include such an aim. In the Korean case, a vast range of technologies was identified, and in two cases, the focus was on a particular industry (agri-food) and a societal challenge (public health). The Delphi method can have the same function as horizon scanning or it can be combined with the horizon scanning approach.
- Provide insight into the expected timeframes for technological breakthroughs (as in the Korean and the agri-food case). When a range of potential technologies and innovations are identified, a panel of experts can assess the current maturity of these technologies (e.g. via a technology readiness level[11]) and time horizons for future technical or commercial breakthroughs.

11 The technology readiness level (TRL) is a method for estimating the maturity of technologies on a scale from 1 to 9. The European Commission has advised EU-funded organisations and projects to adopt this scale.

- Assess the potential to scale up internationally and for European actors to become market leaders within new technologies. The Delphi method can be useful in assessing potential breakthrough technologies as regards the potential for European actors to innovate and become market leaders based on these technologies. In the agri-food case, expected food innovations were identified and their market potential and consumer acceptance were assessed.
- Assess technologies according to their ability to address real-world needs today and future societal challenges. Innovation is not only generated through the push from technological breakthroughs. Game-changing innovations are often generated from needs in the real world today and future developments in societal challenges such as climate change and pandemics. The EIC and similar funding organisations can use the Delphi method to assess the potential of new technologies to tackle these needs and challenges (as in the Korean case and the Asian Development Bank case).
- Evaluate the feasibility and potential risks, challenges or pitfalls of the identified technologies and innovations. Most new technologies and innovations come with both positive and negative implications. The Delphi method can help innovation councils to assess their feasibility, address concerns and develop mitigation strategies to implement new technologies successfully.
- Building consensus and revealing opposing viewpoints among experts. The Delphi method can be useful for a panel of experts to build consensus, but it can also bring to light disagreements between the experts (as in the agri-food case).
- It is difficult to ensure the continued engagement of the participating experts. The response rate typically falls from the first to the second round of the Delphi method. This can be mitigated by considering the experts' thoughts on 'what's in it for me?'. By combining the Delphi method and workshops or teleconferences, learning and networking among the participants can be a valuable outcome and secure the continued engagement of the key actors (as in the Asian Development Bank case).
- Furthermore, large national projects based on the Delphi method can, to some extent, stimulate public interest in innovation and the future (as in the Korean case).
- Assist in matching funding schemes to particular areas of technology. As shown in the Portuguese case, policy instruments depend on existing knowledge bases and key actors in the regional innovation system (e.g. government and central administration, big companies, SMEs and higher education institutions), and the Delphi method might be able to provide an overview of the most suitable funding instruments.

2.5 Recommendations

- The Delphi method can be recommended to the EIC to identify breakthrough technologies and game-changing innovations with the potential to scale up internationally and become market leaders.
- The method can also provide information on the timeframe of future societal challenges and opportunities generated by developments in science and technology.
- In implementing a Delphi project, it is recommended to have clear and distinct roles for the different actors: the EIC as the sponsor, a steering committee representing the EIC and a team that carries out the project in practice.
- It is recommended to use a professional team to execute a Delphi project. In this way, the EIC can ensure a state-of-the-art approach to carrying out a project, including: (1) how to identify experts (e.g. Mauksch, von der Gracht and Gordon, 2020); (2) the practical application of the method (e.g. Belton *et al.*, 2019)systematic approach to the design and delivery of a Delphi survey. We prescribe a sequence of six steps to do with (i; (3) how to construct statements (e.g.

Andersen, 2022); (4) how to secure commitments from the experts and stakeholders involved (e.g. Cairns, Goodwin and Wright, 2016); (5) how to analyse the results (e.g. Beiderbeck *et al.*, 2021; Belton, Cuhls and Wright, 2022) and (6) many other practical details.

- It is recommended to take great care in identifying the panel of experts and to secure their engagement throughout the project. Potential biases and over-optimism of experts are well documented. It is recommended that the selection of expert panels should be based on several criteria, including competence, geography, gender, age, nationality and other relevant aspects of diversity.

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Individual intuition and communicative charisma as enablers of futures envisioning: ‘genius forecasting’ vs ‘forecasting geniuses’

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3.1 Introduction

Futures thinking is as old as humanity, starting with exceptional individuals, from shamans to oracles, whose social function in ancient societies was to mitigate uncertainty (Lopez Galvis & Spiers, 2022). Brilliant individuals – socially identified and semantically described as ‘geniuses’ – have traditionally exercised charismatic leadership to show the way to the rest of us. This chapter investigates the phenomena of ‘genius forecasting’ in foresight and futures research, in parallel to ‘forecasting geniuses’ in entrepreneurship, business and finance. In both domains, individual intuition and charismatic communication enable thought leadership and impact, at different levels and with different purposes. This chapter posits that equivalent, if not the very same principles of indeterminacy, apply to value recognition in forecasting, pertaining to both foresight or futures research and startups in their ecosystems, as one might observe with the impact of the rogue behaviour of Silicon Valley unicorns (Mehta, 2019). Case studies explaining how these approaches were integrated in two different organisational settings are introduced, focusing on Philips and DARPA. These cases discuss the usefulness of the method. The chapter also presents reflections and conclusions on the specific context of public agencies, like DARPA, or innovation funding agencies, such as the EIC.

3.2 The state of the art

What is genius? In Western cultures, the notion that exceptional individual genius is at the heart of creativity belongs to Romanticism. However, while IQ measurement assesses one's ability to solve a given set of problems, it takes more than an exceptionally high IQ to be perceived, positioned, and socially rewarded as a genius, namely the 'practical intelligence' that determines personal success in reading situations by meeting or exceeding expectations at the levels of social interactions and transactions (Gladwell, 2008). Parameters to culturally understand creativity have been developed over the decades, whereby it is possible to extend the field of creativity to all human activities, from new combinations of existing elements to a whole transformative outcome, with challenging existing frameworks and changing existing structures as intermediate steps (Bevolo, 2010).

Contemporary creativity is, however, regarded as the outcome of collective processes of co-creation and co-design, enacted by multidisciplinary stakeholders (Bevolo, 2010). This notwithstanding, genius and its social and performative characteristics have been in high demand since the 1960s, and especially since the late 1990s/early 2000s dot-com revolution. Within the systemic context of Castells' 'informational economy', the organisational integration of individual talent within collectively driven innovation processes might be a valid principle to generate, leverage and valorise individual intuition, in the forms of 'genius forecasting' futures insights and the visionary output of 'forecasting geniuses'.

3.2.1 Genius forecasting

Genius forecasting is a precise identifier in the taxonomy of foresight and futures research: 'The most subjective method [...] strongly connected to intuition, visioning, visualizing...' (Kuosa, 2012, pp.24–25). This definition typically applies to design, fashion and aesthetic-related fields. Here, strongly biased 'futurologists' are traditionally closer to curators or editors than to participatory professionals or scholars (Bevolo, Price, 2006). Examples might include Lidewij Edelkoort, the Paris-based, Dutch trend forecaster (Dezeen.com editorial staff, 2019), who has influenced generations of designers (Jordhan, 2018), educators (Fairs, 2015), and curators (Howarth, 2014) with her leadership based on individual intuition (Fairs, 2020) and communicative charisma.

Genius forecasting practices might be extended to other fields, from technology to business, however its predominant presence is in 'shallow tech' and lifestyle domains. Here, genius forecasting practices potentially play a role in anticipating unthinkable 'wild cards', beyond any reductionist objectivity, e.g. in domains where scientific lacunas exist. Wild cards might be mapped at the highest and most extreme position in the impact-uncertainty matrix, where maximum impact is applicable, in a highly uncertain context (Tõnurist & Hanson, 2020). This is the challenging context where deep tech research and innovation happens.

3.2.2 Forecasting geniuses

Beyond foresight, the ability to anticipate futures by intuition, articulate them into a vision, and engage the world, accordingly, is a competence treasured in the context of venture capital and startups. Here, 'entrepreneurial genius' is defined according to a set of recurring patterns (Mehta, 2019):a desire to accept risk and ambiguity, and the ability to live with them;

Figure 1: city.people.light: Urban Futures Matrix

			SOCIO CULTURAL DRIVERS			
			ACCENT ON INDIVIDUALS		ACCENT ON GROUPS	
			IDENTITY	EXPLORATION	BELONGING	SUSTAINABILITY
CITY STRATEGIES	FOCUS ON TIME	ACCELERATION	Liquid city	Brandscape city	Eclectic city	Open city
		MEMORY	Dialog city	Repurposed city	Regionalised city	Geomantic city
	FOCUS ON PLACE	SEMIOTICS	Integrative city	Augmented city	Storytelling city	De-mineralised city
		CONNECTIVITY	Playful	Hybrid-system city	Themed city	Agricultural city

- an ability to construct a vision and sell it to many others;
- a confidence bordering on arrogance;
- a stubborn belief in one's self;
- a magnet for talent.

From the perspective of founders, the concepts of the 'thesis-driven approach' (Mehta, 2019) and 'thematic focus' (Mehta, 2019) are as mission-critical as the personal charisma that enables genius entrepreneurs to pitch their ideas by compelling storytelling. These concepts are key also to venture capitalists who must stand out with their own brand (Metha, 2019).

From the perspective of decision makers, who select creative propositions to invest in, idea selection is at risk of determining false positives, or the endorsement of failures, and false negatives, or the rejection of blockbusters. Such negative outcomes might be avoided by skilled forecasting based on accumulated experience (Grant, 2016).

3.3 Use cases

3.3.1 Genius forecasting within a corporate innovation programme

Philips city.people.light was a repeatable, multidisciplinary, multipurpose process-based practice, including: qualitative research; co-creative workshops and business networking (Bevolo, 2017), integrating socio-cultural trends with concept generation. The classification of city.people.light in terms of innovation taxonomy is that of an 'elite club' (Pisano & Verganti, 2008). A definition of city.people.light should find its roots in the High Design approach established at Philips Design by Dr. Stefano Marzano (Lambourne et al., 1997).

Several constituencies that pertain to genius forecasting might be identified within the city.people.light process:

- qualitative research was conducted by interviewing thought leaders, therefore connecting their charisma to the reputation of the programme;
- workshop facilitation entailed the dual role of neutral facilitator and influential programme co-director;
- the market leadership positioning of the brand might have exercised a soft power in valorisation dynamics.

Individual talent and *savoir faire* remained paramount in the transition from qualitative research, presented in the form of socio-cultural trends and urban scenarios, to the collective generation of innovation concepts. A proprietary matrix tool (Bevolo, 2017) enabled such a transition (Bevolo & Rosenius, 2014):

Philips city.people.light might be analysed according to two intrinsic polarities and a median point of convergence, however liminal, in its architecture (Bevolo, 2016):

First polarity: collective participation

Collective participation was staged and enacted at different moments of the process; specifically in workshops, positioning and profiling the programme as a co-creative, contributive practice based on design research processes, characterised by networking, participation and shared knowledge, according to the principles of action research:

Action research >>> Collective participation >>> participatory practices (matrix)

Second polarity: individual intuition

Historically, thought leadership has been expressed by contrarians or visionaries in creative industries, including architecture and urban design. This is a modality of leadership expressed, among others but not only, by the architect or the designer in the context of decision-making within complexity. Therefore, in the programme, this polarity can be captured as:

Individual charisma >>> individual intuition >>> genius forecasting (matrix)

Median point: Liminality space: communities of practice

In city.people.light, visioning was a collective and dialectic practice. However, this creative process pertained to very distinctive moments and actors with a distributed ownership of decision-making capacity in professional networks, temporarily consolidated in workshops involving communities of practice:

Informal networks >>> communities of practices >>> innovation concepts

3.3.2 Forecasting geniuses in a governmental organisation

Established in 1958 in Arlington, United States, as a reaction to the Soviet Union's Sputnik space flight in 1957, and positioned within the US Department of Defense, the Defense Advanced Research Projects Agency (DARPA) has the purpose of serving the national interest by enabling the technological superiority of US military forces (CRS, 2021, Update 15). DARPA funding is substantial, accounting, in 2021, for USD 3.5 billion of the science and technology funding within the defense budget, which is allocated to basic research, applied research and advanced technology.

The following organisational constituencies characterise DARPA and determine its unique cultural traits:

- trust and autonomy, enabling a risk-taking attitude;
- tolerance for failure is therefore high, resulting in high freedom of enterprise;
- tenure limit of 3-5 years for programme managers and other key senior staff;
- high levels of commitment to the national and military mission of DARPA;
- flat organisation, with high levels of individual empowerment.

The high degree of freedom at DARPA enabled and encouraged successful 'high risk, high reward' transformative research as well as major failures, like exploring telepathy and psychokinesis in the 1970s (Piller, 2003) or an artificial elephant for transportation in the South Asian jungles (Richard J. Barber Associates, 1975).

It is possible to extract the following key points on project management and programme managers at DARPA (Jackel, 2019):

- DARPA is very individualistic in its values and practices, with programme managers constituting itskey ambassadors and testimonials;
- the tenure of programme managers is limited to a period from 3 to 5 years;
- the duration of projects overseen by programme managers varies from 4 to 6 years;
- well-defined metrics are leveraged to monitor and assess success or failure;
- all research investments are focused on DARPA's specific mission;
- organisational barriers due to risk mitigation in innovation are removed, by design;
- the coordination of projects by programme managers is key to managing the externalised value chain.

Within DARPA, programme managers enjoy exceptional freedom and independence, being able but not forced to work on their proposals with peer reviewers and keeping an influential role in decision-making processes (CRS, 2021, Update 15). Like venture capitalists, they do not work in isolation as they engage in constant dialogues with scholars, professional researchers and government experts, within larger communities of practice. Instead, they often work as 'seeding venture capitalists', in de facto forecasting genius roles, initiating projects and testing programmes with short-term funding (Ranka, J., 2019). Just like genius entrepreneurs, DARPA programme managers must be able to cope with a high degree of uncertainty and unclarity (CRS, 2021, Update 15).

At DARPA, individual intuition is challenged by the highest standards in terms of individual performance, as the failure of a project is never justified by the impossibility of the challenge. Critical thinking is therefore required in assessing ideas and intermediate milestones, rapidly and flexibly, with a focus on concrete outputs (Ranka, 2019). It remains a challenge to combine applicative programmes with deep tech transformative innovation.

The work of programme managers at DARPA can be analysed according to the following polarities:

First polarity: organisational integration

'Continuous evaluation' is a shared conversation between directors and programme managers, based on co-created metrics, with the focus on learning from both successes and mistakes thanks to the common scientific and technical background of directors, who play a dual role as coaches, and programme managers, who share vision, mission and professional grammars (Windham, 2019):

Individual intuition >>> organisational integration >>> (R&D) programmes (metrics)

Second polarity: individual intuition

What strikes in the messaging and reputation of DARPA is the motivational factor that DARPA as an institution claims to have in enabling and ensuring that programme managers have the freedom to identify, articulate and pursue their agendas in various fields, from new technological applications to social sciences (Dugan & Gabriel, 2013). While directors establish a general steer, based on input by the US Department of Defense, programme managers have the freedom to consult their technical stakeholders and knowledge networks, and to propose, design and manage specific programmes (Windham, 2019):

Broad organisational direction >>> individual intuition >>> (R&D) programmes (metrics)

Liminality space: communities of practice

Since DARPA has no internal lab or facility, programme managers are the very centre of highly multidisciplinary communities. Therefore, they must be aware of related power dynamics dictated by the budgets they control (Jackel, 2019). Boone Bonvillain, Windham, and Van Atta (2019, 2021) identify the necessarily flexible mechanism in enabling such versatility in ‘multigenerational programmes’ that might extend across several tenures:

Multigenerational programmes >>> communities of practice >>> transformative innovation

3.4 The role of genius forecasting and forecasting geniuses in innovation funding

The purpose is to identify general lines of managerial style and organisational design to integrate genius forecasting and forecasting geniuses into strategic frameworks, to articulate and harmonise heterogeneous insights with other future-oriented practices and processes.

The first step is to identify and define the constituencies of genius forecasting within organisational models, processes and ecosystems, namely:

- What is the sociological principle behind genius forecasting and what are the ways of working of forecasting geniuses?
- What are the organisational profiles of those performing genius forecasting and of forecasting geniuses?
- What is the typical way of working that enables genius forecasting and forecasting geniuses to deliver value?

The three mission-critical constituencies of genius forecasting and forecasting geniuses are charismatic authority, mavericks and ‘maverickism’, and ‘trained judgement’.

Charismatic authority

The notion of ‘charismatic authority’ (Weber, 1922) pertains to the individual qualities of selected organisational leaders. Charisma entails multiple dimensions of personal expression and relational connection, including physical traits and posture (Reh et al., 2017). Principles of charismatic authority extend into a wide variety of scientific and professional domains, from corporate C-suites (Wowak, et al., 2016) to the medical context (Hollin & Giraud, 2017). It remains contested whether this modality relies on personal traits or relational dynamics (Vergauwe et al., 2016, p. 24-25).

Maverickism

Mavericks might be described as individuals who daringly intend to deviate from the norm, refusing to conform to any given rule, operating in a ‘high risk, high reward’ mode (Heesen, 2019). Extraversion, openness to experience and a low level of agreeableness are predictive indicators of what might be generically defined as maverickism (Gardiner & Jackson, 2012). This categorisation applies to domains as diverse as the creative industry, science (Avin, 2019) and medicine (Grove, et al., 2022). Mavericks have been assessed as a positive component in the workforce, beneficial to the success of companies and organisations, thanks to their ‘positive deviance’ (Fitzsimmons & Callan, 2022).

'Trained judgement'

In science, ‘trained judgement’ might be intended as a judgement-inflected vision, namely an abductive (Fischer, 2001) form of seeing and depicting. This notion inspired the field to rethink the ‘scientific self’ versus scientific objectivity (Daston & Galison, 2010). As an abductive practice, 'trained judgement' requires critical thinking, editing capabilities and intuition guided by experience. 'Trained judgement' is neither repeatable or falsifiable, nor reflexive for theoretical development. It might possibly be categorised as an incremental evolution of past paradigms describing the creative process in applied arts. This is based on an intuitive view of creativity, determined by personal talent, as a discriminating success factor in an apparently unstructured process where accumulated experience results in abductive confidence. One cannot be trained for brilliance, however intuitive thinking relies on transferable skills (Daston & Galison, 2010).

How to rebalance individual genius within collective structures

Innovation in the creative industries is driven by dialectally distributed agency across mavericks and mainstreams (Jones, 2016). In settings like science, technological and business innovation and other equivalent domains, collaborative and convergent processes might benefit from interaction with one or more mavericks, in terms of enabling different perspectives and deviating opinions to be circulated and considered (Hayashi, 2018). Firstly, it is mission-critical to recognise, acknowledge and valorise the presence of mavericks within complex organisations, who leverage their charisma to express their 'trained judgement'. Secondly, it is important to structure processes and tools to optimally connect their individual genius to collective teamwork.

Genius forecasting rebalanced: matrixes and metrics

Within the multipurpose context of city.people. light, a specific element of process continuity was required, unifying a prior research phase (qualitative findings) with the facilitation of the workshop (design direction) (Bevolo, 2016). The Urban Futures Matrix enabled explicit and implicit mitigation of subjective contributions by consistently framing each milestone of the project, namely the tool provided a para-scientific foundation of possible coherence and consistency, however without scientific falsifiability. Ultimately, this matrix enabled traceability and repeatability. Consequently, genius forecasting as a foresight principle and input by contributors working in forecasting genius mode were rationalised and leveraged in the programme.

There are several constraints on DARPA's performance as an agency, from political scrutiny to legal and social constraints in terms of impact in the United States (CRS, 2021, Update 15). As much as there is trust and independence at the heart of programme management, the organisational culture at DARPA challenges programme managers in terms of due diligence, problem definition, problem framing, goal setting, the development of evaluation metrics, risk optimisation strategies and all other factors depending on their superior technical competencies. Metrics are in place to set goals, track output and evaluate the outcomes of projects. Programme managers have the final responsibility for designing and managing these metrics as an intrinsic competence in their portfolio (CRS, 2021, Update 15). In the context of the EU, this might be applicable to a European executive agency such as the EIC.

Forecasting geniuses rebalanced: communities of practice

High Design, the original design approach at Philips between 1991 and 2011, was indebted to the organic ways of working within Italian districts. Here, a synthesis is required to close the gap between the divergence of multidisciplinary, individual creativity, however 'trained' or educated, and the convergence of formalised design and research processes. This synthesis is at the heart of 'design districts' (Verganti, 2009), where participatory dynamics are key (Pisano & Verganti, 2008). Although the everyday reality of design districts is less comparable to the operations of an organisation like DARPA or innovation funding agencies such as the EIC, the very principle of networking within communities of practice is a key background reference to draft a generic view of how genius forecasting knowledge and the output of forecasting geniuses organically generates mission-critical value within a given focus, theme or metaprogramme, e.g. that of a specific industrial district.

Multigenerational programmes and technology thrusts require complex and large innovation ecosystems around DARPA (CRS, 2021, Update 15). Organisationally, considering the short-term tenure of programme managers, whose turnover might reach yearly peaks of 25%, it is mission-critical to mitigate the risks of duplicative efforts and of loss of organisational memory (CRS, 2021, Update 15) in the absence of DARPA's own facilities or laboratories. For example, in the fiscal year 2019-2020, DARPA's R&D obligations were distributed across multiple actors and agencies: only 11% of commitments were intramural (CRS, 2021-b, Table 8, cited in CRS, 2021). Accordingly, the external communities of practice created around each specific programme constitute a key asset over a longer timeline, to counterbalance the turnover of programme managers dictated by the limited tenure (CRS, 2021, Update 15).

3.5 Recommendations

In conclusion, for public agencies, suggestions on genius forecasting and forecasting geniuses converge towards pragmatic solutions. The natural enabling conditions to achieve the integration of individual genius intuition into organisational coherence include:

- recognising geniuses for their specific and unique individual value;
- leveraging their communicative charisma and thought leadership as assets;
- acknowledging individual contributions based on 'trained judgement'.

Methodologically, the design of a process to integrate genius forecasting within the procedural and managerial context of the EIC might be required, including:

- creation of metrics and matrixes to efficiently (self) manage forecasting geniuses;
- formalisation of specific indicators to assess, track and explain their effectiveness.

Organisationally, the clear scope and balance in the contributions of forecasting geniuses, recalling the notion of 'thematic focus', might be pursued through:

- focusing genius modalities on longer-term futures domains, e.g. horizon scanning;
- connecting forecasting geniuses with external experts from innovation ecosystems;
- securing continuity of the EIC in ecosystems by network management protocols.

Ultimately, the goal is to systematically balance diverse generative modalities by design, leveraging opportunities while mitigating risks. What appears mission-critical is to integrate such genius practices into trackable, traceable and repeatable processes within objective frameworks and with accountable output, generating measurable outcomes in terms of impact.

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Roadmapping for strategy, foresight and policy

CHAPTER 4

By Imoh Ilevbare

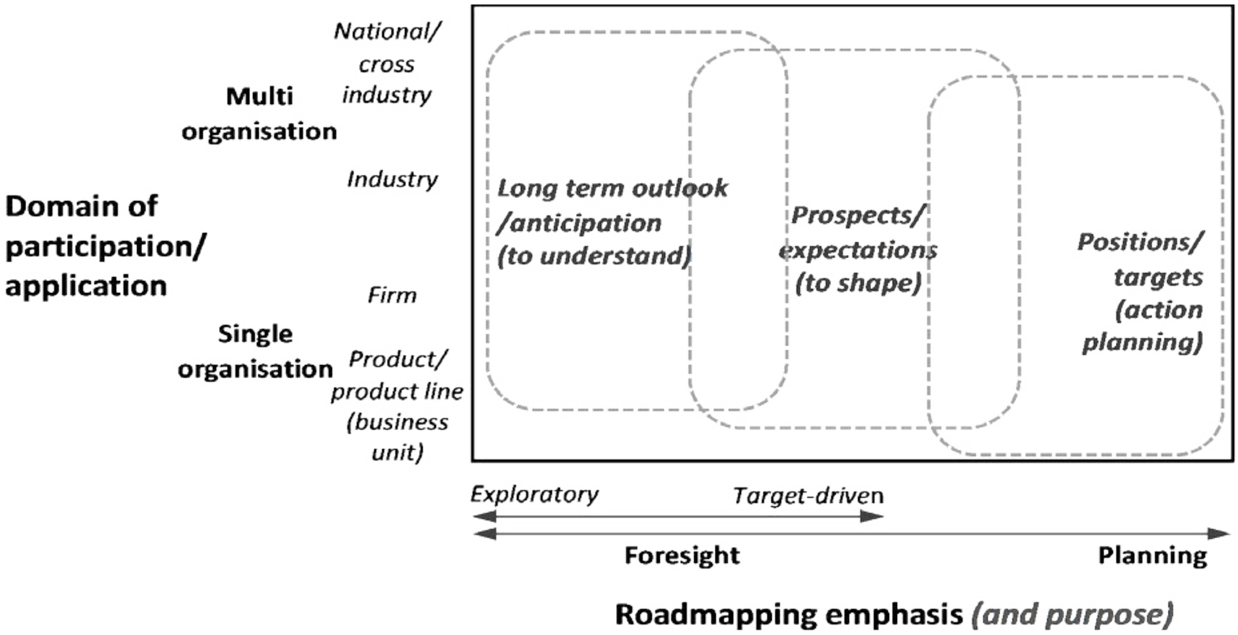
Dr Imoh Ilevbare is Principal Specialist in strategic technology and innovation management (STIM) at the Institute for Manufacturing, University of Cambridge. He works alongside leaders in the private sector and in government to shape their technology and innovation strategies and enable change. He is also the lead for the Cambridge Advance Online Product-Technology Roadmapping Course for professionals, and the Programme Director for the STIM Consortium, a network of multinational companies and researchers sharing best practice and solutions to current and emerging technology and innovation management challenges. His areas of expertise include technology and innovation roadmapping and strategy, foresight and futures thinking (including scenario planning) and creative problem solving. Dr Ilevbare obtained his PhD in Technology and Innovation Management from the University of Cambridge. His first degree was in Mechanical Engineering from the University of Ibadan.

4.1 Introduction

Roadmapping provides a structured approach to developing strategy and foresight. It has become one of the most widely used techniques for these purposes. It is increasingly being applied across industries and within organisations, consortia and sectors due to its ability to support structured decision-making, communication and consensus between key stakeholders. The origin of roadmapping is not precisely known, but early application of roadmapping can be traced back to the 1960s and 70s, especially in the United States by organisations in the aerospace and defence industry, e.g. NASA, Lockheed Martin and Rockwell (Kerr & Phaal 2020). The application of the approach from the 1980s by companies such as Motorola for product strategy, and by the Semiconductor Industry Association for sector-level technology foresight, significantly increased exposure and interest in the approach.

Many of the descriptions of roadmapping in literature reflect its application within the context

Figure 1 - Integrated roadmapping taxonomy (Ilevbare, 2014)



of science and technology, for the exploration and innovation of new solutions to societal and technical challenges. As a result, the term 'technology roadmapping' has been used most often to describe the approach.

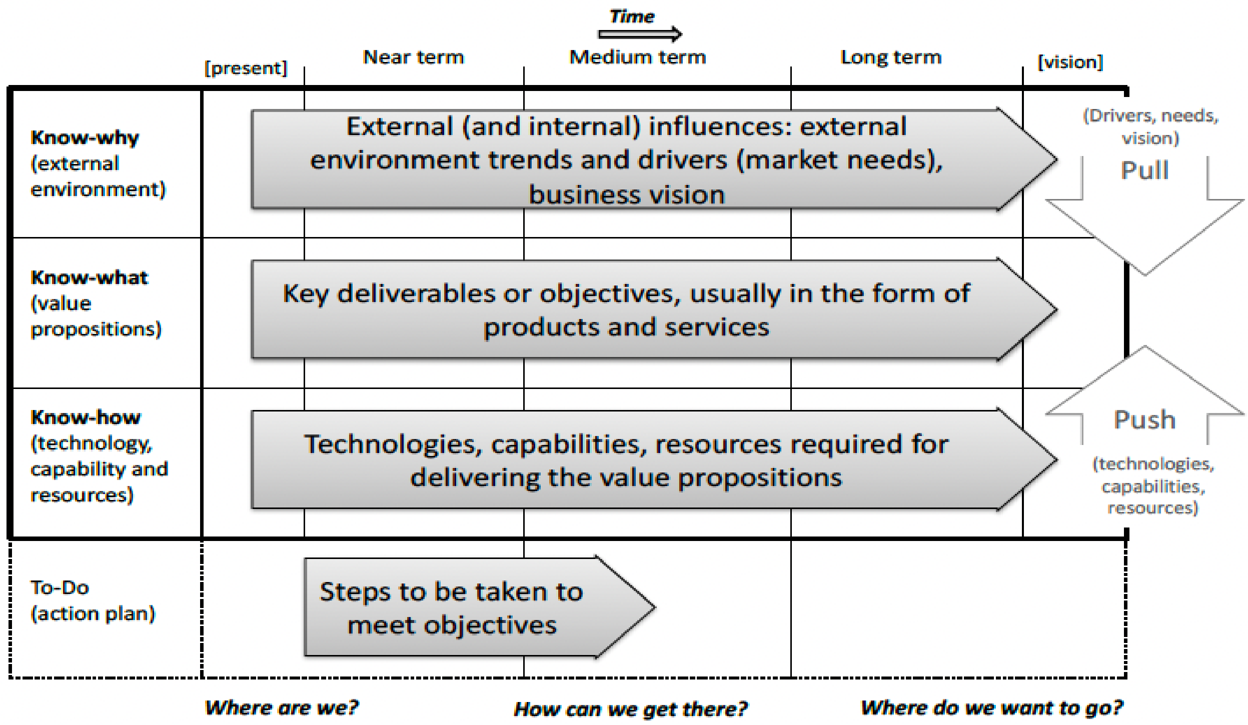
A roadmap provides 'an extended look at the future of a chosen field of inquiry, drawn from the collective knowledge and imagination of the groups and individuals in that field' (Galvin, 2004, p101). It presents 'the best current estimate of the near-term, mid-term and long-term research, development and demonstration needs in technology'[12], and helps to communicate visions, attract resources and facilitate interdisciplinary networking and collaboration. While roadmapping can simply be described as the process of developing roadmaps, it can be further described as 'a process that mobilises structured systems thinking, visual methods and participative approaches to address organisational challenges and opportunities, supporting communication and alignment for strategic planning and innovation management within and between organisations at firm and sector levels' (Park et al, 2020, p2). Due to its ability to facilitate communication, alignment and consensus between stakeholders, it is now widely accepted that the process of creating a roadmap is as important (if not more important) than the possession of the roadmap itself. Also, decision-making during roadmapping is more likely to lead to action, since it has been established that decisions reached via consensus are more likely to be carried out.

There are various ways of classifying roadmaps. The integrated taxonomy shown in Figure 1 explains that:

- roadmaps can be created at different organisational levels, from national level down to product/project roadmaps;
- roadmaps combine elements of foresight and action planning, and every roadmap can be positioned along a foresight-planning spectrum;
- the foresight element itself can either be more exploratory or more normative (i.e., target-driven).

12 US Congress (2009) https://www.congress.gov/bill/111th-congress/house-bill/3585.

Figure 2 - Generic roadmap framework Ilevbare (2014) - adapted from Phaal et al. (2003) and Albright (2009)



4.2 The state of the art

4.2.1 The generic roadmap visual framework

The roadmap framework embodies the visual aspect of roadmapping and is a powerful enabler of strategy and foresight. It helps to break down, organise and align strategic information for complex strategic problems, allowing multiple interacting themes to be represented in a structured manner. This structure promotes understanding of the interdependencies between the themes and encourages communication and discussion between those participating in planning or foresight.

The most common visual structure of roadmaps is the multi-layered time-based format, in which multiple layers and sublayers of strategic information are laid out over time. There are three main layers in a roadmap, as follows (Figure 2):

- The 'know-why' (or Why? layer) – this layer, usually topmost in the roadmap architecture, focuses on the current and future requirements of the system or strategic issue under consideration (e.g. current and future industry/ market needs, challenges and requirements, as well as related trends and drivers) and provides the rationale for the rest of the roadmap.
- The 'know-what' (or What? layer) – the middle layer focuses on the key strategic initiatives, possible solutions, deliverables or value propositions pertaining to the strategic/ innovation issue under consideration, to meet the requirements set out in the know-why layer.
- The 'know-how' (or How? layer) - the bottom layer is concerned with the technology, capability and other resources necessary for actualising the strategic initiatives and deliverables contained in the know-what layer.

The exact composition of these layers (i.e. in terms of their sub-layers) will depend on the specific application of the roadmap. It is useful to point out the presence of a fourth layer – the To Do (or actions) layer – which is sometimes embedded in the know-how layer. The time dimension (also called the 'know-when') makes explicit the time dimension and elicits three important questions: 'where are we?', 'where do we want to go?' and 'how can we get there?' (Phaal, et al., 2003).

4.2.2 The roadmapping process

There are two fundamental approaches to roadmapping: the expert-based approach and the computer-based approach[13]. The expert-based approach uses the knowledge and experience of a team of experts as the main source of information to create a roadmap. The computer-based approach applies data extracted from large textual databases using computer techniques to develop the roadmap[14]. Even though the computer-based approach appears more objective than the expert-based approach, it is limited by the availability of databases with the relevant information and the ability to successfully apply text-mining and bibliometric analysis tools. It is also disadvantaged by the absence of interaction between experts, which is a vital aspect of the roadmapping process. There is a hybrid approach, combining expert-based and computer-based approaches, which helps overcome some of the limitations of the individual approaches. The expert-based approach is the more widely used approach for roadmapping, due to its pragmatic nature.

Perhaps the best-known expert-based approach is the 'fast-start roadmapping' method, developed at the University of Cambridge. Fast-start roadmapping is a time- and resource-efficient workshop-based approach, which has been applied by Cambridge over 500 times globally, across more than 30 sectors and a wide variety of concerns from product-technology strategy to foresight and long-range planning applications, for industry and for policymaking. Many organisations have also taken up the method on their own, embedding it within their planning systems.

There are two fast-start reference processes, which are customisable to specific contexts. These are:

- T-Plan: used specifically for developing ***t***echnology roadmaps for new products, services and systems;
- S-Plan: used for general ***s***trategic roadmaps at corporate and sector levels, for strategy and foresight. It is the more commonly used method due to its wide range of applications. S-Plan helps to develop portfolio-level roadmaps that identify and explore key strategic priorities and initiatives, and how they address crucial needs, challenges, and requirements.

The steps in the S-Plan process are outlined as follows and depicted in Figure 3:

1. Plan: define the objectives, focus and boundaries of the roadmapping process:

- Design the roadmap architecture and process
- Identify the stakeholders that will participate
- Plan the logistics of the workshop event

2. Roadmapping workshop:

- Strategic landscape activity to outline market trends and drivers, and innovation opportunities, and to identify a list of priority topics to focus on.
- Develop topic roadmaps for priority topics to explore in more depth:
  - Summarise key drivers, constraints, and assumptions
  - Clarify the vision and objectives
  - Summarise the current situation
  - Map a route forward
  - Highlight key risks, enablers, barriers, decision points and knowledge gaps
- Present topic roadmaps for discussion and review to agree on which ones to to pursue further

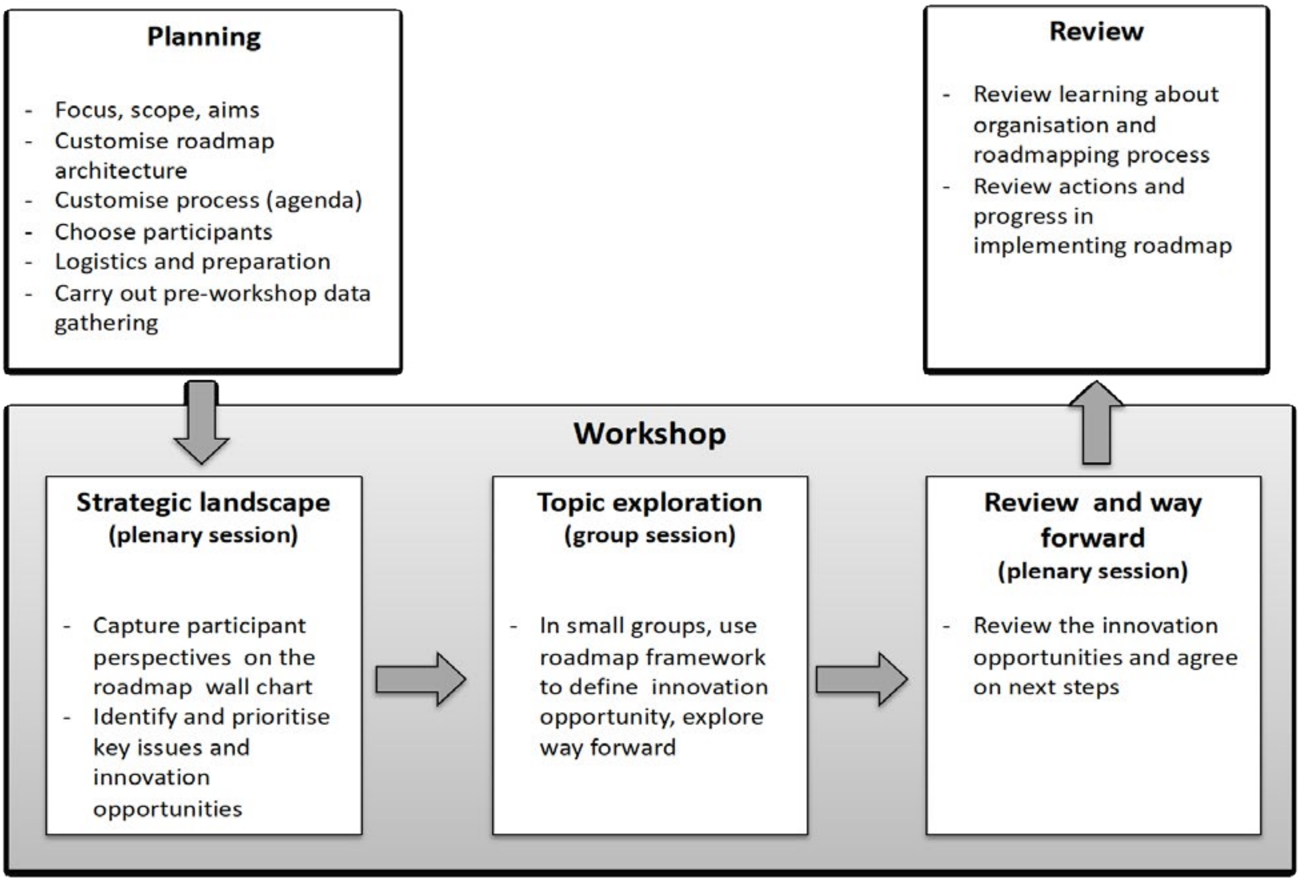
3. Create a report (or presentation, or both) containing a summary of the outputs

4. Communicate and/or implement - develop a communication and/or implementation plan for roadmapping outputs

5. Review actions and progress in implementing the roadmaps.

13 Kostoff & Schaller (2001).
14 See Geum et al. (2015) and Kim et al. (2016) for examples of this approach.

Figure 3 - S-Plan process (adapted from Phaal et al. 2010)



These fast-start approaches are designed so that the workshops can take as little as one or two days to complete.

There is an ongoing effort to digitalise the workshop-based roadmapping process, especially given the shift to hybrid working since the COVID-19 pandemic. Online workshops are now common and can be successfully delivered by using the appropriate software tools and platforms to encourage interaction and collaboration, and to create repositories of roadmaps. Researchers are also exploring the use of augmented reality and virtual reality technologies for roadmapping (Oliveira et al, 2023).

4.2.3 Integration of roadmapping with other tools

The roadmap framework acts as an integrating platform for other tools to support decision-making. This is important because while it provides structure for strategic information, it does not have much analytical power by itself. Therefore, its analytical rigour and its ability to deliver holistic ways to make sensible strategies is often derived from other decision-making tools integrated into it.

Tools that are often integrated with roadmapping include:

- portfolio analysis and selection tools – to help identify priority initiatives;
- linkage grids and matrices (e.g. quality function deployment), to establish relationships and dependencies in the roadmap;
- trends analysis;
- market and technology intelligence;
- assumption analysis;
- structured what-if technique (SWIFT);
- multi-criteria decision analysis;
- SWOT analysis;
- technology readiness levels;
- decision trees;
- scenario techniques.

Scenarios (or scenario planning) are a very important and prominent tool in foresight, so it is worth noting that cases of scenario-roadmapping integration have been reported by different authors[15].

4.2.4 Features of good roadmaps and roadmapping success factors

A roadmap should:

- be clear in focus and scope, and clear about the objectives it is meant to achieve. There should be a well-defined need or rationale for the roadmap. For example, a roadmap might be created to feed useful information into a wider strategic or innovation decision-making process or system, such as an annual plan, portfolio management system or funding programme;
- have a clearly defined timeline that aligns with its focus, scope and objectives;
- be developed based on a logical and collaborative process and make effective use of additional analytical tools and techniques, as necessary, to meet the objectives set;
- be well-defined in structure, showing interacting themes, and preferably containing all three main layers for completeness;
- have clear and logical narratives, explain relationships between elements of the system over time, and communicate strategic intent;
- be easy to read and understand, with necessary aids (such as a legend) to understand the objects used in the roadmap;
- be based on reliable and trustworthy information, meaning contributors should be experts in the strategic issue that the roadmap covers. The involvement of the right range of people and expertise in the roadmapping process is crucial.

Once developed, a roadmap should be regularly updated, given that information in the roadmap becomes obsolete with the passage of time. During the creation of a roadmap, projections of trends and drivers, and any assumptions made regarding the future, may turn out to be inaccurate, and so it would be necessary to adjust the roadmap to reflect these if it is to continue to be useful. Therefore, beyond the initial roadmapping process, the system in place for monitoring, evaluating and refreshing the roadmap is also a key determinant of its quality. The commitment of senior management is crucial if the roadmapping process is to be successful and the roadmap produced is to be effective.

4.3 Use cases

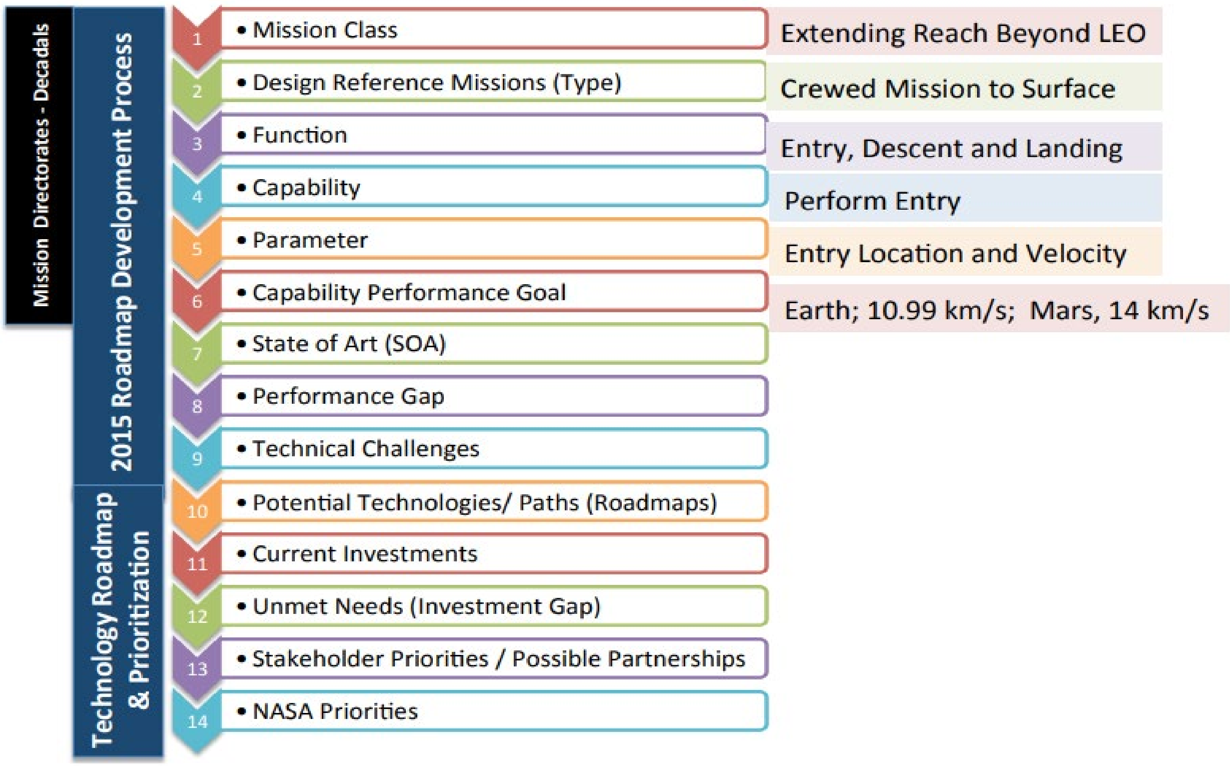
This section of the chapter presents three case studies of roadmapping initiatives available in the public domain. These have been selected to demonstrate different aspects of good roadmapping practice.

4.3.1 Case 1: NASA Technology Roadmaps (2010–2015, 2022–present)

NASA uses roadmapping to improve the management of its technology development, which is key for the United States' ability to maintain its aerospace leadership. These roadmaps are part of a NASA-wide integrated technology portfolio management process, and they identify possible technologies to develop. The roadmaps feed into the Strategic Technology Investment Plan (STIP) for technologies essential to achieving NASA's mission and its goals. NASA's efforts to develop its technology roadmaps date from 2010. It identified 14 Technology Areas (TAs), the key technical challenges and candidate technologies within each TA and the spaceflight missions the technologies could impact. NASA created a 20-year horizon roadmap for each TA to guide the development of the technologies. The draft roadmaps were published in late 2010 and NASA contracted the National Research Council (NRC) to perform an evaluation and review of the roadmaps, including the recommendation of technology priorities. The

15 Ilevbare (2017) identified 11 cases of the roadmapping-scenario combination used for foresight at sectoral or national levels. Scenario-roadmapping combination has also been used in corporate firms – see Lee et al. (2015), Cheng et al. (2016), Hussain et al. (2017) and Ringland et al (2020).

Figure 4 - NASA Roadmap development process (NASA 2015)



reviewed roadmaps were published in 2012 as 'NASA Space Technology Roadmaps and Priorities – Restoring NASA's Technological Edge and Paving the Way for a New Era in Space'. The technology priorities fed into the subsequent STIP.

NASA started updating the 2012 roadmaps in 2013, following a more systematic roadmapping process (outlined in Figure 4), and improving the scope and roadmap content and format. Other improvements included involving a wider set of experts and stakeholders to help to review draft roadmaps.

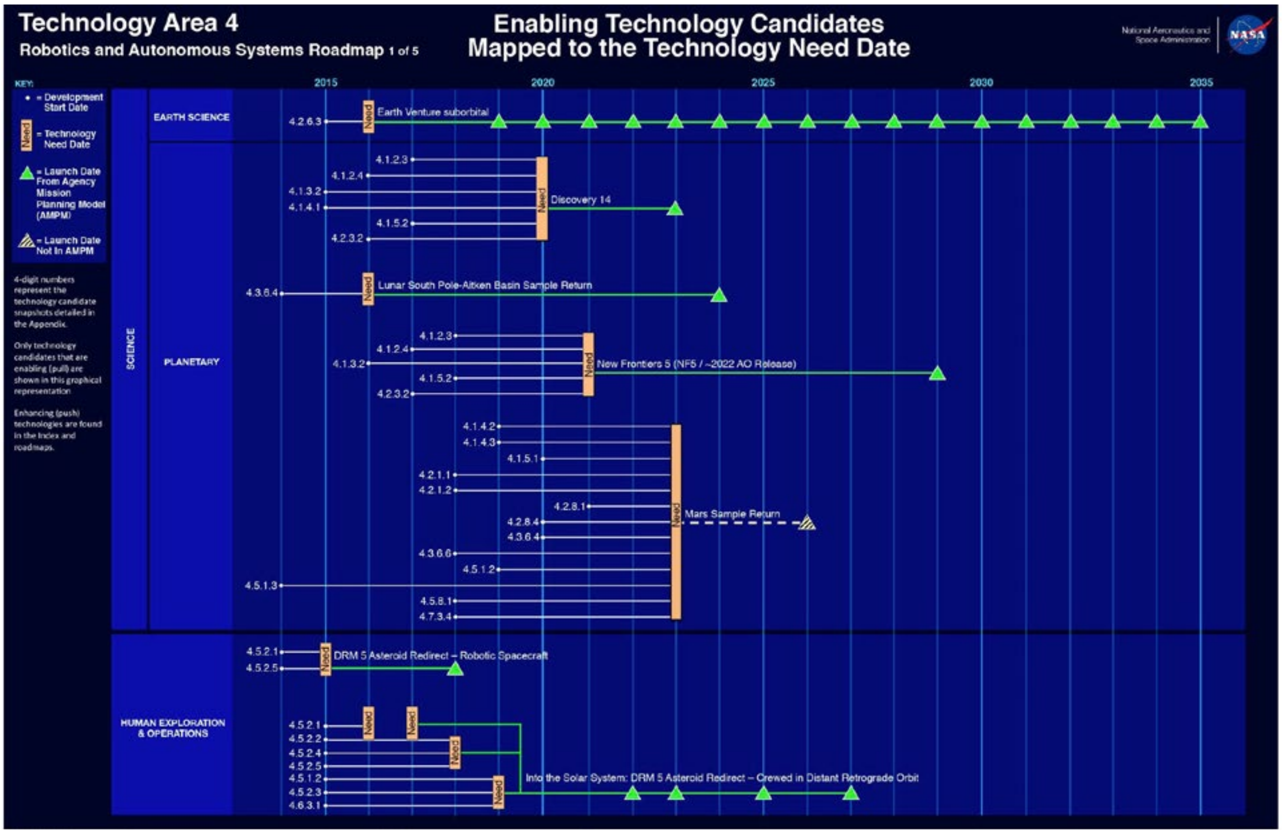
The roadmaps produced covered the following:

- a description of state-of-the-art capabilities *(Where are we now?);*
- the performance goals needed for each relevant mission, and the gaps between the state of the art and the goals *(Where do we want to go?);*
- the proposed technologies to fill the identified gaps, and the potential benefits of those technologies *(How do we get there?);*
- the list of missions for which specific technologies are relevant and appropriate.

These outputs are captured in NASA's roadmap documents, which include the roadmap graphic (see Figure 5). The roadmap graphic is structured according to the time-based multi-layer format and covers a time horizon of 20 years, laid out over the horizontal axis. The layers depict the different missions, i.e. science missions (comprising earth science missions and planetary missions), human exploration and operations missions and aeronautics missions.

Each layer contains specific missions, e.g. *Discovery 14* within the planetary layer, and the different technology candidates that fulfil the technology needs associated with that mission. The roadmaps show the suggested start dates for development of each technology candidate.

Figure 5 - An example of NASA's roadmap graphic (NASA 2015)



The following are positive features of NASA's roadmapping:

- the roadmaps have a clear purpose - they feed into strategic decision making and investment planning;
- they are developed through collaboration between experts and stakeholders[16];
- they are developed following a clearly defined process, including the use of analytical techniques such as multiple criteria decision analysis and quality function deployment for prioritisation of the technologies and linkages to missions;
- the roadmap visuals are clearly laid out;
- the roadmaps align with the generic roadmap framework. They address the *know-why*, *know-what* and *know-how* layers as well as the *Where are we now?*, *Where are we going?* and *How do we get there?* questions. Note that all of these issues are addressed through the combination of the roadmap graphic and the text and tables contained in the report, rather than by the graphic alone;
- the roadmaps are reviewed and updated at least every 4-5 years to reflect changes in NASA's strategic direction;
- roadmapping is treated as an ongoing activity, supported by a system that seeks to improve the procedures used to develop the roadmaps[17].

Note that NASA continues to update these roadmaps and has since done so beyond the activities from 2010 to 2015 summarised above[18].

16 The NASA roadmapping process is led by experts from the Office of the Chief Technologist (OCT) with contributors from NASA Field Centres and other Government agencies.

17 National Academies of Sciences, Engineering, and Medicine. 2016. NASA Space Technology Roadmaps and Priorities Revisited. Washington, DC: The National Academies Press. https://doi.org/10.17226/23582.

18 The 2015 Technology Roadmaps evolved into a 2020 edition entitled '2020 NASA Technology Taxonomy'. It now covers 17 technology areas (https://www.nasa.gov/offices/oct/taxonomy/index.html).

Figure 6 - A part of the IRDS 2022 roadmap showing lithography technology requirements (IRDS 2022)

Parameter	2022	2025	2028	2031	2034	2037
MPU / Logic						
Logic device technology naming [F]	G48M24	G45M20	G42M16	G40M16T2	G38M16T4	G38M16T6
Logic Industry "Node Range" Labeling	"3nm"	"2nm"	"1.5nm"	"1.0nm eq"	"0.7nm eq"	"0.5nm eq"
Logic device structure options	FinFETLGAA	LGAA	LGAA	LGAA-3D	LGAA-3D	LGAA-3D
MPU/ASIC Minimum Metal ½ pitch (nm)	12.0	10.0	8.0	8.0	8.0	8.0
Metal LWR (nm) [C]	1.8	1.5	1.2	1.2	1.2	1.2
Metal CD control (3 sigma) (nm) [B]	1.8	1.5	1.2	1.2	1.2	1.2
Contacted poly half pitch (nm)	24.0	22.5	21.0	20.0	19.0	19.0
Physical Gate Length for HP Logic (nm)	16.0	14.0	12.0	12.0	12.0	12.0
Gate LER (nm) [C]	1.1	1.0	0.8	0.8	0.8	0.8
Gate CD control (3 sigma) (nm) [B]	1.6	1.4	1.2	1.2	1.2	1.2
Overlay (3 sigma) (nm) [A]	2.4	2.0	1.6	1.6	1.6	1.6
Metal CDU (nm)	1.8	1.5	1.2	1.2	1.2	1.2
Metal LER (nm)	1.3	1.1	0.8	0.8	0.8	0.8

4.3.2 Case 2: International Technology Roadmap for Semiconductors and International Roadmap for Devices and Systems (1991 – 2022)

The International Technology Roadmap for Semiconductors (ITRS) roadmaps were developed for the semiconductor industry. They are important because they demonstrated the benefits of sector-level roadmapping and boosted the use of the approach at this level in other industries. The ITRS roadmaps were the result of a collaboration between the world's five leading chip producers: EU, Japan, Korea, Taiwan and the United States. The first edition of the roadmap (then known as the National Technology Roadmap for Semiconductors) was published in 1991 by the Semiconductor Industry Association (SIA) in the United States. However, by 1998, all the key semiconductor associations in the above-mentioned regions had come together to create the first global ITRS roadmap. The ITRS roadmap was updated every couple of years until 2013, and then replaced by the International Roadmap for Devices and Systems (IRDS).

Each edition of the ITRS and IRDS roadmaps predicted the main trends in the semiconductor industry 15 years into the future and covered aspects of the design and production of semiconductor devices. They identified and assessed the crucial technology needs and targets that would have to be met according to key parameters and, as such, provided guidance for the whole semiconductor industry, including R&D and academic research.

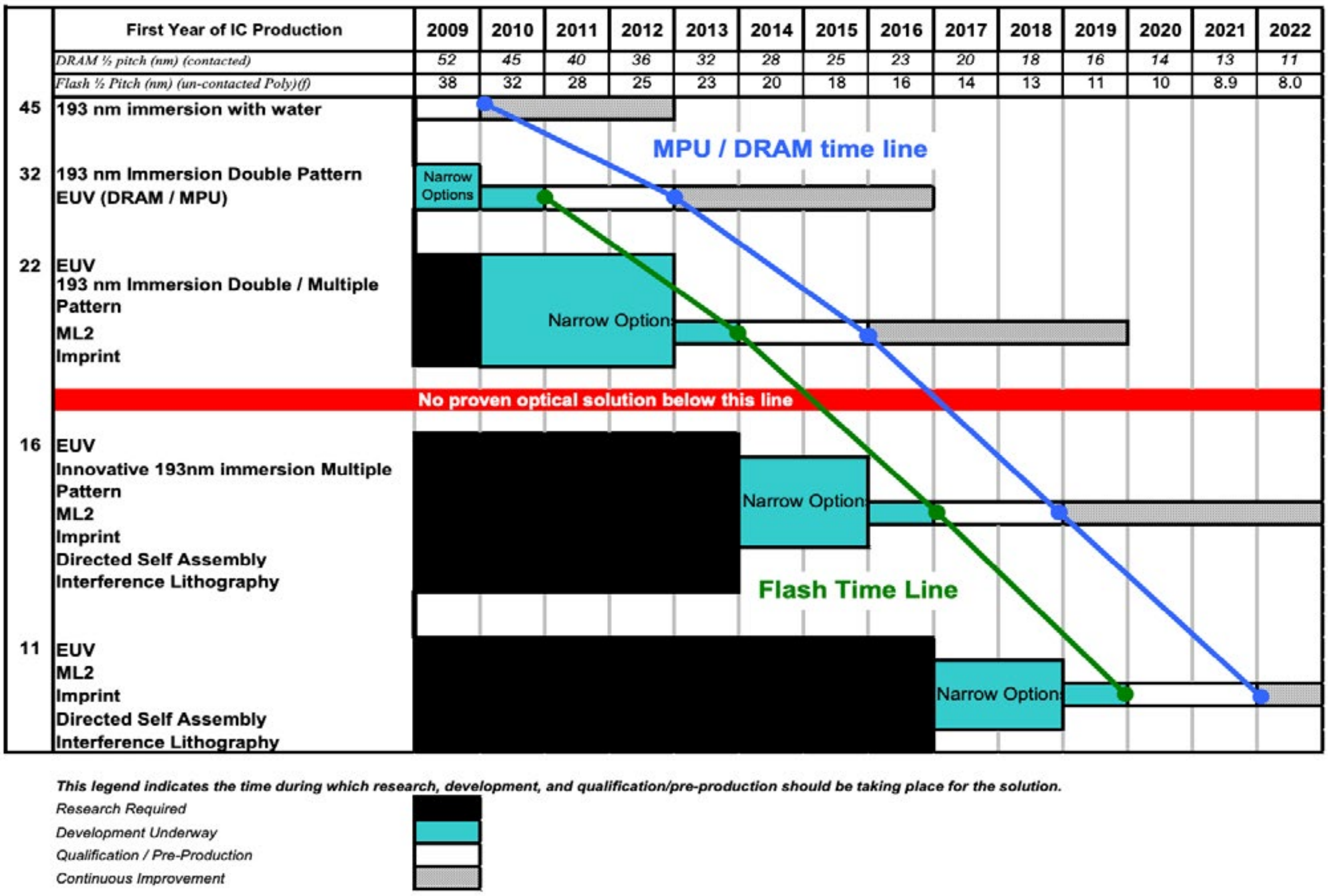
The roadmaps were created through an expert-based, global consensus-building process. Many experts were involved in order to cover the breadth and detail required in the roadmap. For example, over 900 experts participated in the development of the 2003 ITRS[19]. These experts were placed in 'focus teams', also known as 'working groups', and each team was dedicated to developing part of the roadmap. Meetings, workshops and/or consultations were held worldwide for the purposes of discussion among and coordination between the members of each focus team.

Broad steps taken in the development of the roadmaps include:

- identifying market and application drivers, challenges, etc.;

19 Schaller (2004).

Figure 7 - Part of the ITRS 2009 roadmap showing potential solutions for a lithography exposure tool (ITRS 2022)



- mapping the performance of these applications for the next 15 years, identifying which applications are the most important and critical for each market, and therefore defining projected technology requirements and targets (see an example in Figure 6);
- identifying potential solutions to meet the targets and address challenges (see example in Figure 7).

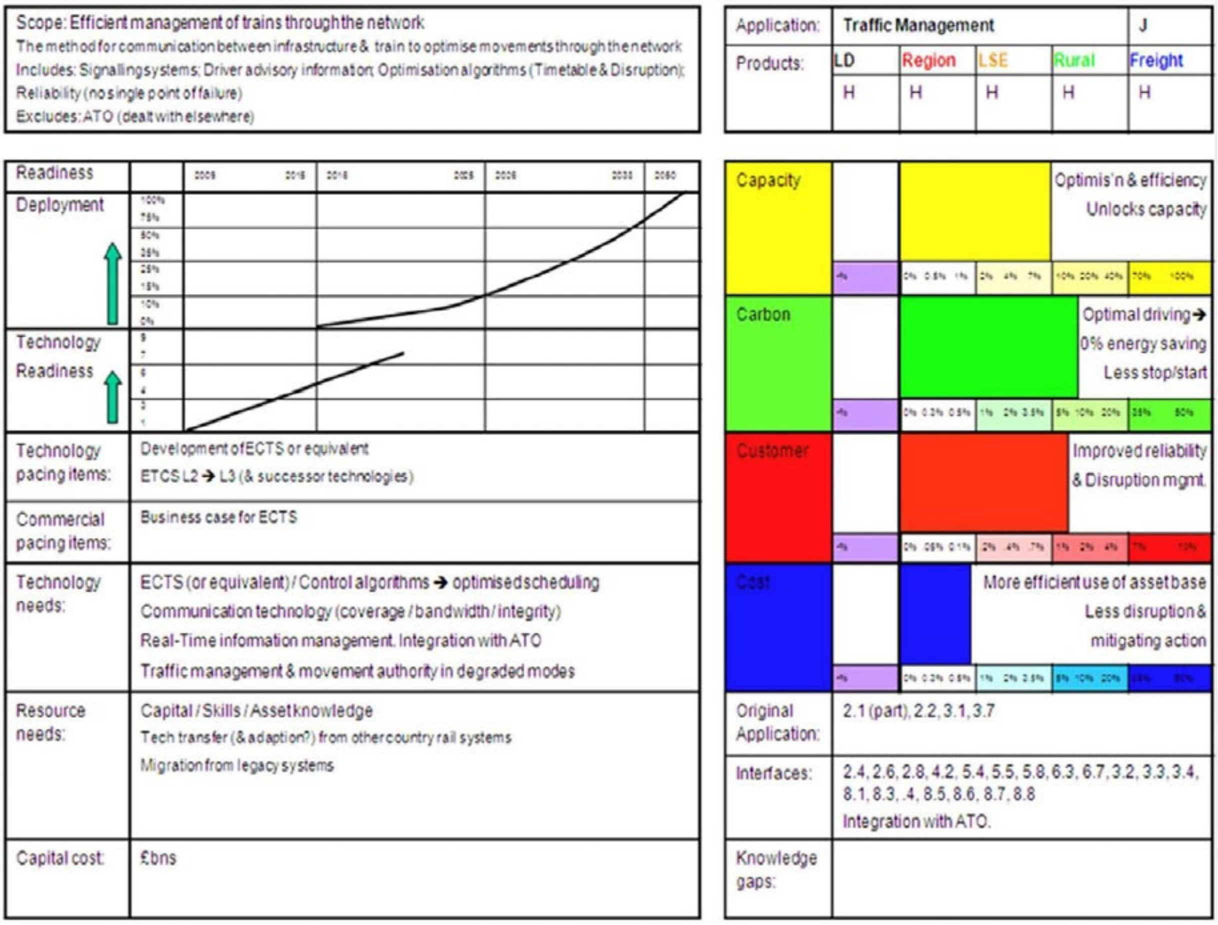
These targets are quantified and expressed in tables, showing their evolution over time, thereby producing a very structured roadmap. Colour coding is used to distinguish different targets, highlighting where effort is most necessary and research most required.

The ITRS-IRDS roadmaps have been hugely influential as sector level roadmaps because they demonstrated that innovation and R&D can be accelerated through collaboration at the industry level. They also show that roadmapping can be used to generate industry-wide consensus across a large number of experts, and can provide a structured means for doing so.

4.3.3 Case 3: Roadmapping to support planning for rail's 30-year vision (2009)

This sector-level roadmap was commissioned by the UK Railway Safety and Standards Board's (RSSB) Technical Strategy Advisory Group (TSAG), an industry group concerned with the long-term technical development of the national railway system in the UK. The purpose of the roadmap was to identify strategic initiatives or 'applications' (which included activities, technologies and resources) that could help deliver the 30-year vision (also referred to as the 4C targets) of improving **c**ustomer satisfaction, doubling **c**apacity, reducing **c**osts and reducing **c**arbon emissions. The roadmapping exercise enabled the selection of priority areas for research and helped identify dependencies between the long-term goals,

Figure 8 - Example of a roadmap for an application (RSSB TSAG (2009))



applications, technologies and research needs. This helped the TSAG to influence the wider strategic direction of the industry as well as to understand gaps where further action was required.

The roadmapping process followed was based on the Cambridge S-Plan fast-start method. It followed a workshop-based approach involving about 150 rail industry professionals, academics and representatives from other sectors.

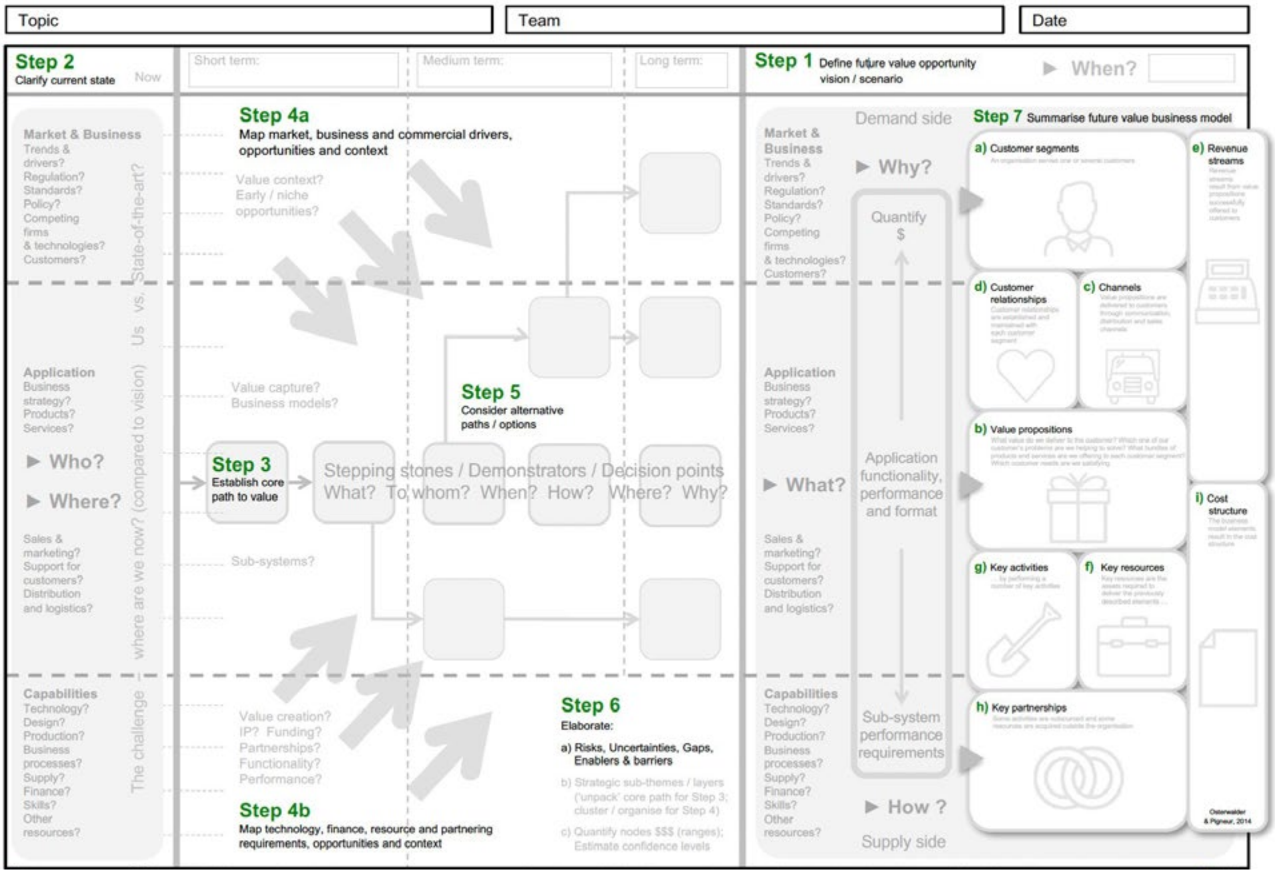
In broad terms, the steps followed were:

- identifying key trends and drivers via PESTLE analysis
- setting down current industry activity and plans;
- identifying future initiatives/applications and estimating their contribution to the vision;
- prioritising the applications against the 4C targets and developing 'route-maps' for each application (see Figure 8). These 'route-maps' were essentially the topic roadmaps developed as part of an S-Plan roadmapping process;
- testing the priority applications against four scenarios for the future of the rail industry. In this step, the prioritised list of 50 applications was 'wind-tunnelled against the scenarios'. The purpose of this activity was to identify which applications were relevant across multiple scenarios. Fifteen such 'top priority' applications were identified, and these were translated into projects within a strategic research programme;
- developing implementation plans for the top priority applications.

In the wind-tunnelling step, each application derived through the roadmapping process was assessed in terms of its applicability to each scenario. This was done through a simple method whereby participants were asked to indicate whether they thought an application would be relevant or useful in a given scenario[20]. Applications that were thought to be relevant to two or more scenarios were identified as priority applications.

20 More sophisticated techniques involving scoring models that help determine scenario applicability can be used for wind tunnelling.

Figure 9 – Topic roadmapping template embedded with business model canvas from Osterwalder & Pigneur (2010). Source: Rob Phaal (https://www.cambridgeroadmapping.net/moretemplates/)



4.4 How roadmapping can be used to make innovation and technology development funding programmes and decisions

Roadmapping can be used in at least two ways to support innovation and funding decisions in organisations such as the EIC:

- As in the case studies presented in the previous section, the EIC and other such organisations can carry out roadmapping to identify and outline priority challenges and map the research themes that will benefit from innovation and, therefore, funding. As explained, a key objective of NASA's roadmapping was to identify priority technologies that would feed into an investment plan. This was also the case for the RSSB TSAG case study. Moreover, the ITRS and IRDS roadmaps have been used within organisations to focus R&D efforts and funding on the priority challenges identified by the roadmaps.
- The identification of a set of well thought-out challenges that align with industry and societal grand challenges, along with the possible strands of R&D and technologies under each one, can be achieved using the Cambridge fast-start S-Plan approach[21]. To do this, experts and key stakeholders in the respective areas of interest, such as *Clean and Efficient Cooling*[22], can be brought together from across Europe to create a roadmap that will define key requirements to which proposals for funding would be advised

21 The Cambridge S-Plan approach has been used over 500 times for industry and policy. Examples of its application for defining research areas can be found at https://engage.ifm.eng.cam.ac.uk/roadmapping-case-studies/. These examples include *Materials for Energy Transition Roadmaps* developed in 2020 (https://www.royce.ac.uk/materials-for-the-energy-transition-caloric-energy-conversion/).

22 European Innovation Council Work Programme 2023.

to respond. Such roadmaps could be developed and updated every few years to shape the EIC's work programme.

- Funding applicants can be encouraged to develop innovation roadmaps to support their proposals for funding. By developing roadmaps with clear *why-what-how* and time-based narratives, applicants will be able to clarify the rationale for their research and innovations (the 'why', i.e. the benefits such innovations bring to society and industry and/or the advancement of science and technology), key research initiatives and steps within their plans (the 'what'), and the resources, capabilities and knowledge required (the 'how'). Such roadmapping would help applicants map these out over time, clarify the uncertainties in their plans and help them to de-risk their initiatives. Evaluators are likely to have greater confidence in proposals that include such roadmaps.
- The EIC may choose to advise evaluators to consider using roadmapping and propose a format for the roadmaps, such as the S-Plan topic roadmap framework shown in Figure 9. This roadmapping template (which included the business model canvas concept by Osterwalder & Pigneur (2010)) was used for early-stage ventures (ESVs) and small and medium enterprises (SMEs) as part of the ERDF-funded PriSMS programme[23] to help outline their innovation strategies and strengthen the business case for their R&D activities. Note that the roadmap structure can be customised to align with the EIC's funding context and expectations. Beyond the initial application, programme managers for the funding agencies may continue to support successful applicants by regularly examining their innovation roadmaps and supporting updates to these roadmaps, especially where the innovators are trying to push for higher TRL levels and commercialisation.

4.5 Recommendations

- Organisations that want to apply roadmapping need to develop their organisational capability to implement it. The initial level of effort required to do so depends on the approach taken, i.e. whether roadmapping is implemented centrally before being rolled out across the organisation in one go, or a more gradual or incremental approach of experimentation and learning is taken.
- A gradual approach is often more appropriate and can be broken down into three phases[24]:
  - In the **initial or pilot phase** the organisation tests the application of roadmapping to planning or foresight challenges and can experience some of its benefits. While doing so, it starts to adapt the chosen approach to better align with its context and needs. For example, the EIC might choose to modify the Cambridge fast-start approach to meet its needs and ways of working.
  - In the **learning phase**, a community of roadmapping practice can be formed so that experience can be shared between programme and portfolio management teams across the organisation. A central support team with practical experience and knowledge can be created to support further implementation of the method across the organisation.
  - In the **final phase**, formal links between the roadmapping process and core decision making activities within the organisation (as in the NASA case study) are established as the norm. Also, standard roadmapping processes are formalised and used on a regular basis to provide valuable input into other business activities. In a roadmapping-mature organisation, roadmaps are updated regularly, and it is normal to have dedicated resources (e.g. a team, budget, tools and software) to ensure delivery quality and impactful roadmaps.

23 The ERDF-funded Practical and Innovative Solutions for Manufacturing Sustainability was commissioned to improve innovation among ESVs and SMEs: https://www.ifm.eng.cam.ac.uk/uploads/News/PrISMS-overall-project-web.pdf.
24 Phaal et al., 2010.

- The transition to such roadmap-based planning might require culture change and this should be managed appropriately, using change management techniques[25].
- Alongside success factors such as the commitment of senior managers, noted earlier in this chapter, the long-term sustainability of roadmapping implementation within an organisation also depends on the actual usage of developed roadmaps, whether for communication to key stakeholders, or to drive decision making or both. If the roadmaps are not seen to be useful, implementation efforts are likely to lose credibility among members of the organisation.

25 Cosner, 2007.

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The role of large language models in science and technology policy

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5.1 Introduction

In recent months, we've seen an explosion (Bommasani, R et al., 2023) of developments in Generative AI, a branch of artificial intelligence that uses *large models* to autonomously create new content, such as text, images, music or other forms of data, which mimics or replicates the statistical patterns of the data it was trained on. Large language models (LLMs) display capabilities ranging from automating tasks to parsing complex legal, scientific and financial information and complex reasoning.

The advancement of LLMs such as GTP4 has the potential to shape the future of science, innovation and the economy, as well as to enhance research and innovation (R&I) funding and policymaking (Boiko, D.A et al., 2023). While their capabilities in scientific discovery and experimentation are numerous (Jablonka, K.M et al., 2023; Nolan, 2022; Ahmad, W., 2022), they are beyond the scope of this article, which will focus on metascience and public-purpose implementation of LLMs. This essay further explores the potential applications of LLMs in R&I by identifying knowledge gaps, promoting combinatorial innovation, aiding bottleneck analysis and augmenting science and technology foresight.

5.2 The state of the art

LLMs have already been implemented in various sectors to solve complex problems and enhance decision-making processes. While there are fewer publicly available use cases in the public sector, preliminary evidence shows they have the potential to **enhance public services**. A case in point is Yokosuka, Japan, which is pioneering the use of ChatGPT for administrative tasks, marking a significant stride in AI-driven public administration (Osaki Exum, 2023).

Moreover, the UK Government already employs large language models for specialised applications, such as finding patterns in healthcare reports. They plan to expand their use to a ChatGPT-like interface with Gov.uk, the government's comprehensive information portal (Wodecki, 2023). Similarly, TaxGPT.ca, developed by an Ottawa-based programmer, simplifies tax filing in Canada, particularly for low-income individuals. The recent commitment by the Canadian Revenue Agency to automate tax filing for this demographic further underscores the role LLMs can play in catalysing public service transformation (Paul Craig, 2023). A cautious approach should be taken regarding these cases due to the risks involved around privacy and bias. The European Parliament's adoption of the AI Act in June 2023 is a case in point: it will regulate AI applications in the European Union based on their potential risk, for example, by prohibiting the police from using live facial-recognition technology in public spaces.

LLMs may also improve public comprehension and inclusivity. For example, the city of Boston recently released guidance on using LLMs (Noveck, 2023) . The policy outlines how officials can convert legal terminology into simpler, everyday language, thus making critical public service details more easily comprehensible to citizens, or how they can specify the desired reading level or target group in the prompt, enabling the AI model to generate appropriate text, whether it is for young students or another specific demographic.

Simultaneously, the development of both open-source and sector-specific LLMs has gained momentum. By way of example, Bloomberg's BloombergGPT (Wu, S, et al. 2023) is an LLM tailored for finance and designed to address domain specificity, security, privacy, regulations, and IP protection. Moreover, the advent of open-source, compact, efficient models such as LLaMA and Chinchilla has encouraged more organisations to create bespoke LLMs. These trends are positive signals for the use and development of agile and custom language models for public purpose R&I.

5.3 Use cases

In exploring the application of large language models in foresight, it is notable that there is a relative scarcity of published or publicly known use cases. This gap can be attributed to a variety of factors. Firstly, LLMs represent a fairly new area of artificial intelligence, and their potential uses are still being understood and explored. Additionally, the use of such tools may be kept undisclosed by consultancies and businesses for competitive reasons. Secondly, their successful application requires a combination of technical expertise, a deep understanding of the specific domain and access to a large volume of relevant data.

Below, I propose new ways in which LLMs can aid the work of R&I policymakers and enhance their capability to conduct comprehensive research, support horizon scanning processes and provide insightful assessments of emerging technologies. These prospective use cases are grounded in real evidence and highlighted based on their potential to enhance the work of the European Innovation Council.

6.3.1 Identifying gaps in knowledge and suggesting new areas of research

Today, four scientific papers and six patents are published every minute. This rapid growth presents a paradox: while the quantity of publications grows exponentially (Bornmann, L. and Mutz, R., 2015), the space for novel scientific ideas expands only linearly. This has led to a considerable decline in research productivity despite increased research efforts (Bloom, N., Jones, C.I., Van Reenen, J. and Webb, M., 2020). Furthermore, we cannot know the second order or combinatorial potential of knowledge, the constraints on that potential functionality and hence cannot effectively prioritise applied research. This poses a challenge for funding agencies and strategic intelligence units who are tasked with deciphering this data to extract meaningful insights for research and funding prioritisation. A solution may lie in applying large language models to the process of foresight, specifically within the context of horizon scanning, bottleneck analysis and evaluation of emerging technologies.

Firstly, LLMs could assist in performing more scalable and dynamic bottleneck analysis. Bottleneck analysis in science and innovation involves identifying and analysing factors that slow down or prevent progress in research, development and commercialisation of ideas. Bottlenecks can involve technological challenges, regulatory hurdles, lack of funding or gaps in talent and skills, among other things. While existing language models come pre-trained on a vast corpus of internet text, smaller open-source language models might benefit from further training or fine-tuning on domain-specific data like scientific literature, patent data, industry news, funding grant reports (L. Graham,2023), research institution publications and social media posts from relevant stakeholders. The models would then process this data to identify potential bottlenecks. This could be done by searching for key terms or phrases or using unsupervised learning techniques to cluster the data and identify discussion topics. For example, it could flag areas where there is a lot of discussion about challenges or barriers or where there is a mismatch between the amount of research being done and the number of successful outcomes.

Large language models also can tap into the combinatorial potential of innovation. A key mechanism of combinatorial innovation involves identifying synergies or overlaps between different research areas and considering the utility and impact of different scientific combinations. For instance, a technology or methodology developed in one field might be applied to solve problems in another, leading to breakthroughs that would not have been possible within a single disciplinary context. To achieve this, we first need **to identify knowledge units at the right level of *abstraction***. LLMs can be prompted (White, J., 2023) to identify more granular and useful knowledge from publications and different innovations, such as hypotheses, experiments or results from a paper or other innovation primitives like constraints, tactics, requirements and solutions for more applied innovation contexts (Malliaraki, 2023). By analysing abstracts and reports, they can identify similarities in methodologies, materials and research questions across different projects (Wang, Q., Downey, D., Ji, H. and Hope, T., 2023).

Secondly, LLMs could be employed to assess the maturity of different technologies by analysing their current state of development, the availability of necessary resources and the progress of ongoing research projects. Based on this analysis, LLM-based applications could generate a ‘technology readiness score’ for each technology and combination thereof, thus helping policymakers prioritise funding for technologies that are on the verge of achieving significant breakthroughs or those that require additional support to overcome critical challenges. This could further be used to explore thousands of technoscientific combinations for different societal missions and rank them based on how mature, valuable or impactful they may be and even to generate new innovation concepts through the use of creative cross-domain analogical reasoning and other creative approaches (Ding, Z., Srinivasan, A., MacNeil, S. and Chan, J., 2023).

6.3.2 Exploring multiple versions of the future

Foresight methods help science and technology (S&T) policymakers explore and make sense of a range of future possibilities. **Large language models can aid in this process by simulating plausible future scenarios** based on various influencing factors, such as emerging technologies, socioeconomic trends, political changes, environmental issues, etc. By altering the values or states of these factors, the model can generate a broad spectrum of plausible future scenarios, which correspond to the widening cone of uncertainty as we project further into the future.

Suppose we were to try to forecast the growth of a particular technology, such as electric vehicles. A language model with access to specific databases and/or the internet could consider data - production rates, government policies, public sentiment, technological advancements, etc. The model could then generate multiple scenarios like 'rapid growth', 'moderate growth', 'stagnation', or even 'decline'. Each scenario would be accompanied by a narrative explaining the combination of factors that could lead to that outcome. *These scenarios are not predictions strictly*; instead, **they are structured ways of thinking about different possible futures** and reasoning about the conditions under which each might occur. This playful expansion of multiple futures can open up more possibilities for consideration.

Moreover, it is crucial to incorporate a plurality of perspectives into this process in a scalable manner. **LLMs could further assist in participatory horizon scanning and priority setting by facilitating large-scale, real-time signal collection and processing.** Horizon scanning exercises aim to gather evidence and signals about future trends. For example, policymakers can collect text from public consultations, online forums, social media discussions, forecasting fora and expert opinions about different missions or research areas. They can then use LLMs to summarise the preference landscape and provide a clearer understanding of the primary concerns and interests of stakeholders. By further designing interactive preference elicitation systems (Bakker, M et al., 2022), LLMs can even generate hypothetical scenarios to probe stakeholders' preferences and priorities and aid strategic planning.

It is important to note that these generative models are trained on past data; therefore, any predictions or foresight they provide is essentially a projection of past trends and patterns and may not accurately account for unforeseen future events or technological innovations. There is preliminary evidence (Lampinen, A.K. et al., 2023) that LLMs can extrapolate and utilise causal links that were never part of the training data and that they can apply their learned experimentation strategies to new sets of variables that they did not encounter during training. More research and evaluation are needed before using LLMs for foresight purposes to understand how they represent cause-and-effect relationships, which may affect the quality of predictions, especially in complex domains such as technology foresight.

6.3.3 Learning from the past

Counterfactual analysis is a technique used to understand what could have happened under different circumstances. It explores alternate realities in which some conditions or decisions were different. **Language models can help generate these 'what-if' scenarios and explore their implications.** For instance, imagine a situation in which a company decided to launch a new product, which eventually failed. Using counterfactual analysis, a language model could help generate alternative scenarios such as 'What if the company had conducted more market research?', 'What if the launch was delayed to address design flaws?' or, 'What if the company had targeted a different demographic?'. Once the model generates a range of counterfactual scenarios, human analysts evaluate them to understand potential outcomes under different circumstances. This evaluation can provide insight into the causal relationships involved and highlight the potential impact of various factors. However, while language models can generate counterfactuals, it ultimately falls to human analysts to interpret and evaluate these scenarios.

5.4 Recommendations

The quality of output of LLMs is still variable, and they do not behave consistently, whereas both these factors are critical for the credibility of publicly funded organisations and the predictability and reliability of the results. Moreover, privacy and ethical concerns related to data usage can also hinder the wider dissemination of these use cases. Given these circumstances, the EIC and other funding agencies need to cultivate an experimental mindset when approaching the use of LLMs.

Addressing the limitations of AI models in S&T requires continuous research on some of the following:

- Augmentation of large language models with real-time S&T data;
- Development of unified frameworks that leverage the power of structured knowledge graphs and LLMs (Pan, S. et al., 2023). These models are capable of capturing and accessing factual knowledge better than current black-box models;
- Exploration of hybrid AI models incorporating expert knowledge and judgement for more reliable and accurate predictions (Morgan, D et al., 2023).

In the short term, the EIC should consider:

- Conducting pilot projects focusing on strategic intelligence and foresight and evaluating the effectiveness of LLMs in these contexts;
- Establishing clear data usage guidelines and protocols to address ethical concerns and ensure the responsible use of LLMs.

Mid-term goals for the EIC should encompass:

- Using open-source LLMs to increase transparency and foster collaboration between researchers, policymakers and the public (Lorica, 2023);
- The development and evaluation of models using relevant datasets such as past proposals, funded projects, scientific literature and policy documents;
- The establishment of multi-stakeholder advisory boards or coalitions to contribute to the development, evaluation and governance of the models. These boards should consist of diverse perspectives from academia, technology transfer offices, businesses (small, medium and large), private and public funders and policymakers.

Lastly, while these generative language models are impressive and have the potential to augment the workflows of S&T policymakers, human imagination will be key in envisioning and enacting future scenarios, even as the capabilities of AI models continue to progress. Those models are fundamentally limited by the data they are trained on and the biases encoded in them. Humans can assess the relevance and plausibility of predictions, drawing on a deep understanding of context, past experience and intuition. By maintaining a balanced approach, combining the strengths of both LLM-generated insights and human expertise, we can better anticipate, understand and enact plural future possibilities.

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CHAPTER 6

The role of horizon scanning in anticipating and monitoring emerging technologies and disruptive innovations

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6.1 Introduction

Over the last two decades, a growing number of researchers and policymakers have devoted significant efforts to the study of emerging technologies and disruptive innovations. This chapter looks into the role and benefits of horizon scanning (HS) in anticipating emerging technologies (ET) and disruptive innovations (DI) for policy and funding in science, technology and innovation (STI). It presents four case studies that showcase innovative HS practices in Europe and other regions, highlighting their relevance for European policymakers and stakeholders. The cases demonstrate that HS is not about predicting the future, but rather about examining how different futures could emerge based on contextual conditions. When focused on ET and DI, HS emphasises transformative changes while acknowledging incremental socio-technical transitions toward more sustainable futures.

The academic and grey literature extensively discusses definitions, frameworks and categories of emerging technologies and disruptive innovations. These terms are sometimes used as buzzwords, with disruptive innovations sometimes mixed with radical innovations (see e.g. Markides, 2006; Rotolo et al., 2015; Antonio and Kanbach, 2023). For the purposes of this chapter, the term 'emerging technologies' will refer to a novel and rapidly growing technology that exhibits coherence over time and has the potential for significant socio-economic impact (see Rotolo et al., 2015). The term 'disruptive innovations', adapted from Nagy et al. (2016), will refer to innovations that alter market performance metrics or consumer expectations through new functionality, technical standards or ownership forms.

6.2 The state of the art

Before discussing concrete HS practices, it must be recognised that the concepts of ET and DI are very much relative in terms of time and space. While certain technologies like 3D printing, artificial intelligence and blockchain are considered emerging technologies in Europe and leading economies, they may still be classified as future and emerging technologies (FET) in developing countries. In fact, even within the EU, especially in widening countries[26], several of these technologies have not been widely deployed. Similarly, and perhaps even more challenging in terms of contextual conditions, the concept of DI as originally described in the book *The Innovator's Dilemma* (1997) distinguishes between low-end disruptions, when innovations disrupt a market by offering more affordable solutions with acceptable performance, and new-market disruption, when an innovative solution creates a new market or a new segment in an existing market.

Europe's research performance is strong, leading to scientific excellence in various fields, yet it struggles to translate scientific achievements into breakthroughs or disruptive innovations that enhance its industrial leadership. Countries excelling in disruptive innovation have different approaches to empower their innovation ecosystems. The United States relies heavily on state-funded institutions like the Defense Advanced Research Projects Agency (DARPA) to support disruptive emerging technologies. Israel takes a mixed public-private funding approach through the Israel Innovation Authority. Japan combines various state-funded programmes, such as Impulsing Paradigm Change through Disruptive Technologies, to foster strategic disruptive innovations.

A recent study by Hansmeier and Koschatzky (2021) focused on addressing societal challenges through disruptive technologies. It proposed combining two paradigms: strengthening innovation and technological competitiveness, and solving societal problems through innovation. By aligning with these premises, the European Innovation Council (EIC) got EUR 10 billion budget aimed at identifying, developing and scaling up breakthrough technologies and disruptive innovations in Europe. This initiative aims to position Europe as a leading player in the global innovation ecosystem.

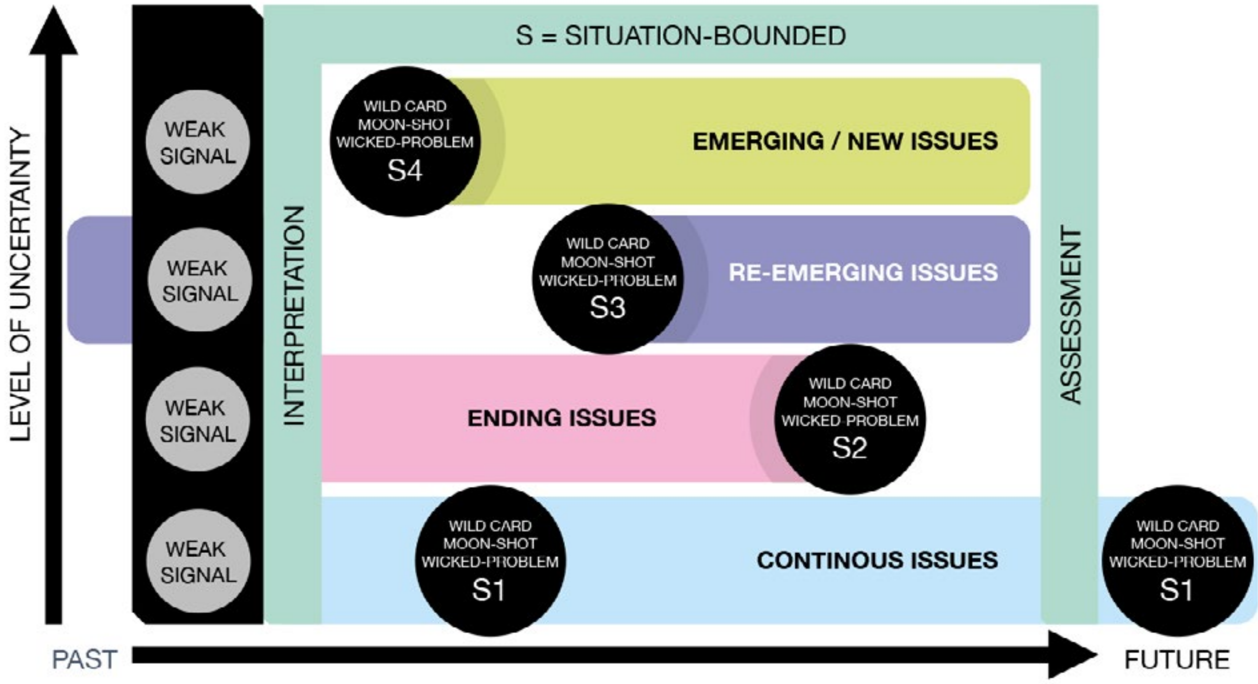
6.3 Use cases

To showcase the value of HS to the EIC and policymakers in Europe and beyond, this chapter presents and draws practical lessons from four case studies:

- Case study 1: iKnow project
- Case study 2: Technology Horizon project
- Case study 3: The ENISA trends in AI for cybersecurity project
- Case study 4: The CASI/BOLERO projects

26 Widening countries include: Bulgaria, Croatia, Cyprus, Czech republic, Estonia, Greece, Hungary, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovakia and Slovenia, as well as associated countries with equivalent characteristics in terms of R&I performance, such as Albania, Armenia, Bosnia and Herzegovina, Faroe Islands, North Macedonia, Georgia, Moldova, Montenegro, Serbia, Tunisia, Turkey and Ukraine.

Figure 11: Issues Analysis Framework for the interpretation and assessment of future-shaping issues



By examining these real-world examples, the chapter highlights the importance of HS in shaping policy and funding strategies in STI, to promote breakthrough advancements in Europe's innovation landscape.

6.3.1 The iKNOW project

The iKnow project (2008-2011) – interconnecting knowledge for the early identification of issues, events and developments (e.g. wild cards and associated weak signals) shaping and shaking up the future of STI in the European Research Area (ERA) – was a groundbreaking EU-funded initiative that introduced new HS approaches, frameworks and tools. It aimed to align with the sponsor's needs by developing a HS methodology focused on proactive European research policy, anticipating changes in the research system and revealing emerging issues with long-term implications for European STI.

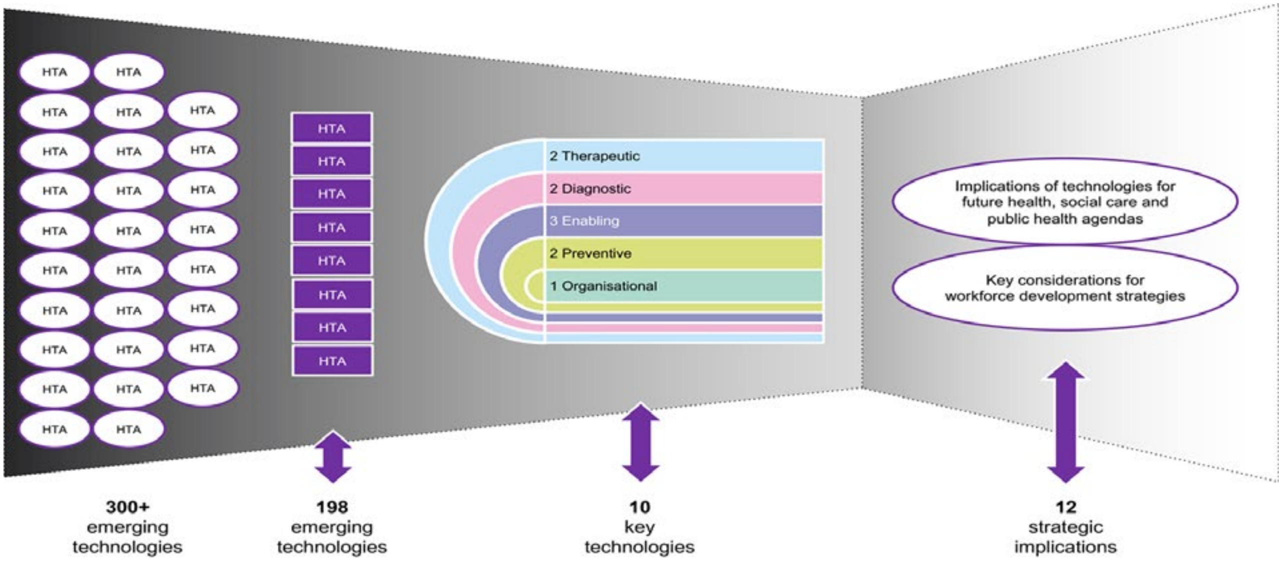
To achieve a more global reach, the project combined top-down, bottom-up, inward- and outward-looking HS approaches to implement the following four HS strategies: inward-looking top-down, outward-looking top-down, inward-looking bottom-up, and outward-looking bottom-up, which involved the scanning of knowledge sources 'outside' the European research space with the voluntary help of the growing community of horizon scanning practitioners and thematic experts.

The project developed an 'Issues Analysis Framework' (see Figure 11) that introduced uncertainty assessment to anticipate disruptive situations. Through futures workshops, policymakers used multiple interpretation policy lenses to co-create wild cards, moonshot opportunities and wicked problems, namely: continuous, ending, re-emerging and emerging/ new issues. The workshops' collective intelligence was supplemented with expert interviews and input from the STI community through a dedicated knowledge platform.

A pan-European Delphi survey and multi-actor workshops were conducted to assess the expected impact of prioritised issues on key dimensions of the ERA. The project produced reports such as iKnow Policy Alerts (Popper and Butler, 2011) and the iKnow ERA Toolkit (Ravetz et al., 2011), which became a point of reference and source of inspiration for stakeholders connected to the ERA.

Overall, the iKnow project pioneered HS methodologies and strategies to inform research

Figure 12: A horizon scanning framework for the analysis of future-shaping issues



policy, anticipate emerging issues and shape the future of STI in the European context.

6.3.2 The Technology Horizon project

One of the most groundbreaking and systematic horizon scanning initiatives conducted in the United Kingdom was led by the Centre for Workforce Intelligence (CfWI) (2010-2016), established to provide workforce-planning advice for healthcare, public health and social care in England. Commissioned by the Department of Health, Health Education England and Public Health England, the CfWI conducted horizon scanning on specific workforce groups and pathways, generating future-driven intelligence in the form of reports, tools and resources to inform workforce-planning decisions at national and local levels.

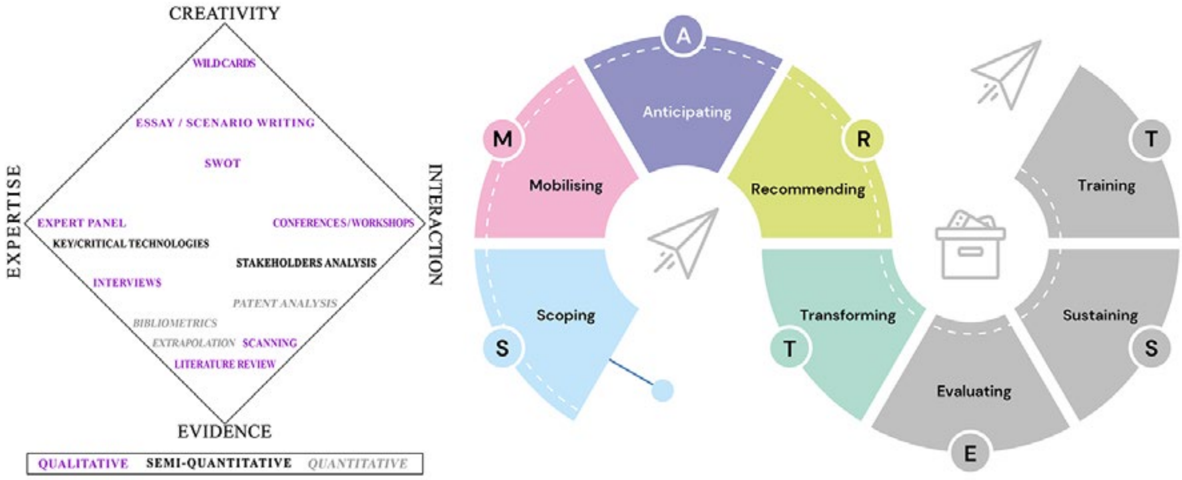
The Technology Horizon Project, one of the studies conducted by the CfWI, used horizon scanning to explore technologies impacting the future of the health and social care workforce. Its objective was to identify the top 10 technologies with the potential to transform the health sector in England, addressing challenges such as rising demand, patient-centred care and cost reduction, while improving workforce efficiency and productivity (see Lu et al., 2013).

The project utilised outward- and inward-looking approaches, conducting web-scanning, literature reviews and documentary analysis of reports from health technology assessment agencies in various countries. Through a double-funnel horizon scanning methodology (see Figure 12), over 300 technologies were initially identified and narrowed down to a prioritised list of 198 emerging technologies relevant to the UK. Expert focus groups and workshops further refined the selection, resulting in the identification of ten emerging technologies clustered into five major groups: therapeutic technologies, diagnostic technologies, enabling technologies, preventive technologies and organisational technologies.

The Technology Horizon Project employed an agile and top-down methodology, involving regular interactions between the expert group from the University of Manchester and the CfWI's horizon scanning team. The process included targeted expert interviews, brainstorming sessions and desk research to assess the implications of technologies for future health, social care and public health agendas and to develop key considerations for workforce development strategies.

Overall, the CfWI's Technology Horizon Project provided valuable insights for workforce planning by identifying transformative technologies and their potential impact on the healthcare sector in England.

Figure 13: A fully-fledged methodology for trends analysis related to an emerging technology (artificial intelligence)



6.3.3 The ENISA Trends in AI for Cybersecurity project

Artificial intelligence (AI) is a disruptive emerging technology with great potential for cybersecurity (Truong and Papagiannidis, 2022; Sardana et al., 2023). However, it also involves risks, which means that weak signals must be carefully analysed. Collaboration and interaction are crucial for responsible research and innovation agendas, where human expertise and creativity play a vital role in shaping desirable futures and anticipatory governance processes in Europe.

The project employed a methodology combining horizontal, thematic and sectoral desk research and analysis to address uncertainties in the cybersecurity sector, particularly those arising from AI-related advancements. It complemented the European Union Agency for Cybersecurity's Cybersecurity Threat Landscape (CTL) approach. The CTL methodology encompasses three categories: horizontal (holistic view across sectors and industries), thematic (focused on specific themes across sectors), and sectoral (concentrated on a specific sector and target group). This methodology supports decision-making, risk management, policy formulation and prioritisation of recommendations, and identifies training and capacity building opportunities.

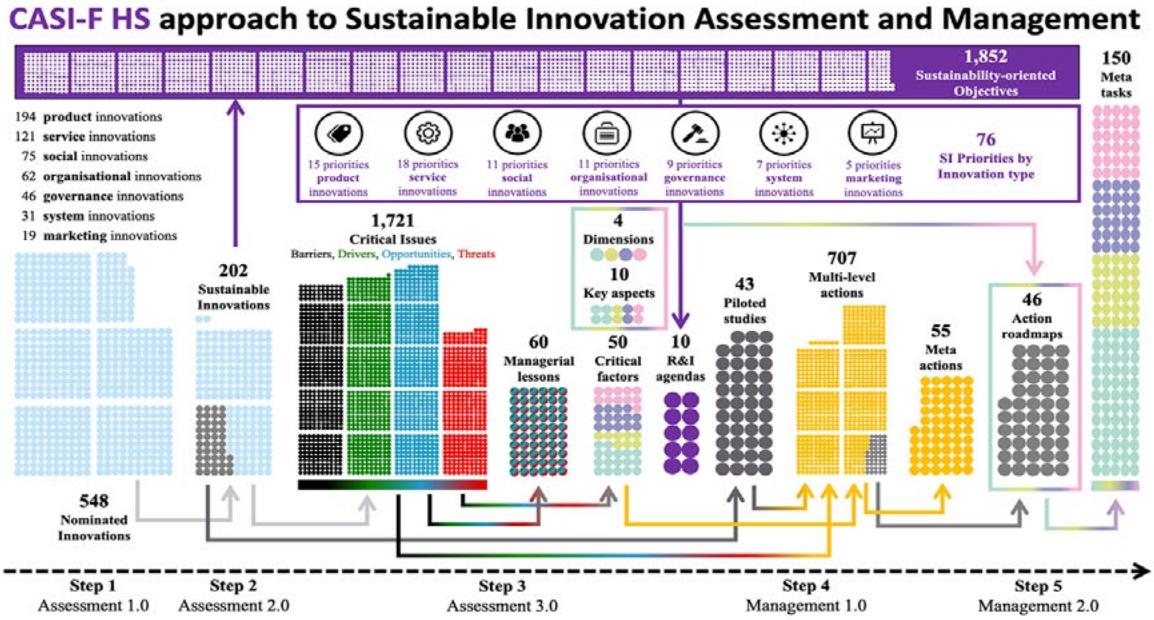
The horizon scanning activities were facilitated by the Foresight Diamond and SMART Futures frameworks (Popper, 2008, 2012) by integrating several methods combining evidence, expertise, interaction and creativity, as illustrated in Figure 13. Evidence-based activities focused on scanning academic literature, mapping future-oriented projects (including ENISA initiatives), data analytics (bibliometrics and patent analysis), while expert interviews with key AI stakeholders supported the expertise aspects. Interaction was fostered through participation in relevant AI events and conferences, such as the European Robotics Forum 2022, and the organisation of focus groups and roundtables with AI and foresight researchers, such as the 2022 Foresight Executive Course in Manchester. Finally, the project used creativity-driven knowledge through scenario-based analysis of strengths, weaknesses, opportunities, and threats related to AI for cybersecurity, as well as with the identification and analysis of wild cards from the scanned literature.

In summary, the project employed a comprehensive methodology combining various research and analysis methods to explore the complex challenges and opportunities presented by AI in the cybersecurity domain, ensuring a holistic and forward-looking approach.

6.3.4 The CASI/BOLERO project

The CASI project – Public participation in

Figure 14: A systematic use of horizon scanning for the assessment and management of sustainable innovations



Developing a Common Framework for Assessment and Management of Sustainable Innovation[27] - aimed to address the societal challenge of 'Climate action, environment, resource efficiency and raw materials' outlined in the Horizon 2020 programme of the European Union. It employed horizon scanning to assess critical issues related to sustainable innovations and explore the impacts of social and technological innovation, as well as the involvement of stakeholders with different objectives.

The project integrated the perspectives of government, business, civil society and research and education actors, following a quadruple helix approach to innovation. CASI viewed innovation as a driving force for societal progress in an era of technological advancements and future uncertainties.

The project developed a five-step framework called CASI-F (see Popper et al., 2017, 2020), and the thorough knowledge co-creation process depicted in Figure 14 It began with the nomination of 548 sustainability-driven innovations aligned with the European Commission's priorities. A comprehensive analysis of 202 sustainable innovations followed, examining their practices, outcomes and the key players involved. The third step involved critical issue analysis and assessment, in which over 1 700 issues with potential impacts on innovation development and sustainability were identified and prioritised. The fourth step involved a multi-level approach that generated more than 700 actions to support the strategic, programming and operational decision-making of stakeholders. These actions were evaluated based on their importance, feasibility and potential impact on the environment, society and economy. The final step involved the co-creation of action roadmaps to effectively implement and manage the selected actions. Feedback from innovators involved in pilot cases indicated high satisfaction with the five-step process, with many recognising the benefits of action roadmaps in innovation management. The CASI-F pilots engaged 43 innovators from 12 EU countries, resulting in the creation of 46 action roadmaps.

Disruptive innovations can lead to changes in policy, evolving from the immediately preceding state and involving people in multiple contexts who change their attitude based on their aspirations. CASI introduced a new approach to co-creating action roadmaps for the management of critical issues (see Figure 15) resulting from the horizon scanning activities supporting the assessment of sustainable innovations.

In line with the European Commission's knowledge

27 Public Participation in Developing a Common Framework for Assessment and Management of Sustainable Innovation | CASI | Project | News & Multimedia | FP7 | CORDIS | European Commission (europa.eu)

Figure 15: An action roadmap framework for the management of sustainable innovations

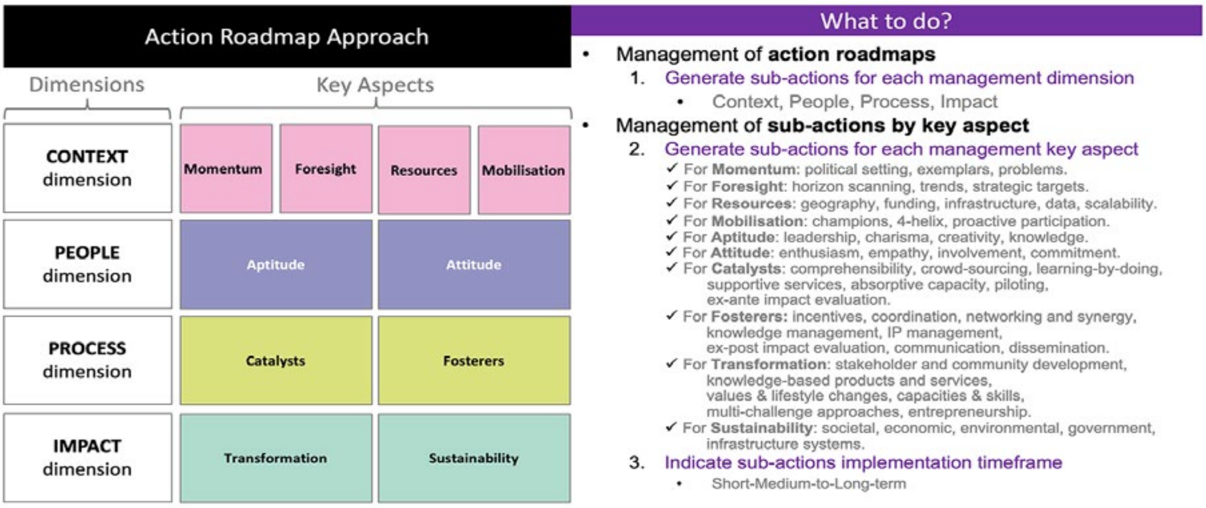
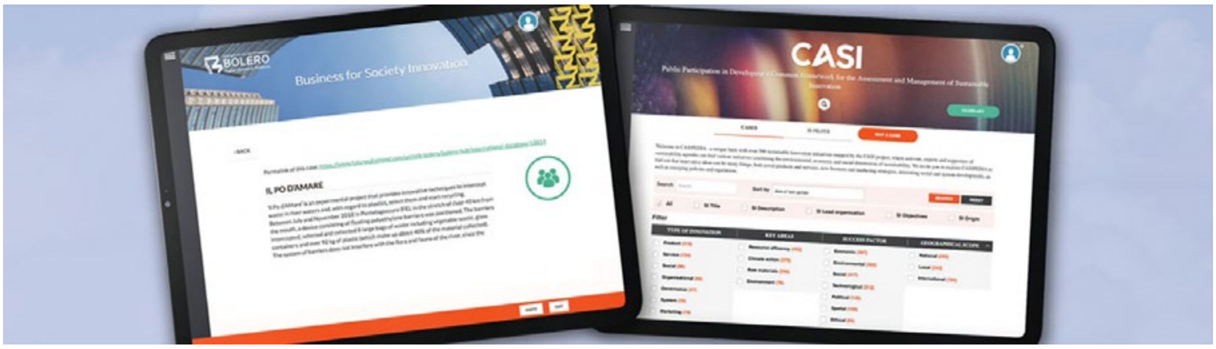


Figure 16: Integrating knowledge platforms into horizon scanning processes focused on innovations



valorisation agenda, the CASI Framework methodology has been further adapted by a team from the University of Milano-Bicocca and Futures Diamond to meet the unique requirements of a regional ecosystem, particularly in managing the innovation initiatives of small and medium-sized enterprises (SMEs) in Italy. The BOLERO Framework, aligned with both Commission priorities and the global Sustainable Development Goals, offers a practical tool for fostering anticipatory governance (see Figure 16), amplifying the impact of regional innovation and driving positive change in the regional ecosystem and beyond.

6.4 Use of Horizon Scanning for funding innovations

The four cases presented in this chapter (compared in Figure 17 vary in terms of scope, focus and their relevance to EIC funding opportunities, yet they all illustrate to a certain degree the benefits of horizon scanning for the EIC and policymakers alike.

In terms of the EIC's 2023 work programme, the key HS approaches, methods and lessons from the iKnow project are most relevant to the EIC Pathfinder instrument, which supports the exploration of bold ideas for radically new technologies. The EIC Pathfinder could benefit from the analysis of potential wild cards and weak signals in order to support funding decision-making. The 'Issues Analysis Framework' (see Figure 11) developed by the iKnow project is of particular relevance for the JRC and EIC as it introduces uncertainty assessment to anticipate four types of disruptive situations and/or interpretations of them. The framework can be used for the systematic analysis of weak signals with different levels of uncertainty, as well as to co-create four types of

Figure 17: Relevance of the selected case studies for key EIC Funding opportunities

CASE STUDY	SCOPE	FOCUS	EIC PATHFINDE	EIC TRANSITION	EIC ACCELERATOR
iKnow	N, E, G	DI	●●●	●●	●
Technology Horizon	N, G	ET	●●●	●	●
Trends in Ai for Cybersecurity	E, G	ET, DI	●●	●●●	●●
CASI/BOLERO	R, N, E, G	SI	●	●●●	●●●●

Legend:

R= Regional, N= National, E= European, G= Global, SI= Sustainable Innovation

● LOW ●● MODERATE ●●● HIGH

situation-bounded issues or futures intelligence in the form of wild cards, moonshot opportunities and wicked problems, namely: continuous, ending, re-emerging, and emerging/new issues. These can be collectively assessed with the help of expert consultations and a bottom-up approach involving the broader STI community through a dedicated knowledge platform, where registered users can assess the expected impact that prioritised issues could have on key aspects of the vision and priorities of the EIC. Furthermore, the Technology Horizon project approach would be very relevant to the EIC Pathfinder, which could benefit from a systematic review of recent technology assessment reports and prioritisation of technologies that are relevant to the six Horizon Europe clusters and EIC priorities.

The EIC Transition programme provides funding for innovation activities that go beyond laboratory proof of principle, supporting the maturation of solutions and the development of a business case for future commercialisation. ENISA's approach, applied to AI technologies with great potential for disruption, could be beneficial for this programme. By utilising bibliometrics and patent analysis, trends associated with emerging technologies across various fields can be analysed to identify opportunities and threats for research and innovation, including disruptive ones.

The EIC Accelerator programme assists start-ups and SMEs with game-changing innovations that have the potential to disrupt existing markets or create new ones. It supports the scaling up of ambitious projects and provides substantial funding to minimise serious investment risks. Incorporating the CASI/BOLERO projects approach, which includes critical issue analysis and action roadmapping, would be advantageous for the EIC Accelerator. This approach recognises the need to pay careful attention to four dimensions when managing sustained and disruptive innovations:

1. Context dimension: recognising changes in regular, positioned products, sustained innovations and disruptive innovations. This understanding leads to responsible policies tailored to each type of change.
2. People dimension: supporting sustained and disruptive competences and behaviours to consolidate new ideas.
3. Process dimension: focusing on materialising ideas, whether sustained or disruptive, into innovative products, services or business models.
4. Impact dimension: contributing to achieving stability and desired outcomes.

The following four types of HS approaches can further enhance the funding of innovations by enabling the EIC Work Programme to identify disruptive ideas and assess applicants' capacities and strengths to tackle future challenges. These approaches are as follows:

1. (Top-down HS: driven by projects and sponsors, providing a project-oriented perspective.
2. Bottom-up HS: driven by the STI community, enabling a community-driven approach.
3. Inward-looking HS: explores issues related to EC-funded research and innovation activities, including EIC programmes.

4. Outward-looking HS: explores issues related to knowledge sources outside of EC-funded research.

While all four approaches are relevant to the EIC Pathfinder, the top-down approach would be particularly beneficial for the EIC Transition programme, while the bottom-up approach aligns well with the EIC Accelerator programme.

Finally, it is important to take into consideration that, although HS has positioned itself as an effective anticipatory governance approach empowering policymakers with future-oriented tools to strengthen STI systems, HS should not be considered a panacea. The insights and priorities resulting from HS projects still need to be translated into sound recommendations capable of transforming the policymaking ecosystem through policy implementation and evaluation (see Velasco et al., 2021).

6.5 Recommendations

Based on the best practices discussed in this chapter, the following set of recommendations could contribute towards a more effective use of HS to better anticipate and monitor emerging technologies and disruptive innovations of relevance to the EIC and other stakeholders in the EU:

- Integrate horizon scanning approaches, such as the issues analysis framework and action roadmapping (see Figures 11 and 15), into the EIC funding instruments to anticipate and monitor opportunities effectively.
- Consider the development, adaptation and maintenance of a web-based knowledge platform similar to those supporting the HS activities of the iKnow, CASI, BOLERO and Technology Horizon Project, to gather anticipatory intelligence and support the systematic mapping of critical issues.
- Promote the systematic clustering and meta-analysis of critical issues related to EC priorities, in order to identify new research and innovation agendas and generate new ideas on possible calls for proposals.
- Create a cross-EIC funding opportunities team focused on mapping innovations aligned with European strengths and opportunities, as well as those addressing key weaknesses and threats, in order to better navigate potential disruption.
- Promote cross-fertilisation within the innovation ecosystem to drive desirable transformations and propel organisations to the next level through effective HS-driven knowledge valorisation, co-creation and sharing.

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Using scenarios to assess innovations

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7.1 Introduction

Which innovations should be selected for acceleration? Thomas Watson, chairman of IBM in 1943, said, 'I think there's a world market for maybe five computers.' Half a century later, the internet search engine Yahoo! called up science fiction author Ray Bradbury on the phone to ask him if they could sell a book of his online. Bradbury called it a 'scam' and responded, '[t]he internet is a big distraction … It's meaningless; it's not real. It's in the air somewhere.' A recent conjecture by Alphabet (Google) CEO Sundar Pichai stated that artificial intelligence would be 'more profound than fire or electricity or anything that we've done in the past.' If we could consistently predict the future with accuracy, making decisions about what technologies to develop would be trivial or meaningless. But we cannot: so how can we assess an innovative idea now, when we will only know at some future time whether it will be affirmed or rejected?

Contemporary modes of scenario planning emerged to bridge this time-information gap: making futures in the present can function as 'laboratories' for testing our concepts, technologies, innovations, options, or strategies, by simulating how they might impact us and our societies in the future. This is not unnatural: the construction of scenarios in the mind is a common, and even constant human undertaking, which we share, discuss, and refine everyday with the people around us. Over the last 50 years, however, this capability for foresight has been developed into formalised and structured processes and survives because their users out-compete, out-innovate, and out-endure the competition (Gordon et al., 2020). This chapter will introduce scenario-based innovation portfolio stress testing and review four case studies of public sector experimentation used for informing innovation option prioritisation. It will then provide recommendations for investment portfolio managers and strategists on how to get started using scenarios in innovation assessment to bridge the time-information gap.

7.2 Stress tests and wind-tunnels

Stress testing involves subjecting a system or entity to extreme or adverse conditions to evaluate its robustness and performance limits. While stress test simulations grew in use after the 2008 financial crisis to enhance confidence of bank and financial resilience, a similar concept, wind-tunnelling, was already present in the scenario planning literature. Wind-tunnelling harks back to the aviation testing that took place after WWII which provided a semi-controlled and safe environment to simulate functionality under different conditions. Blast the aircraft with high winds, rain, ice, or birds until the wings fall off or other critical failure occurs. Or, remove parts or add weight until it cannot fly. Now, instead of an airplane, imagine the innovation portfolio in the wind tunnel, where we can vary the conditions to understand how the portfolio as a whole or innovation concepts individually will perform under different constraints. We can use what we learn about critical failures to then change the qualities of the innovation, portfolio and strategic parameters, to improve their robustness, and re-run the simulations.

Portfolio stress tests may take many forms. For example, the one-off ad hoc activity when a novel disruptive technology or event emerges, the aspects of the technology or event are extrapolated into trends, and the trends are then overlaid onto the portfolio in order to identify their impact on the performance of the portfolio. While this may sound technical, it is commonplace in meetings where participants brainstorm the “what-ifs” and “what-elses” that might also impact their plans in the future. Such tests constitute a check of the resilience or robustness of an existing portfolio to identify possible contingencies or strategic options to strengthen, alter, or abandon an initiative.

A second type of stress test involves the deliberate scenario planning process. The test is deliberate in that it is planned in advance and organised as a structured sequence in which outputs from one step feed as inputs into the next: Stakeholders contribute to the process of constructing or identify a set of relevant scenarios; the criteria for passing the tests are decided based on a strategy or constituted as an implicit strategy; the rating of the portfolio options is undertaken systematically; points of critical failure are identified, improvements are recommend, and outcomes are acted upon.

7.2.1 Construct a set of relevant scenarios

Important information from the context in which our decisions play out emerges in incomplete and unstructured states. Scenarios are developed to research, organise and communicate a set of potential development pathways to provide the contexts in which our decisions can be evaluated. While the content of the scenarios may include a blend of elements such as geopolitical changes, macroeconomic shifts, regulatory and legal conditions, social movements and/or behavioural changes, and technological breakthroughs, it is important that the scenarios are built for purpose and for a particular user or group (van der Heijden, 2005; Spaniol et al., 2019). ‘Built for purpose’ means that the user’s core concerns about the future are made salient in the scenarios. This can be accomplished in different ways, but a common approach involves the identification of uncertainties which critical to the user group and extrapolating endstate values for each uncertainty.

7.2.2 Establish or reify the criteria for evaluating options

How does your unit, organisation or institution judge success? In private companies, options are commonly evaluated on the basis of their expected return on investment, a discounted cash flow, their ease of implementation/technical feasibility/risk of failure, the extent to which they can be defended against copycat competitors, their affinity to the core business, scalability and estimated time to market. In the public sector, however, rating criteria can include factors such as delivery across strategic autonomy metrics, contribution to public welfare, furthering or developing regional technological competitiveness, delivering on sustainability metrics or goals and/or climate mitigation potential, regional security, or potential success in securing future private investment.

7.2.3 Evaluating the options across the scenario set[28]

By simulating the performance of each option, one by one, through each of the scenarios in the set, the programme manager can create an assessment of the performance of each individual option. Option ratings are then aggregated and characterised across the different scenarios (see e.g. Courtney et al. 1997). The innovations may be characterised, for example, as 'no regret', 'risky bets', and 'reserve option'. 'No regret' moves are those that perform well under all future scenarios, 'risky bets' entail high risk-reward payouts, and 'reserve options' can be held-back to be later scaled-up or down depending on contingent factors. Options that do not perform well in any of the scenarios considered, and could thus be justifiably abandoned as a 'write-off'.

Making this evaluation process an anonymous rating assignment allows individuals to be more forthright in their assessments as they are less subject to social pressure inherent in group settings (see e.g. Spaniol et al., 2022). Ratings can be aggregated over multiple rounds, during which raters on the high and low ends of the spectrum are given a chance to explain their reasoning (either anonymously in writing or in conversation, if there is sufficient trust to avoid the bandwagon effect[29]). Using multiple rounds, evaluators can use the outputs as starting points to rerate in an attempt to move the aggregate score toward consensus (Diamond et al., 2014). In the event that desirable options receive low ratings, work can be done to make them more robust or antifragile (Derbyshire & Wright, 2014).

Table 1: Example of a scenario stress test for options.

	Scenario A	Scenario B	Scenario C	Scenario D	Evaluation
Option 1	- -	- - -	-	+ + +	*Risky bet*
Option 2	+	+ +	+ + +	+	*No-regret*
Option 3	+ + +	+	-	+	*Reserve option*
Option 4	- - -	-	- -	-	*Write-off*

7.3 Use cases

Scenario planning has long been used by governments to develop geopolitical strategy and policy, but their use by governments for innovation portfolio management lags behind that of private corporations. This section reviews relevant cases of portfolio management, using cases from the European Patent Office, Business Finland, the European Space Agency and Shell Oil and Gas to illustrate diverse practices.

28 Without a structured scenario approach, it has been demonstrated that idea raters and decision makers will in any case revert to personal, ad-hoc 'mini-scenarios', 'to reflect on how to actually assess the idea in relation to certain criteria' (Magnusson, Netz, & Wästlund, 2104). Cognitively, the rater combines the capabilities of the proposed innovation with their past experience and memory in an attempt to speculate about its feasibility and time to implementation. Prudent individual ad-hoc idea rating requires that individual raters' expertise benefits from learning from the experiences of others.

29 For more on the role of trust, see Lang & Ramírez (2017).

7.3.1 European Patent Office

The mission of the European Patent Office (EPO) is to support innovation, competitiveness and economic growth. Since its establishment in 1973, the EPO has been an independent and self-financed intergovernmental organisation that aims to create a consistent patent system and unified procedures for Member States. Its scenario process was initiated by a CEO who wanted to gather intelligence to understand how different contextual developments might impact the service model of the organisation (EPO, 2007).

Across each of the scenarios, they examined how strategic options would perform if they were developed. The options included:

- automatic patent processing
- harmonizing patent laws across countries
- patent troll litigation approaches
- open-source patent systems
- entering into the provision of business protection services by the EPO
- allowing second filings to piggyback off first filings

In the rating exercise, they found that each option's score varied across the different scenarios. A 'market rules' scenario favoured options that streamlined processes and penalised options that relied on decentralised operations. A 'trees of knowledge' scenario favoured options that dovetailed democratic, open and citizen science and rebuked options that walled off collaboration. A 'blue skies' scenario favoured options that cleared the way for technology development and punished options that reduced interoperability.

The scenarios used by the EPO played a role not only in making decisions related to institutional collaboration between patent offices, but also in establishing a patent classification scheme and in the initiation of events and awards to advance its mission (Ramírez et al., 2020). Additionally, the organisation adopted a risk management approach to enhance the quality of its operations and services and to ensure continuous improvement.

7.3.2 Business Finland

In 2019 Business Finland, the governmental organisation for innovation funding and trade, set out to explore plausible futures for Finland's competitiveness (Business Finland, 2019). The project aimed to generate insight into the future of a range of industries by offering alternative perspectives. Questions driving the process included: Where will the attractive markets and growth opportunities for Finnish companies be in the future? And how do we ensure the competitive development of the business sector in an uncertain global operating environment?

The scenarios they imagined ranged from high-speed AI development, to corporate-owned tech consolidation, to Asian-based leadership, to scenarios about regulatory action and the break-up of the tech giants. In each of these scenarios, they learned how Finnish businesses in bioeconomy, energy, health, consumer products and digital technologies could start preparing and investing today to be able to compete under the conditions of each of the different scenarios.

7.3.3 European Space Agency

In 2020 the European Space Agency (ESA) commissioned 'post-crisis scenarios for the space industry' (Bochinger, 2020). The project set out to provide insight into the vulnerabilities and achievements of the space sector in light of the pandemic, as well as assess the options for navigating the industry into the future.

Three recovery scenarios – 'fast recovery', 'bounce back' and 'double-dip' – were used to assess the manufacturing, launch, satcom, and earth observation capabilities that would be needed for future missions. The project also undertook a stakeholder analysis to anticipate the behaviours of different actors in each scenario, which served to provide guidance on investment and acceleration opportunities for each segment, and to generate insights into what could be done to ensure the overall healthy recovery of the ESA.

Furthermore, it was found that the pandemic crises had accelerated pre-existing trends in the space industry, and that new entrants would have a hard time entering the industry. From this, it could be concluded that governments had a role in ensuring support for the industry to ensure that it remains competitive in the decades to come.

7.3.4 Shell Oil and Gas

Shell Oil and Gas (Shell) has perhaps the best documented scenario planning programmes. It is a complex organisation operating globally in diverse product and service segments. Their scenario programme's architecture is based on sequential thought experiments: If scenario A comes to pass, what would Shell's ideal configuration be, and which game-changing innovations would be driving its profitability? If scenario B comes to pass, what would Shell's ideal configuration be, and which game-changing innovations would be driving its profitability? If scenario C comes to pass… etc. This architecture illustrates that any given technology may have potential, but not the same potential across each scenario, and that the appropriate timing of its development depend on the time horizon assigned in any given scenario. Shell's scenarios are constructed using qualitative-narrative methods that are modelled using concept mapping. From there, Shell identifies plausible values for concepts that are deemed appropriate in each scenario that are then used as inputs into its econometric models.

Ramírez et al. (2011) documented how, at that time, Shell was developing 85 projects in its portfolio, from a pool of 1 435 ideas. Instead of assessing these individually, Shell organised the projects into about a dozen 'domains'. These groupings helped to ensure that management's attention remained focused at a higher level of abstraction and on longer-term objectives, rather than on experiments and one-off projects. Innovation incubation in these domains targeted key challenges and root causes and developed through logical stages, from creation to maturation, execution and finally graduation. The authors claim that grouping the innovations into domains has led to fewer projects being initiated, but more projects reaching graduation.

This points to a focus on the core business of the domains. Shell is not interested in what made it successful in the past, but in how the future might be different. Evaluating the project portfolio across the range of scenarios makes clear that some projects would graduate only in the most optimistic or utopian of scenarios. Shell uses the scenarios to think and decide rationally in order to deliver on their innovation mandate.

7.4 The utility of scenario planning for European Innovation Agencies

One thing about the future is certain: driving and commercialising innovations will remain a strategic imperative that shapes Europe's future competitiveness, security, and autonomy. Europe is expending resources and effort to identify and incubate technologies and scale innovations in an era of rapid change. For innovation programmes, their managers and their agents, cultivating portfolio management capabilities and processes are important for ensuring robust chances of success.

Adopting processes to systematise and routinise innovation portfolio management will improve on its performance effectiveness. Processes that are subject to continuous improvement can expect greater returns and, given that scenario-based stress testing is undertaken in conversation and group deliberation, identification of ways to integrate and sequence other routines for improved performance are likely to follow. Regularly revising or overhauling scenarios as the future continues to unfold provides the opportunity to integrate them into the daily language, thinking, practices and fabric of the unit or organisation.

For managers, monitoring the operating environment for change and identifying opportunity are, perhaps, their core tasks. Scenario-based stress testing can support and structure these tasks in a number of ways. Reflecting on the cases discussed above, consider:

- At the start of the agenda-setting and pathway development phase, scenarios can be used as a tool to engage with and source input from stakeholders with influence and the capability to act (such as in the European Patent Office case).
- As they are being developed, scenarios can be used to think divergently and to shed light on emerging issues in society and beyond, and how the programme might prompt the organisation to change and rethink its role in the world (such as at Shell).
- As they become integrated and embedded into the fabric of the programme, scenarios become reference points for the ongoing development of the strategic conversation (as in the Business Finland case).
- As they are being operationalised, scenarios can be structured and modified so that they can perform the experiments for maintaining the portfolio required by the innovation portfolio manager (such as in the European Space Agency case).

The ultimate benefit of scenario-based stress testing is the time advantage that it offers: we do not have to wait for the future to arrive but can leverage the scenario right now as a proxy for the present to evaluate options, projects, and initiatives. Scenario building organises and links the signals of change together to make them more coherent and comprehensible. This in turn can align perspectives and ideas and sharpen the focus of an analysis, making it a powerful tool of rationality and deliberation. Without scenarios, important decisions occur in unstructured forums with closed communication, which can lead to political in-fighting, and even the shifting of the locus of power to outside the organisation. Even then, we will construct mini-scenarios in each of our imaginations to evaluate our options. Engaging in conversation in the context of scenario stress testing offers opportunities to exchange ideas and ambitions.

Furthermore, the approach outlined in this chapter, when implemented, will match practices elsewhere in the EU to orientate policy toward the future (see Fernandes & Heflich, 2021). Such alignment will enable the integration of disparate operations to produce network effects.

7.5 Recommendations

Persistence, in the form of strong and courageous leadership, is needed for any change to take hold. On numerous occasions over the decades, the scenarios team at Shell was nearly shut down. It survived because its value became widely understood over time: many employees and executives have rotated through the team, and many business units have benefited from enhanced strategic planning and portfolio management.

To get started using scenario-based stress testing, consider:

- Conducting internal pilot tests on subsets of the portfolio can enhance familiarity with stress testing and build experience within a core team.
- Individually pre-rate innovations or options before coming to a workshop to require raters to develop assumptions and opinions about them. It is these assumptions and opinions that are stress-tested (not the innovations themselves).
- If it is not a fun exercise, there is a problem. A skilled facilitator will decipher if there is a lack of open communication and when raters' energy is spent.
- Use the front-end of the workshop to reconstruct the scenario set instead of discussing options.
- For external audiences, present the results of the stress test but not the scenarios. Blending quantitative and qualitative ratings into a spreadsheet allows for different rankings of the 'winners', depending on filters.
- Once a rhythm has been established over a few iterations of the process, invite diverse and influential stakeholders in to collect fresh ideas, enlarge engagement and distribute ownership of the programme.

The radical and final recommendation of this chapter is to establish scenario-based portfolio stress testing as the foundation for planning cycles and operational processes. But it is not without its pitfalls and requires proper allocation of resources and the enrolment of multiple champions to ensure success and endurance.

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Open data from the EU

The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.

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