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SCANNING DEEP TECH HORIZONS

Participatory Collection and Assessment of Signals and Trends

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DISRUPTIVE INNOVATION

STRATEGIC FORESIGHT

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SCANNING DEEP TECH HORIZONS

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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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Contents

Abstract

The Joint Research Centre (JRC) and the European Innovation Council (EIC) conducted a series of Horizon Scanning exercises across six EIC programme managers' (PM) portfolios as part of an ongoing collaborative effort to strengthen EIC strategic intelligence capacity through the use and development of anticipatory approaches. The fields covered include: Space Systems & Technologies; Quantum Technologies; Agriculture & Food; Solar Fuels & Chemicals; Responsible Electronics and Architecture, Engineering & Construction.

The main findings of this Horizon Scanning – the identification and analysis of 'signals' from nascent research, technologies, or trends on the periphery of the mainstream – show opportunities for investment in emerging technologies and breakthrough innovations that can advance EU competitiveness while also serving to support the EU's long-term policy and societal visions.

Other insights were taken from this exercise, namely the identification of drivers, enablers and barriers to technology development and adoption, that could be the starting ground of further foresight exercises and policy initiatives.

The report highlights three main themes – sustainability, energy, and scalability, which are overarching across signals, drivers, enablers and barriers. And concludes with a series of recommendations to streamline Horizon Scanning activities in the specific context and needs of the EIC.

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Executive summary

As part of their ongoing effort to foster an anticipatory approach to their operations, the Joint Research Centre (JRC) and the European Innovation Council (EIC) conducted eight Horizon Scanning workshops in six fields that match EIC programme managers' (PM) portfolios.

Horizon Scanning involves the identification and analysis of 'signals' - nascent research, technologies, or trends on the periphery of the mainstream – to better understand the opportunities that can be invested in and the challenges that might be faced.

A multi-modal signal scan was conducted for the EIC and supported in expert-based contributions, literature review and text data mining on patents, publications, and EIC funded and non-funded proposals.

The results of this process were afterwards subject to multi-stakeholder analysis and sense-making via participatory workshops to collectively identify, assess and prioritise the most promising topics for the consideration of the EIC. The results of these Horizon Scanning workshops are summarised in the following table and detailed in this report.

Table 1 - Priority signals identified for each of the EIC PM portfolios[1] following the Horizon Scanning process.

EIC PROGRAMME MANAGER'S PORTFOLIO	PRIORITY SIGNALS
Space Systems & Technologies	Workshop 1
	The Port - A business platform in space Space debris recycling and refuelling 'User-driven' on-orbit servicing, assembly and manufacturing (OSAM) Thin film solar cells based on CIGS (copper indium gallium selenide) technology
	Workshop 2
	Reusable rockets/launcher systems and components In-space solar Cellular satellites and modularity Data centres at the extreme edge AI and ML solutions for distributed systems and satellite constellations Space awareness and automated collision avoidance Space-based production of food and related life-sustaining technologies Orbital recycling
Quantum Technologies	Workshop 1
	Error resilient quantum algorithms New types of qubits Quantum energetics Application of machine learning to quantum Enabling tech – scaling up capacity tools Linking quantum systems for advanced quantum network applications
	Workshop 2
	Competitiveness in particular bridging research to industry Photonics Scaling up of quantum processors Novel qubits and novel qubit platforms Key European weakness: private/public funding Quantum algorithm and software testing Energy efficiency Machine learning and quantum Supply chain for QT
Agriculture & Food	Systems and solutions to support farmers' decisions Novel foods and biotechnology Precision nutrition Alternatives for antibiotics and fertilisers Agriculture contribution to energy production (green hydrogen, water reusing, ocean-based energy storage and desalination) Ecosystem restoration coupled with food production Waste-free farm Smart aquaculture
Solar Fuels & Chemicals	Interface engineering Scalability and application challenges CirculAIR fuels Stability of any CO2 reduction process Carbon efficiency in whole process cyanobacteria

1 The PM portfolio names used throughout this report are a simplification of the official denomination, agreed with the EIC Strategic Intelligence Team.

EIC PROGRAMME MANAGER'S PORTFOLIO	PRIORITY SIGNALS
Responsible Electronics	Circular electronics New bio-inspired materials / semi-conductors Printed and flexible electronics technologies could become omnipresent High-performance, low-power materials/devices (and circularity) Technologies for next generation neuromorphic-type hardware and sensors' bioelectronic interfaces
Architecture, Engineering & Construction	Digital fabrication / accelerated construction & manufacturing/ robotic construction Bio-based materials - wood / timber, clay, and natural fibre hybrids AI combined with real-time monitoring Recycling for low carbon re-raw materials / decarbonised materials Human-centred: processes, tool, living environment, management Energy efficiency

The analysis of the workshop findings additionally surfaced four areas of technological development that hold common interest across the PM portfolios. While the top-ranking signals may still be differentiated based on the sectors for which they were gathered and discussed, the aggregated analysis of the results reveal cross-cutting enabling technologies and R&I clusters such as:

- Robotics and automation,
- Artificial intelligence and machine learning,
- Biomimicry and biological processes, and
- Materials sciences.

Additionally, each workshop included a 'futures triangle' activity designed to encourage expert discussion about contextual macro-level trends and issues that are shaping the progress of the fields within each PM portfolio. These issues were categorised as drivers, enablers and barriers to help bring a multi-stakeholder perspective to the environmental, social, economic, and policy conditions that influence future advances within each PM portfolio, and how they might be either encouraged or hindered. Examples of recurring issues across the 6 PM portfolios (set out in Chapter 4) include:

- Drivers – Green deal and climate change; strategic autonomy and energy resiliency
- Enablers – Standardisation, education and skills development and legislation (such as carbon tax)
- Barriers – Access to raw materials and resources, geopolitical tensions, and lack of private investment

The aggregate results of this exercise point to three themes – sustainability, energy, and scalability – that cut across the PM portfolios and relate to opportunities and challenges that the innovation ecosystem is focused on addressing. Some of these shared issues relate to the long-term vision of the European Commission as envisioned in the twin transitions (digital and green), while other results relate to the challenging economic and business realities that are being confronted.

Finally, this report outlines some recommendations for advancing the EIC's use of Horizon Scanning as one component of a more comprehensive and systematic strategic intelligence architecture. These recommendations include:

- Covering all current EIC PM fields as well as currently non-existent portfolios;
- Creating expert communities to continuously support Horizon Scanning;
- Aligning the timeline of the Horizon Scanning outputs with the drafting of the EIC challenges;
- Integrating AI or other advanced machine-based techniques into processes;
- Streamlining the workshop design through time adjustment and enhanced pre-analysis and pre-clustering of signals:
- Exploring the combination of Horizon Scanning with other foresight methodologies, such as reference scenarios.

CHAPTER 1

Introduction

In the context of an increasingly volatile, uncertain, complex, and ambiguous (VUCA) world, policymaking faces significant challenges and could benefit considerably from foresight and other anticipatory frameworks. Such frameworks would focus on identifying trends, recognising signals, acknowledging risks, and anticipating the potential challenges and opportunities of emerging issues.

ANTICIPINNOV (Anticipation and monitoring of emerging technologies and disruptive innovation) is a project designed to address some of these aspects at the European Innovation Council (EIC), framed by a collaboration between the European Innovation Council and SMEs Executive Agency (EISMEA) and the Joint Research Centre (JRC).

The project was led by the JRC's Competence Centre on Foresight (CCFOR) from unit JRC.S.1 – EU Policy Lab, in collaboration with the EIC Strategic Intelligence Team, EISMEA.D01, and the EIC Programme Manager's Office, EISMEA.D02. The JRC's Competence Centre on Text Mining and Data Analysis (CCTMDA) from unit T.5 also participated.

The main goal of ANTICIPINNOV is to strengthen the EIC's strategic intelligence capacity through the development and use of anticipatory approaches at the intersection of qualitative and quantitative streams.

To help achieve this goal, the ANTICIPINNOV project conducted eight Horizon Scanning workshops that targeted the following six EIC PM portfolios:

- Space Systems & Technologies;
- Quantum Technologies;
- Agriculture & Food;
- Solar Fuels & Chemicals;
- Responsible Electronics;
- Architecture, Engineering & Construction.

These PM portfolio names, used throughout this report, are a simplification of the official denomination and were agreed with the EIC Strategic Intelligence Team. These six domains were chosen because the six PMs in charge were the ones that joined the EIC more recently. Their portfolios therefore presented an earlier level of maturity that could benefit most from the findings of a foresight exercise.

Two pilot workshops were delivered in May and June of 2022 focusing on the PM portfolios of

Space Systems & Technologies, and Quantum Technologies. These pilots allowed the team to design and improve the customised methodological approach, applied in the following six workshops conducted between January and May 2023. The pilot topics were included again in this last set.

The workshops benefited from the ongoing presence and support of the European Research Council (ERC) Sector on Scientific Impact and Feedback to Policy, ERCEA.B0, which facilitated the internal ERC inputs on signals, and with which the EIC has ongoing collaboration on foresight and strategic intelligence for Feedback to Policy.

This report includes a brief state-of-the-art of Horizon Scanning methodology and a description of the customised approach designed and implemented for this project (Chapter 2).

This procedural description is followed in Chapters 3 and 4 by an overview of the primary outputs of each workshop, including the expert-selected signals and additional insights on potential future developments and contextual shifts of each portfolio's domain. Further details about the initial workshop inputs (raw signal data captured through expert-based contributions and text mining of internal EIC data, patents and scientific publications) were included in the individual workshop reports, delivered to the EIC.

Given the broad range of research and innovation activities represented across the six EIC PM portfolios covered by this Horizon Scanning process, this report focuses on synthesising key common features shared by multiple PM portfolios.

Finally, in Chapter 5, the report points to some conclusions and recommendations for further use of Horizon Scanning in the EIC.

CHAPTER 2

Methodology

2.1 Horizon Scanning

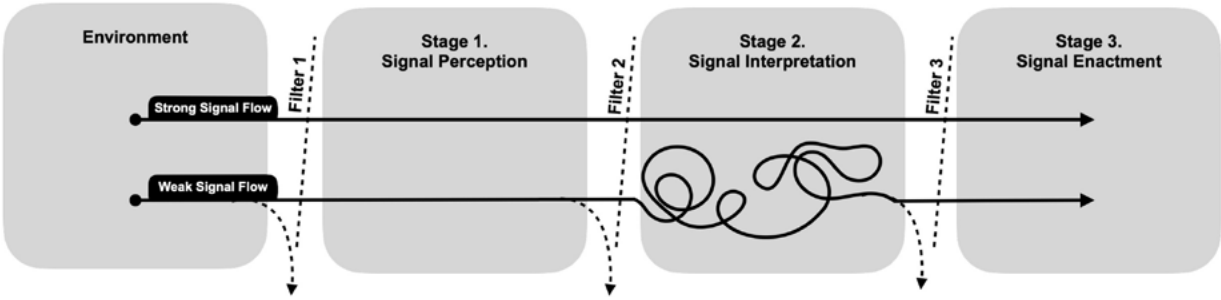
Horizon Scanning is a foresight method aimed at the early discovery of developments whose potential may not yet be widely recognised by most experts, decision-makers, or the general public. This method focuses on monitoring the margins of current thinking, research and innovation for novelties and phenomena that may offer distinct opportunities or challenges in the medium- or long term[2].

As part of the broader strategic foresight toolbox, Horizon Scanning activities are not predictive, nor are these activities sufficient in terms of anticipatory approaches to navigating alternative futures[3]. Rather, the method is a qualitative exploration of the periphery of mainstream knowledge. It encourages consideration of the possible futures suggested by novelties and their current uncertainties, potential configurations, plausible impacts and more. The method has a long, rich history in business and organisational management literature[45] and has evolved as it has entered the field of foresight and futures research[6].

Horizon Scanning enables us to better anticipate tomorrow's changes or disruptions through the assessment and sense-making of specific signals[7]. While there remains some discussion within the literature regarding the definition of a signal[89], for the purpose of this project, *signals* are understood as tangible manifestations of novelty in science, technology, innovation, markets, media, and other fields. Signals are raw informational material that can drive our focus to certain possibilities instead of others. In practice, signals can be drawn from: the related scientific literature, news articles on early technological developments, artistic and creative uses of nascent innovations, patents, projects, etc.

2 Amanatidou, E., Butter, M., Carabias, V., Könnölä, T., Leis, M., Saritas, O., ... & van Rij, V. (2012). On concepts and methods in Horizon Scanning: Lessons from initiating policy dialogues on emerging issues. Science and Public Policy, 39(2), 208-221.
3 Cuhls, K. E. (2020). Horizon Scanning in Foresight–Why Horizon Scanning is only a part of the game. Futures & Foresight Science, 2(1), e23.
4 Aguilar, F. J. (1967). Scanning the Business Environment. New York: Macmillan.
5 Ansoff, H. I. (1975). Managing strategic surprise by response to weak signals. California Management Review, 18(2), 21-33.
6 Ilmola, L., & Kuusi, O. (2006). Filters of weak signals hinder foresight: Monitoring weak signals efficiently in corporate decision-making. Futures, 38 (8), 908-924.
7 Könnölä, T., Salo, A., Cagnin, C., Carabias, V., & Vilkkumaa, E. (2012). Facing the future: Scanning, synthesising and sense-making in Horizon Scanning. Science and public policy, 39(2), 222-231.
8 Rossel, P. (2012). Early detection, warnings, weak signals and seeds of change: A turbulent domain of futures studies. Futures, 44(3), 229-239. https://doi.org/10.1016/j.futures.2011.10.005.
9 van Veen, B. L., & Ortt, J. R. (2021). Unifying weak signals definitions to improve construct understanding. *Futures*, *134*, 102837.

Figure 1 – A diagram of the Horizon Scanning perceptual filtering process. Credit van Veen & Ortt (2021)



Source: 1) Van Veen, B. L., & Ortt, J. R. (2021). Unifying weak signals definitions to improve construct understanding. *Futures*, *134*, 102837. 2) Ilmola, L., & Kuusi, O. (2006). Filters of weak signals hinder foresight: Monitoring weak signals efficiently in corporate decision-making. Futures, 38(8), 908-924. 3) Lesca, N., Caron-Fasan, M. L., & Falcy, S. (2012). How managers interpret scanning information. Information & Management, 49(2), 126-134. https://doi.org/10.1016/j.im.2012.01.004. 4) https://doi.org/10.1016/j.futures.2005.12.019.

After signals are collected, they are subject to a multi-stage perceptual filtering process during which they are assessed and either discarded or utilised in the next phase of the sense-making process. The three main phases of filtering are known as:

- Signal perception (pre-workshop scanning and analysis in the context of this project) – in which assessors identify true 'signals' from the 'noisy' information collected in the initial scan.
- Signal interpretation (workshop analysis in the context of this project) – a process by which one or more individuals assess the signal within the context of the project goals, and
- Signal enactment (workshop filtering and prioritisation in the context of this project) – selection of the final signals which can be acted upon within the current scope and goals of the decision-maker(s).

Signals can be assessed via different factors, including, but not limited to: uncertainty, potential impacts, distance, or time horizons in which they may unfold. Based on these assessments, we can classify them in a range between weak signals and strong signals, depending on the type or amount of information they can offer, and their utility within the specific objectives of an exercise.

As shown in Figure 1, strong signals pass through each of the perceptual filtering phases with little to no resistance from the assessment during each stage – they are recognised as important influences on the decision-making process in a frictionless manner. Weak signals, by contrast, are subjected to more rigorous analysis given the uncertainty of their development, their pertinence to the project, or their potential future influence. Weak signals are often advanced based on the interpretation and sense-making activities conducted with the participation of expert advisors and decision-makers.

2.2 Customised approach

2.2.1 Overview

This chapter includes a detailed description of each phase of the customised Horizon Scanning process. A variety of factors encouraged the design of a custom Horizon Scanning approach for the ANTICIPINNOV project, including:

- a very broad search spectrum cutting across the various fields and sub-fields of science, technology, and innovation (STI) that are part of the six EIC PM portfolios,
- the ambition to include technologies across all technology readiness levels (TRL), given the idea that novelty can happen at all maturity stages,
- the EIC's range of funding programmes, and
- the need for fast delivery given the EIC's internal needs to support the definition of EIC challenges and inform upcoming EIC work programmes.

The customised process, summarised in Figure 2, is composed of three main steps: pre-workshop, workshop and post-workshop. These steps are further described in this chapter.

Figure 2 – Customised Horizon Scanning methodology applied to the ANTICIPINNOV.

PRE-WORKSHOP	WORKSHOP	POST-WORKSHOP
• Expert recruitment • Signal collection(expert based data mining) • Signal filtering • Signal sharing with participant • Signal analysis and clustering (by JRC and EIC)	• Signal analysis and clustering (by participants) • Signal prioritisation • Identification of Drivers, Enablers and Barriers	• Report

Source: authors.

The approach was designed to focus on weak signal filtering – to help reveal blind spots in the EIC's strategic intelligence, but also – considering the coverage of a wide spectrum of TRL – to understand what, and how, stronger signals and trends are of relevance for the development of the fields inherent in each PM portfolio.

The exploratory scanning approaches[10] used in this exercise utilised both automated (data and text mining) and participatory (expert-based) modes of initial scanning for signals. Automated exploratory scanning was conducted in conjunction with the JRC's Competence Centre on Text and Data Mining (described further on), while participatory scanning activities were conducted by selected experts representing relevant stakeholder groups. Additional signals were added through literature review.

By pursuing multiple modes of scanning, this project aimed to provide a broad initial signal set for each PM portfolio. After which sense-making and interpretation efforts could concentrate on the prioritisation of the more relevant topics within each of these sectors.

Perhaps the most important phase of the Horizon Scanning process is the signal analysis and prioritisation activities. Within the ANTICIPINNOV project, this phase was accomplished through a series of online workshops, each focused on a single PM portfolio and designed as participatory sense-making activities with topic-relevant stakeholder groups.

The goal of these workshops was to produce a short list of priority signals of disruptive and game-changing innovations and emerging technologies, looking in particular at possible funding topics for the upcoming EIC challenges.

2.2.2 Methodology experimentation and redesign

Two pilot workshops took place in May and June 2022 to test methodological assumptions and understand how the process could yield the most robust and relevant information. Two specific PM portfolios, Space and Quantum Technologies, were used for that purpose considering that in the case of Space a significant number of technologies across several maturity levels are encompassed, and in the case of Quantum, it is in itself an emergent and disruptive field.

Through a thorough review of the process flow and its outputs, the team was able to iterate the workshop design, and a more effective design and choreography was stabilised for the next six workshops (as described further on).

The most significant improvements introduced in the final six workshops were the inclusion of signals

10 Amanatidou, E., Butter, M., Carabias, V., Könnölä, T., Leis, M., Saritas, O., ... & van Rij, V. (2012). On concepts and methods in Horizon Scanning: Lessons from initiating policy dialogues on emerging issues. *Science and Public Policy*, *39*(2), 208-221.

from data and text mining, the pre-workshop analysis and clustering of signals and the exercise on drivers, enablers and barriers.

2.2.3 Expert recruitment

Given the specific stakeholder composition of each PM portfolio, invitations to experts (to submit signals and participate in the workshop) were primarily coordinated between the EIC Strategic Intelligence Team, the respective PM and the JRC.

For each workshop, participant pools were created to provide diverse and balanced representation from academia, research and innovation centres, private sector actors (mainly startups and SMEs, but also in some workshops larger businesses and investors) and policy officers.

Initial invitations and background information were sent to prospective expert participants, accompanied by information on the exercise objectives and guidance for individual registration.

2.2.4 Expert-based signal identification

The expert sourced scanning for each workshop was initiated by a request for signal detection sent to relevant experts, including the workshop participants. This request was accompanied by a link to the EU Survey[11] website where the collection took place, and to a document containing instructions. These included:

- Broad definition of Horizon Scanning and its objectives.
- Definition of what a signal is and what it is not.
- Examples of where a signal could be spotted based on manifestations and evidence captured in: published or non-published scientific papers; conference proceedings; technical and commercial reports; books; patents; data sets; specialised or general media; blogs and other online publications; newsletters; social media; non-fiction works such as documentaries; fictional works, from short literary stories to blockbuster movies; artistic productions in any format; or other sources considered relevant by the survey respondent.
- Information to be included in each signal submission, namely: title, summary, and sources.

Additionally, two rules for scanning and collection were given:

- the signal needs to clearly represent novelty in one or more fields (science, technology, innovation, markets, media, and other fields), and
- the signal needs to have a clear traceable link to a source or reference.

2.2.5 Signals from data and text mining

In addition to the signals submitted by experts, each workshop utilised signals collected through data and text mining methodologies that harvested insights in several databases, namely: PATSTAT (Patent Statistical Database), SCOPUS (Elsevier's abstract and citation database of peer reviewed scientific journals) and EIC's data on previously funded projects and non-funded proposals.

The data and text mining approach, using the Tools for Innovation Monitoring (TIM) platform[12], put forth by the CCTMDA can be summarised as:

For the purpose of detecting weak signals in technology development, scientific publications and patents are considered as proxies for early technological development. The assumption is that a weak signal of technological development in a certain domain will see a sudden increase in the number of publications or patents. Scientific publications and patents are complementary when it comes to detecting signals in technology and innovation, as weak signals from scientific articles tend to be of a low TRL (1-3) while signals in patents are usually characteristic of technologies under development with a shorter time-to-market horizon or very high commercial/strategic potential[13].

11 EU Survey is an app of the European institutions through which surveys can be conducted. It can be reached through the following link: https://ec.europa.eu/eusurvey/home/welcome

12 https://knowledge4policy.ec.europa.eu/text-mining/topic/tim_analytics_en

13 Eulaerts, O. (2023) Anticipation and monitoring of emerging technologies and disruptive innovation - Input for T.2.1.

Table 2 - Scanning results by different methods for each workshop.

EIC PM PORTFOLIO	NUMBER OF SIGNALS FROM DIFFERENT SCANNING METHODS		
	Survey	Data mining	Total signals
Space – Workshop 1	54	-	**54**
Quantum – Workshop 1	50	-	**50**
Agriculture and Food	44	155	**199**
Space – Workshop 2	100	105	**205**
Quantum – Workshop 2	39	99	**138**
Solar Fuels	70	115	**185**
Responsible Electronics	41	74	**115**
Arch., Eng., Const.	28	63	**91**
Total	426	611	**1 037**

Note - The first two pilot workshops on Space and Quantum did not include signals from the data mining, as this step was a methodological improvement introduced later.

Under this approach, CCTMDA, CCFOR and the EIC utilised an exploratory scanning approach through the extraction, analysis and use of signals related to each EIC's PM portfolio. For this purpose, each PM defined a set of keywords that could define the scope of the portfolio. These keywords were fed into the TIM system. The short reports developed by the CCTMDA for each of the EIC portfolio workshops, including a detailed description of the process and its outputs, are included in the final report to be published under another work package of ANTICIPINNOV

2.2.6 Filtering and sharing signals with participants

In total, 1 037 signals were collected throughout the project (see Table 2). The signals from both streams underwent a first filtering and optimisation process to assess their connection and relevance to the PM portfolio, harmonise the granularity and remove signals that were not clear enough.

For each workshop, the first filtered list of signals was organised into a reference document and distributed to workshop participants as preparatory background material for the workshops, so that participants could acquaint themselves with the signals in advance and actively participate in the workshop discussions. The full list and details of these shared signals are included in the individual workshop reports.

2.2.7 Pre-workshop analysis of signals

After the first filtering and optimisation process, and in preparation for each workshop, the signals captured through both the survey and the data and text mining were analysed and grouped by the CCFOR, the EIC Strategic Intelligence Team, and the EIC PM. The information was also cross-checked and complemented with findings from the literature review on technology and innovation signals and trends.

This second round of analysis aimed to make a clear distinction of signals related directly to specific technologies and innovations, and signals related to drivers, enablers and barriers. Those that connected more with this later group of contextual factors were used in the last exercise of the workshops (see workshop flow and Chapter 4).

As signals still presented different levels of detail, this pre-workshop analysis allowed the team to propose thematic clusters and, in some cases, sub-clusters as an initial organisational scheme for the workshop. Here the engagement of PMs, as experts in their portfolio, was crucial. Some signals were significantly 'high-level' to the extent that they could be clusters of technologies or trends in and of themselves. These were mainly converted into sub-clusters and therefore helped group the other signals.

Table 3 - Pre-workshop signal clustering conducted by the horizon scanning team in collaboration with the EIC PM.

EIC PROGRAMME MANAGER'S PORTFOLIO	INITIAL SIGNAL CLUSTERS
Agriculture & Food	Connectivity, digital & automation Nanotech & biotech Synergies and innovative business models New methods for sustainable use of resources Novel foods & health
Space Systems & Technologies	Satellite communications In-space solar energy harvesting for innovative space applications & innovative propulsion Space debris actions, in-orbit servicing, in-space assembly & manufacturing Launchers Enabling technologies Robotics Earth observation Exploration missions Microgravity
Quantum Technologies	Energy-efficient QT Machine learning/AI - quantum Semi-conductor fabrication for QT Photonics Quantum computing for chemistry
Solar Fuels & Chemicals	Multistep conversion Novel electrochemical devices Advances in photosynthetic devices Key enablers Sustainability
Responsible Electronics	Materials and processes for sustainable electronics Solutions to lower power consumption or heat conductivity Application-driven solutions Sustainability strategies
Architecture, Engineering & Construction	Planning and design Sustainability Materials and components Fabrication and assembly

Note - The first two workshops on Space and Quantum (pilots) did not include this step, as it was introduced later as a methodological improvement.

Other signals contained overly detailed solutions, not helpful for this exercise. They were grouped and merged into single signals or sub-clusters. Other signals required additional detail to be understandable in the workshop context and were complemented with descriptions and examples of application when that information was available, otherwise they were removed.

Considering the relatively short duration of the workshops, this clustering exercise aimed to provide participants with an easy way to navigate the number and diversity of signals. Framed as an open clustering solution, workshop participants were free to challenge and amend the initial clusters during the workshop, both on the number and the topics they comprised. The list of initial clusters developed for each workshop is set out below (Table 3).

2.2.8 Workshop flow and choreography

The workshops were held online and organised through WebEx, a video-conference platform, with the additional use of Miro, a collaboration platform that virtually reproduces canvas, frameworks and post-its.

Each workshop was 3 hours long and relied on the involvement of experts with multiple profiles relevant to the respective portfolio. As previously stated, given the broad scope of the EIC and the importance of signal interpretation to the utility of Horizon Scanning, the success of these sense-making activities required participation from diverse stakeholder groups. Participant pools varied slightly according to the topic, but often included: researchers, startup founders, representatives from established businesses, industry associations, venture capital investors/ business angels, business incubators and policy makers. This diversity was key to bringing different perspectives to the conversation and helped build significant collective intelligence insights around the topics at hand.

The workshops followed a process composed of **12 steps**, as followed:

1. **Introduction**, including presentation of the EIC and its funding instruments, the facilitation team and the workshop objectives;
2. **'Tour de table'** with each participant introducing themselves;
3. **PM portfolio scope presentation** by the EIC PM;
4. **Icebreaker** exercise connected to the topic and helping to troubleshoot the issues of access and the use of the digital whiteboard;
5. **Overview presentation of the signals collected**, the different sources and the methodology used to collect them, and the main steps of the workshop. An example of the visual presentation of the signals collected can be seen in Figure 03. The black rectangles mark the primary categories under which the signals were clustered in pre-workshop analysis. Below each category are the collected signals, using different-coloured digital 'stickies' to demarcate the sources for the signals. Orange signals were provided by experts, where the green (patents), blue (EIC proposals), and pink (scientific publications) were collected through the data and text mining process. Purple post-its were added to the list for additional signals emerging from the literature review.
6. **Breakout groups**. To facilitate the first round of discussions, the main group was divided into 2 to 4 breakout groups. The number of groups varied depending on the total number of participants and aimed to have an optimal number of 5 to 8 members. In this stage, each group analysed the full set of signals and proposed a list of no more than 10 emerging and disruptive technologies and innovations considered as most relevant for the PM portfolio. These signals were decided on by participants' vote after each participant had shared and discussed the signals that were most important from their perspective. Some of the propositions encompass more than one signal or concern new topics proposed during the group's discussion. This round of voting used digital red dots, as seen in Figure 04 above.
7. After a short break, participants were brought to the plenary room and **each group's rapporteur debriefed the plenary on the group's outputs**.
8. **After the debrief, the facilitators proposed the connection and aggregation of signals with common topics** among the various proposals of each group. These connections between groups discussing similar topics were drawn on the board during plenary discussion, providing the workshop participants with the opportunity to witness and comment on the connection and aggregation process. Figure 05 provides an example of the results of this process at the conclusion of the plenary discussion. Different-coloured connecting lines were used to reinforce the common discussion points across the different group inputs. Clusters were titled in collaboration with the workshop participants to ensure transparency and broad agreement.

Figure 3 - An example of the visual presentation of the horizon scanning signals used in the Responsible Electronics workshop, as introduced to the workshop participants. This visual language was replicated across all workshops.

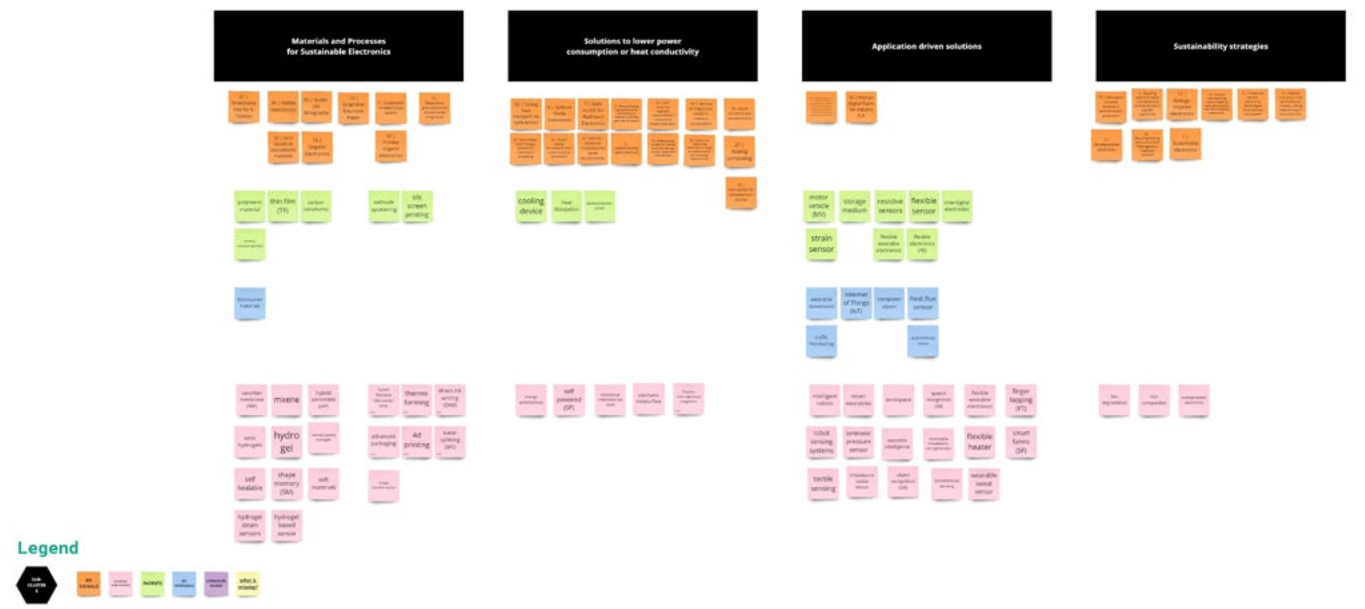


Figure 4 - This shows how the breakout groups in the workshop on Architecture, Engineering, and Construction were encouraged to select, discuss and group signals, as well as the process of Top 10 signal selection in the breakout groups (using red-dot voting).

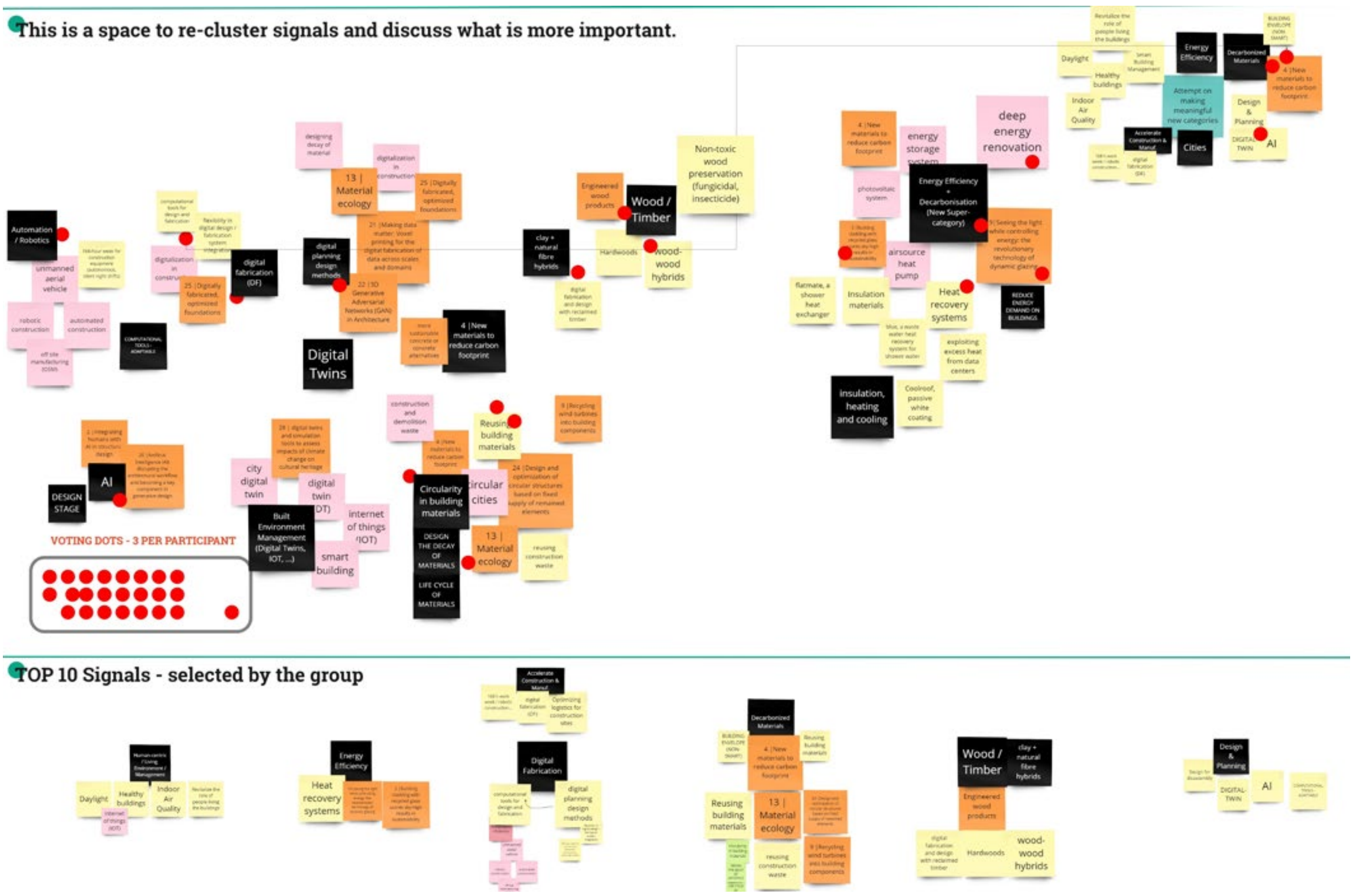
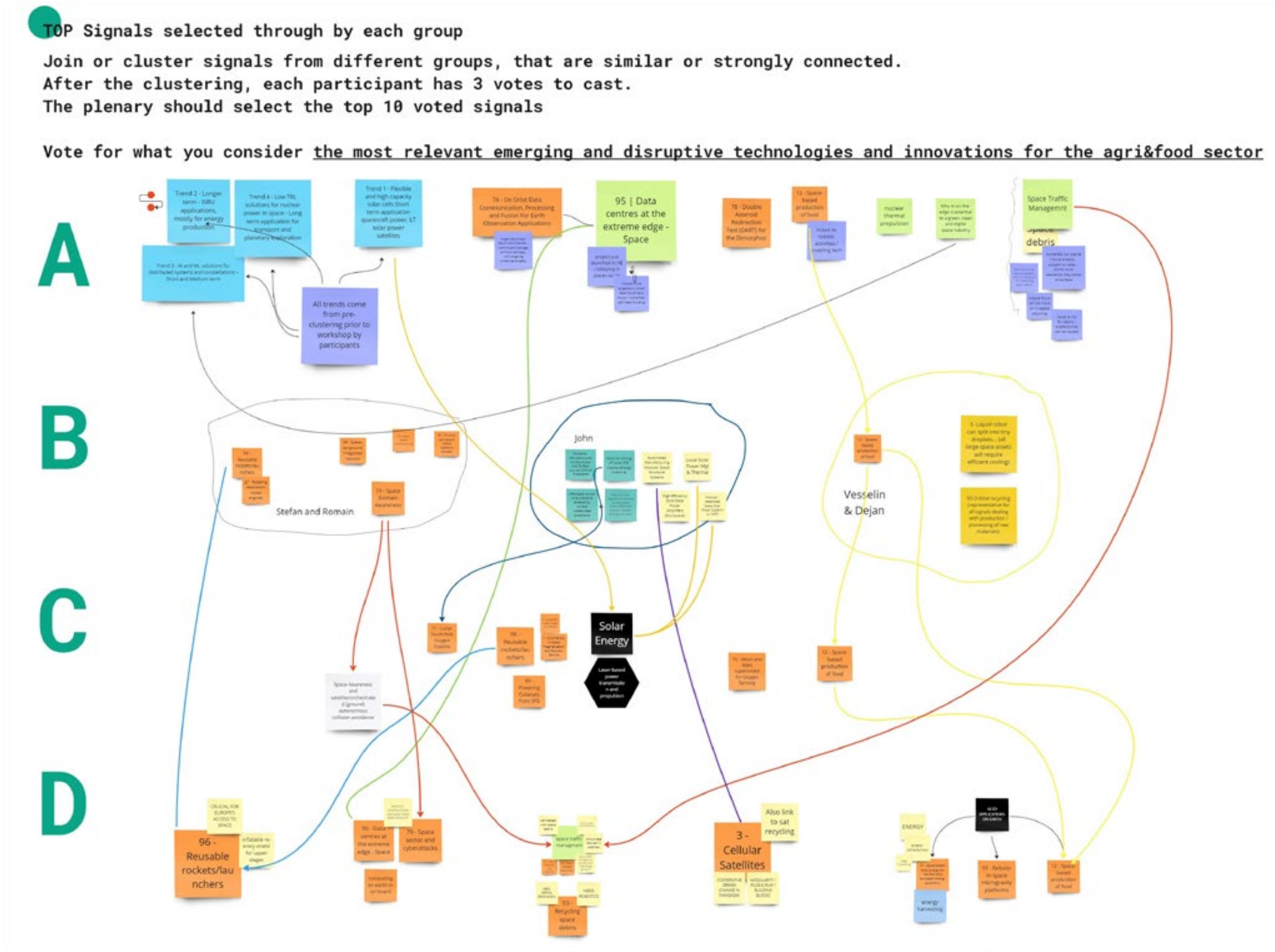


Figure 5 - An example of the plenary discussion findings at the Space Systems and Technologies workshop. The connection and aggregation of breakout group results is essential to the final stage of signal filtering.

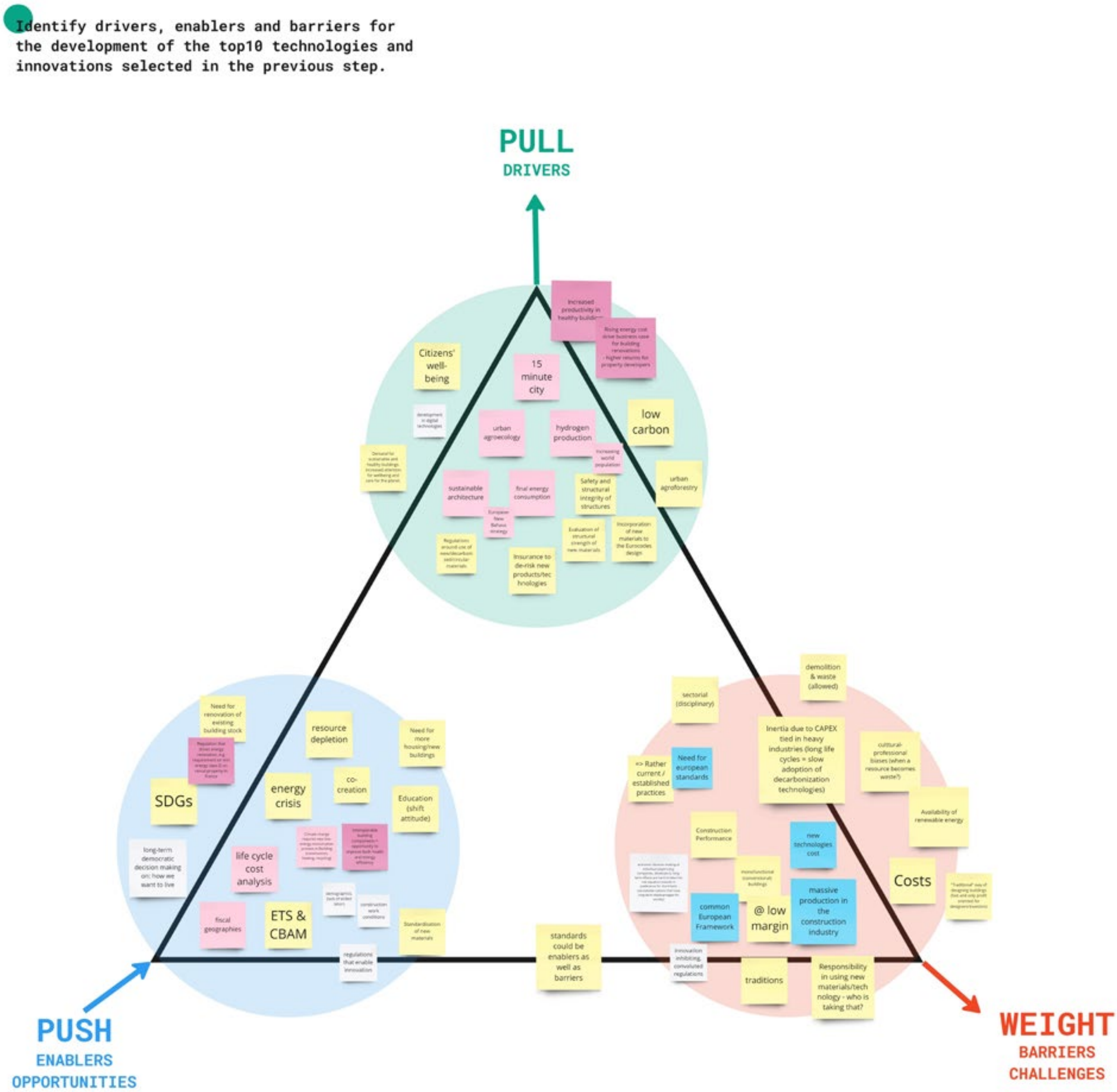


9. **Plenary voting on the top technologies and innovations** based on the same criteria of the previous vote – the top emerging and disruptive technologies and innovations considered as most relevant for the PM portfolio. At this stage, the facilitators made clear that this prioritisation exercise did not imply that unselected topics would be completely discarded: all signals and the analysis made at all stages of the workshop would be included in the reports for further consideration by the EIC.

10. **Plenary commenting on the results of the voting**, including adding additional insights and highlighting other relevant signals that were left behind and might be relevant to keep in mind.

11. **Final exercise aimed to capture drivers, enablers and barriers** for the development of technologies and innovations in the context of the workshop topic, including but not limited to those selected in the previous step (Figure 06).

Figure 6 - The ''futures triangle' was the final activity of the workshop,, exploring the topics and issues that pull, push, and weigh down future change. The different coloured 'stickies' reflect participant colour choice and do not hold special meaning in this



12. **Wrap-up and conclusions** – the EIC's programme manager spoke briefly about the outputs of the session and how they might be used.

Apart from small deviations from the time allotted for each step across the six final workshops, this structure served as a consistent workshop process for interpreting and making sense of a broad signal set for each of the PM portfolios.

2.2.9 Workshop report

After each workshop the JRC delivered a report containing all the information collected and produced during the process, as explained in more detail in the next chapter.

Results – trends and signals

3.1 Overview

As mentioned before, after each workshop the results were analysed and the main findings summarised in a summary report. The focus of the summary reports was to communicate which of the signals and signal clusters had been assessed and selected as having the greatest potential for long-term gains and benefits in the light of the EIC's mission and the broader goals of the EU's strategic vision. The report included the initial signals list, (produced by the scanning activities), a detailed description of the methodology, and the results of each workshop step.

The current report contains only the signals and clusters prioritised in each of the workshops together with an aggregate analysis of their implications. The selected signals, arranged by EIC PM portfolio[14] and ordered by the number of final votes received in the plenary voting (see step 9 above), are set out in the beginning of this chapter. Further on, the cross-cutting enabling technologies and R&I clusters and the common features for key emerging technologies and breakthrough innovation are discussed.

3.2 Space Systems & Technologies

This PM portfolio was the subject of two horizon scanning workshops, including one of the pilot sessions in 2022. Both sets of prioritised signal results are set out below to demonstrate the shared findings across the workshops. In the second workshop, the top three signal clusters reflected developments and technologies in different fields, details of which are provided below.

Workshop 1

- **The port** - a business platform in space
- **Space debris recycling and refuelling**
- **'User-driven' in-orbit servicing, assembly and manufacturing (OSAM)**
- **Thin film solar cells based on CIGS** (copper indium gallium selenide) technology

14 As mentioned previously, two prototyping workshops were held in late 2022 as a way to test the horizon scanning workshop and the online format. The primary lesson learned from these prototypes was to conduct some preliminary signal clustering before the workshop so that experts might best use their time in assessing the signals. The signal results of those prototype workshops are also included in this report. However, the results of these prototyping workshops can be integrated and do not impact the quality of the outputs, despite a slightly different approach in starting points and clustering.

Workshop 2

- **Reusable rockets/launchers systems and components** - This was viewed by multiple work groups as an essential area for the EU to encourage development and entrepreneurship.
  - Lower and upper stage rocket reusability
  - New avenues for return and capture of reusable assets
  - Supports sovereign European access to space and can be an important capacity for external trade and partnership.
- **In-space solar – modular power systems, high-capacity solar cells, solid state amplifiers –** Multiple groups indicated that this technology field was ripe for investment along with multiple channels and would be essential for numerous space activities:
  - In-space solar to provide power for space-based activities
  - Solar harnessed as a new mode of propulsion (laser based)
  - Modular solar design can enable new configurations
  - Management software and distribution of power will be essential for these technologies to thrive in harsh, dynamic conditions.
- **Cellular satellites, plug and play modularity, and a new cooperative design paradigm** – Evolving satellite technologies that enable more interchangeability and the potential to expand on satellite capabilities after initial launch.
  - Promoting new satellite design for increased reusability and recycling.
  - Modular standards incentivise plug and play activities, research partnerships and cooperation.
  - Collaboration and open design standards to encourage modularity.
  - New constellation-based operations or capabilities might be enabled.
- **Data centres at the extreme edge of space**
- **AI and ML solutions for distributed systems and constellations as short- and medium-term technologies for investment**
- **Space awareness and satellite/orchestrated (ground) autonomous collision avoidance**
- **Space-based production of food and related life-sustaining technologies**
- **Orbital recycling and other topics related to production and processing of raw materials**

3.3 Quantum Technologies

The portfolio for Quantum Technologies was also included in the pilot workshop stage in addition to a workshop developed with the final process design. Again, prioritised signals from both workshops are presented here, with a deeper analysis of the four priority clusters identified in the final workshop.

Workshop 1

- **Error resilient quantum algorithms**
- **New types of qubits** for quantum computing applications, combined with hybrid/interfaces
- **Quantum energetics** (optimise the energetic of the Q system under the engineering point of view)
- **Application of machine learning to quantum** (controllers and algorithm)
- **Enabling tech** – scaling up capacity tools
- **Linking quantum systems for advanced quantum network applications**

Workshop 2

- **Photonics** – Increasing research into photonics applications to quantum technologies was recognised by all three working groups and was noted for both the potential to make direct contributions to QT and the potential spillover benefits it might have for other fields.
  - Essential for its potential to enable scaling of processing through energy efficiency increases.
  - Can contribute to both smaller system designs and increases in the numbers of qubits that might be available for processing.
- **Scaling up of quantum processors** – Semi-conductor fabrication for quantum technologies is one of the possible avenues through which

the larger topic of scaling difficulties might be addressed:

- To better bridge research to application, scaling will be required.
- Platform differences and potentials for scaling must still be tested before longer-term commitments are made.
- However, scaling infrastructure to provide more reliable and timely access for ongoing R&I might be prioritised to better identify more fruitful platforms and methods.
- Supply chain issues (#9) are also viewed as an important area to monitor as these can quickly create challenges for scaling and R&I.

- **Energy efficiency** – While this research is currently not included in most QT funding instruments, it was recognised as critical to furthering QT research and EU competitiveness.
  - Energy efficiency is seen as a critical aspect of bridging quantum research to the business and industrial context.
  - This aspect of QT development also shows potential for spillover benefits for other fields.
- **Machine learning and quantum** – This field has the potential to be mutually beneficial to both QT and for ML/AI.
  - Participants envisioned ML/AI as being able to help QT research in identifying new configurations, parameters, or processing methods that can better leverage quantum affordances (#6).
  - Other researchers are hopeful that quantum computation might be able to offer ML/AI sciences new platforms and tools that reduce energy costs and increase algorithm performance (#8).
- **Competitiveness - research to industry bridging**
- **Novel qubits**
- **Key European weakness that needs to be addressed: private/public funding**
- **Quantum algorithm / software testing**
- **Supply chain for QT**

3.4 Agriculture and food

Within this portfolio's workshop, participants identified a total of eight priority signals and signal clusters. The top three priorities areas comprise several technologies and innovations.

- **Systems and solutions to support farmers' decisions** - technologies and innovations supporting decision-making structured in four domains:
  - Integration of technologies in machinery to support daily operations
  - Control of machinery through robotics and AI
  - Sensing
  - Knowledge-intensive agriculture - analysis supported by AI and digital twins, demanding the use of reliable data.
- **Novel foods and biotechnology** – this signal cluster can be summarised as developments in five areas:
  - Development of artificial food and dairy
  - Alternative and diversification, namely plant-based proteins, insects, algae, and cultivated meat
  - New protein sources and molecular farming
  - Need for more research on cellular and genes (genome, transcriptome, metabolome) and explore applications of AI for research in these fields, e.g. to predict the highest yield strains
  - Innovative methods such as 3D printing.
- **Precision nutrition** – this cluster includes development in:
  - Individualised food production
  - Personalised healthy diets
  - Nutritional biomarkers
- **Alternatives for antibiotics and fertilisers**
- **Agriculture contribution to energy production** (green hydrogen, water reusing, ocean-based energy storage and desalination)
- **Ecosystem restauration coupled with food production**
- **Waste-free farm**
- **Smart aquaculture**

3.5 Solar Fuels & Chemicals

As this workshop focused on a more specific set of technologies and innovations, the main findings are organised in a smaller number of clusters as follows.

- **Interface engineering** - Interfaces (e.g. liquid/solid, solid/gas) are central to solar fuel devices and their engineering and optimization will contribute to next generation solar fuel devices. Stemming from R&I developments across categories, several interface related signals were identified by experts. Experts noted that these interfaces are central to the pursuit of efficiency gains, scalable solutions, and the generation of fuel from readily abundant sources.
- **The challenge of scalability and application** - assuming the development of singular process or technologies in due course, many experts noted that proving the scalability of production and deployment of these projects within one or more real world applications is becoming essential.
- Given the concern that **solar fuels** are inheriting the popular perception that they will always be 30 years away from providing realistic results, the group discussion again highlighted the issue of scalability as a defining aspect for the field at this juncture.
  - Investing in modes of assessing scalability and the challenges and opportunities that various solar fuel technologies face when attempting to scale will be critical if solar fuels are to realise their potential value.
- **CirculAIR fuels** – this pertains to the direct production of fuels and other products from solar interactions via hydrothermal liquefaction.
- **Stability of CO_2 reduction processes –** a long-held promise of this sector is that processes may both provide fuel and be used to capture carbon dioxide. Finding stable processes that can achieve this at industrial scale remains an important area for research, development and innovation (R&D&I). Carbon efficiency in whole process - efforts to develop products and services must be viewed as low to zero emissions, especially by the public. Not only is this proof demonstrative of the potential for solar fuel production, but it also aligns with public sentiments for 'good living'. Moreover:
  - Numerous group discussions highlighted the need for this encompassing topic to be a focal issue in determining the way forward for solar fuel technologies.
  - This can be both an area of research and an indicator area to help select technologies and methods for research and potential scaling.
  - This concern cuts across various fields that contribute to the development of solar fuel R&I, thus making it a consolidating issue.
- **Cyanobacteria** – as exemplary of research into harnessing microbiological processes to generate a variety of products based on organisms' interactions with sunlight and abundant materials.

3.6 Responsible Electronics

Several signals and clusters of signals coming from different working groups within the Responsible Electronics workshop were organised by participants. These clusters take relevant overlaps into consideration, account for similar topics selected by different groups, and emphasise connections between topics as suggested in plenary discussion.

Participants selected the following signals or clusters of signals as most relevant in the responsible electronics sector.

- **Circular electronics** - Group discussion differentiated between two major routes for encouraging circularity for electronic components – production with recycling of materials as essential design parameter, or the engineering and integration of organic and biodegradable materials or components.
- **New bio-inspired materials / semi-conductors** - Research directions in biologically integrated electronic components, 'biomimicry' derived systems or processes, and products

that are safe for use within biological systems, particularly human or animal.

- **Printed and flexible electronics technologies could become omnipresent** - Group discussions on this topic were particularly focused on production processes that could limit materials costs and waste and could be more tightly integrated into many different applications or environments. Another fact stated was that the higher the level of component integration, the more complicated it is to treat and dismantle them, therefore it is important to integrate an end-of-life strategy through eco-design.
- **High-performance, low-power materials and circularity** - Discussion on this topic included not only the creation of materials to increase energy efficiency, but also process by which these materials could be used multiple times in different products through recycling programmes.
- **Technologies for next-generation neuromorphic-type hardware, sensors, bioelectronic interfaces** - The group noted multiple R&I development pathways that could result in products capable of dramatically shifting how and where computing capacities might be integrated and utilised.

3.7 Architecture, Engineering & Construction

The last workshop held was dedicated to the Architecture, Engineering and Construction (AEC) sector. As this domain covers a significant scope of activities, the main findings include a wide range of innovation fronts, from sourcing materials to the design and the building stage.

- **Digital fabrication, accelerated construction & manufacturing and robotic construction** – This was the largest cluster and the most wide-ranging discussion topic. The group noted that computational tools and digital design were connected to robotics and automation, while also providing affordances to design, monitoring, and other important aspects of the AEC sectors.
  - Computational tools for design and fabrication (including AI and adaptable systems)
  - Flexibility in digital design / fabrication system integration
  - Optimising logistics for construction sites
  - 168-hour work week of automated robotic construction
  - Designing for disassembly
- **Bio-based materials** (wood / timber clay + natural fibre hybrids) – Some workshop participants noted that more specific biomaterials were largely missing from the initially sourced signals and created a new cluster of signals. They pointed out that while eco-cement was present, many naturally occurring materials like timber and clay would benefit from increased research and development into their physical properties and best-use practices.
  - Engineered wood products
  - Clay + natural fibre hybrids
  - Wood / timber
  - Digital fabrication and design with reclaimed timber
  - Hardwoods
  - Wood-wood hybrids
- **AI combined with real-time monitoring** – While computational tools were addressed in a separate cluster, there was an additional discussion that raised the benefits of artificial intelligence systems being used for the design and monitoring of the built environment. AI was seen as complimentary to human design and planning, and not as a replacement.
  - BIM (building information modelling) models combined with real-time monitoring for sustainability and structural health monitoring
  - AI for the construction of earthquake-resistant structures
  - Integrating humans with AI in structural design

- Assessment and optimisation
- Transparency, open process, gains, and losses

- **Digital twins and simulation tools** to assess impacts of climate change on cultural heritage
- **Recycling for low carbon re-raw materials/ decarbonised materials –** Participants highlighted a cluster connected with materials while recognising two separate tracks that should be followed up on: (1) the opportunities and technologies for reclaiming and reusing materials from existing construction, and (2) the development and use of materials with little to no carbon emissions.
  - Design and optimisation of circular structures based on fixed supply of remained elements
  - Narrow the material flows (perhaps recycling can be avoided)
  - Material conservation (life-cycle assessment; lifespan extension)
  - Geopolymer concrete
  - Ground granulated blast furnace slag
  - 3D-printed bioceramic bricks give new life to eggshell waste as building materials
  - Cement paste
  - Eco-efficient cement
- **Human-centred: processes, tool, living environment, management** - Members of the group advocated for the centring of the human experience across the entire process of architecture, engineering, and construction. They concluded that new tools or processes that are being developed should account for comfortable human interactions as much as the final end products that are being developed.
  - Planning and design: use of artificial intelligence
  - Materials: graded materiality high-strength and low-impact materials
  - Manufacturing techniques: hybrid manufacturing - combining additive and subtractive manufacturing
  - Healthy buildings including daylight and air-quality integrating IoT (Internet of Things) to improve interior spaces.
- **Energy efficiency –** The emphasis on energy efficiency across the AEC sectors was discussed, though it was relatively limited to reviewing some of the more technological breakthroughs captured in the signals. Energy efficiency across the entire process was discussed as important, but also as facing some challenges and incumbent inertia.
  - Heat recovery systems
  - Building cladding with recycled glass scores sky-high results in sustainability
  - Seeing the light while controlling energy: the revolutionary technology of dynamic glazing

3.8 Cross-cutting enabling technologies and R&I clusters

When analysing the results across the workshops, we can spot four key enabling technologies or R&I clusters that recur in most of the priority listings that experts proposed. These include:

- Artificial intelligence and machine learning
- Biomimicry or harnessing biological process
- Robotics and automation
- Material sciences

Each of these technological areas was identified as playing a role in defining the cutting edges of research and innovation inside and across most of the six sectors that were chosen for the Horizon Scanning exercise. In this sub-chapter, examples of the relevance of these cross-cutting enabling technology or R&I cluster are given.

3.8.1 Artificial Intelligence and Machine Learning

Artificial intelligence (AI) and machine learning (ML) systems have unique applications within each of the sectors. Experts believe that they can be applied to a variety of tasks including the creation of novel material compounds, the examination of vast data oceans, solving complex problem sets and the creation of improved algorithms for specific tasks. Experts noted the following ramifications for AI/ML technologies across the EIC portfolios:

- **Agriculture & Food** - Within Agri/Aquaculture, AI/ML systems might be used to support farmers in decision-making, accounting for various environmental conditions including real-time monitoring data from a variety of sources. Within Food there may be some applications of the AI/ML technologies to help create nutrient-rich and robust genetic strains of various food species, find new modes of pest management, and identify other applications of genetic adaptation.
- **Space Systems & Technologies** - AI/ML might be applied to help create or discover novel materials fit for the space sector. There are also some applications for in-orbit autonomous vehicles and robotics, the management of large arrays, and the awareness of space debris.
- **Quantum Technologies** - The use of AI/ML technologies to help improve quantum computing, or to find novel solutions to problems in the design of quantum systems. There is a reciprocal relationship here, as Quantum computing will enhance or accelerate capacities for AI/ML as well.
- **Solar Fuels & Chemicals** - Experts mentioned the possibility for AI/ML to help understand and change the genetics of certain species that might be able to naturally produce certain compounds, capture CO2 or demonstrate other desired traits.
- **Responsible Electronics** – AI/ML technologies might be applied to the discovery of chemical materials able to perform specific processes or exhibit certain parameters or properties that are essential to different research areas within this field. There was also discussion on the integration of electronics with clothing or accessories termed 'wearable intelligence' as monitoring data is combined with algorithmic analysis to provide real-time insights.
- **Architecture, Engineering & Construction** - Experts suggested that the application of AI/ML systems within the AEC sectors can help design the built environment with respect to various environmental and social parameters. These technologies can also bring improvements to the planning and execution of projects - optimising logistics, integrating with automated construction technologies, and designing end-of-life cycle for new builds.

3.8.2 Biomimicry or harnessing biological process

- **Agriculture & Food** – Experts identified the use of nutritional biomarkers for meeting highly personalised nutritional needs, plus a very robust number of signals relating to novel food and biotechnology including protein sources from molecular farming.
- **Space Systems & Technologies** – During the signals analysis, the research area concerning the production of food in space would include the harnessing of biological processes to increase yield and potentially create foods that serve nutritional needs for long-term human settlements among other life-sustaining technologies.
- **Solar Fuels & Chemicals** – Direct conversion of CO_2, water, and sunlight into complex products via microorganisms (e.g. cyanobacteria) was discussed by workshop participants, as well as continued efforts at developing interfaces that may be either biological or may borrow from biological systems.
- **Responsible Electronics** – Organic electronics and biodegradability were seen as two key signals for increasing the circularity of electronic components. There was also discussion of electronics that were 'biologically inspired' including neuromorphic hardware and bioelectronic interfaces.
- **Architecture, Engineering & Construction** – Bioceramic bricks and other hybrid materials that might add to the reusability or recyclability of construction materials was one area of discussion during signal analysis. The workshop participants also identified and added the signal cluster relating to the use of bio-based materials (clay/natural fibre hybrids and engineered wood).

3.8.3 Robotics and automation

- **Agriculture & Food** – Participants discussed the continued automation of various parts of industrialised agriculture systems, including the use of various autonomous robotics.

- **Space Systems & Technologies** – In-orbit robotics was seen as a key enabling technology for a variety of tasks – maintenance and recycling in particular. Automation of processes like coordinating satellite constellations or solar arrays was also discussed at some length.
- **Quantum Technologies** – Quantum research is affected by semi-conductor fabrication, a highly automated and roboticised process given the need to maintain sterile conditions. There is also the possibility that quantum computing can enable new types of robotics and automation, though this was not a priority signal group.
- **Solar Fuels & Chemicals** – This discussion did not directly discuss the area of robotics, though it is possible to include automation as a component of the sector's desire to scale as device architectures are selected for larger demonstration installations.
- **Responsible Electronics** – This field viewed printed and flexible electronics as being potentially ubiquitous and as thus changing the way robotics is designed and integrated into various environments.
- **Architecture, Engineering & Construction** – Digital fabrication and the acceleration of construction and manufacturing were considered the most important signal group for this sector. In part, automation and robotics can transform all three fields – enabling new designs with robotic construction capabilities in mind.

3.8.4 Material sciences

- **Space Systems & Technologies** – The dramatically different conditions in which materials across the space sector must perform has made this sector an important engine of material sciences. This is expected to continue, with space research providing new materials or essential research for other fields to adopt.
- **Quantum Technologies** – The top signal group for this workshop was photonics, which is partly enabled by new materials and systems that can facilitate an energy-efficient approach to quantum computing.
- **Solar Fuels & Chemicals** – Interface engineering was directly related to the discovery of new materials that can conduct conversion processes more efficiently and produce complex compounds.
- **Responsible Electronics** – Again, this sector is pushing material sciences research and reaping the benefits from materials developed in other fields. Exploring new configurations of organic and hybrid materials that can enable new physical attributes and new production modes (like printed organic electronics) is central to the sector.
- **Architecture, Engineering & Construction** – New materials for construction of the built environment are critical to this sector being able to achieve improved circularity, reduced emissions, and general decarbonisation. This includes the design of materials that can be more easily and sustainably recycled or reused.

3.9 Common features for key emerging technologies and breakthrough innovation

Beyond the cross-cutting enabling technologies, during the analysis of the workshops' results, a series of common features emerged: **Scalability, Energy, and Sustainability**. While these topics are too general to be 'signals', they summarise some of the main ideas expressed by workshop participants. On the one hand, these topics relate to technical dimensions of key emerging technologies and their potential future applications on a larger scale, in ways that are specific to each PM portfolio. But at the same time, the broad scope of these topics reflects some of the common challenges and opportunities across PM portfolios that became apparent only in the aggregate analysis. Additionally, this analysis hints at some of the overlaps shared by issues like scalability, energy use/production, and modes of sustainability.

3.9.1 Scalability presents one of the major challenges

Scalability was a recurrent challenge mentioned in all workshops. The shared view among participants across fields was that this challenge can and should be addressed as a technical and engineering problem and often as a business/investment challenge as well. This idea underscores the confidence among participants that many of the signals and clusters identified are indeed indicative of progress and potential across sectors.

For sectors that are emergent in the EU economy – in particular, **Solar Fuels & Chemicals, Quantum Technologies, and Responsible Electronics** – there was notable optimism from scientific research experts that continued R&I efforts will facilitate the discovery of compounds, processes, and designs that can address scalability. However, the challenges of scalability issues were often discussed from multiple perspectives, giving voice to the complexity of the innovation ecosystems that they are embedded in.

One key aspect of this challenges was the critical role of discovery and study of novel processes, materials, or systems that could lead to more efficient and effective scaling. This was mentioned with respect to **Solar Fuels & Chemicals** as they seek to bring some of their advances to demonstration scale.

In this portfolio workshop discussion, scientists were confident that with more time, biological and industrial process could be discovered and designed to confront some of the barriers that were holding back scaling[15], such as the proximity to sources of raw materials (e.g. water source) and proximity to infrastructure (e.g. energy grid or supply chains) to receive their products. While the current state of some innovations in the sector may be able to scale to a point, these limiting circumstances propel researchers' interests in finding solutions through continued experimentation and design.

Similar sentiments were voiced during the discussions involving **Quantum Technologies**. With novel qubit research and development[16], photonics[17], new types of processors and fabrication techniques[18], some participants favoured extending experimentation phases, as opposed to scaling less than optimal present-day solutions. It was mentioned that the sector still has a significant funding gap that needs be addressed by public investment as long as private investors wait for the solutions to be more mature and scalable to the point of commercialisation and wider adoption. Similar remarks were made in the **Space Systems & Technologies** workshops for specific capabilities and technologies.

In the **Responsible Electronics** workshop, participants looked at scaling from a different perspective. On the one hand, they noted that there was a lack of the necessary materials and other resources available within the EU for industrial scale manufacture that aligned with technological sovereignty and autonomy. The group did create a signal cluster – titled 'omnipresent printed and flexible electronics technologies' – that focused on technologies that reduce material demands[19] might be more easily integrated with legacy production and assembly[20].

However, an additional barrier to scaling was the current power of incumbent actors in the sector – influencing standard setting processes, accepting circular solutions, and being open to changes in production.

The idea that scaling innovations was challenged by slow rates of adoption by strong industry actors was also echoed in the **Architecture, Engineering & Construction** (AEC) workshop. The economic importance of the AEC sector for the EU (around 9% of GDP)[21] incentivises it to continue forward, adopting new technologies only as they are mature and can be easily integrated. This challenging condition led participants to discuss modularity as an effective response to more rapid adoption of innovative materials or building components.

Modularity was also discussed in the **Space Systems & Technologies** workshop, in combination with the strategic development of standards to address fabrication and logistical concerns. As these fields may be more familiar with these concepts (developing systems and products

15 Chen, C., Jiao, F., Lu, B., Liu, T., Liu, Q., & Jin, H. (2023). Challenges and perspectives for solar fuel production from water/carbon dioxide with thermochemical cycles. *Carbon Neutrality*, *2*(1), 9

16 Zhou, X., Koolstra, G., Zhang, X., Yang, G., Han, X., Dizdar, B., ... & Jin, D. (2022). Single electrons on solid neon as a solid-state qubit platform. *Nature*, *605*(7908), 46-50

17 Mojaver, K. H. R., & Liboiron-Ladouceur, O. (2022, May). Towards Large-Scale Silicon Photonic Programmable Optical Processors for Machine Learning and Optical Quantum Computing. In *2022 Photonics North (PN)* (pp. 1-1). IEEE.

18 Gonzalez-Zalba, M. F., de Franceschi, S., Charbon, E., Meunier, T., Vinet, M., & Dzurak, A. S. (2021). Scaling silicon-based quantum computing using CMOS technology. *Nature Electronics*, *4*(12), 872-884.

19 Saadi, M. A. S. R., Maguire, A., Pottackal, N. T., Thakur, M. S. H., Ikram, M. M., Hart, A. J., ... & Rahman, M. M. (2022). Direct ink writing: a 3D printing technology for diverse materials. *Advanced Materials*, *34*(28), 2108855

20 Tong, C. (2022). *Advanced Materials for Printed Flexible Electronics*. Bolingbrook, IL, USA: Springer.

21 https://single-market-economy.ec.europa.eu/sectors/construction_en

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that must often address multiple functions simultaneously), the discussions were also quick to note that modularity demonstrates its viability and applicability across several current fields and lends itself to some of the visions that these sectors have concerning their future development.

For instance, multifunctional space-based assets, including autonomous robotics, and satellite constellations, benefit from the upgradability and extendibility that modular approaches enable. Similarly, scaling the use of new construction materials is enabled by a modular approach to designing different aspects of the built environment and designing engineering modules to have a multitude of uses. Modularity also lends itself to the automation of fabrication, and in **AEC** might also enable designed disassembly and recycling of building materials.

While funding availability for scaling was also a constant theme (as already mentioned), it took a back seat to the idea that improved solutions could be engineered such that the current scaling challenges might be handled by technology integration and advancements in R&D&I. Scaling a technology presents a myriad of challenges, for example: designing and engineering industrial-scale production facilities, acquiring sufficient components and materials to maintain production, and integrating these processes within existing infrastructures for logistics, energy, etc. However, the pillar of sustainability puts additional restrictions on addressing these challenges, and thus makes sustainability a key discussion point when considering long-range implications of a technology.

For instance, in **Solar Fuels & Chemicals** - where research implies the field's potential to fundamentally change the production of energy and novel materials - there is already consistent agreement that the field must try to focus on concepts and approaches that can already point to being sustainably scaled. This case is described in greater detail below, but it implies an unfortunate reality facing many innovative sectors: ideas are being foreclosed on, perhaps prematurely, not because they do not show potential to achieve goals that fundamentally change industries, but because there is too much uncertainty about their ability to be scaled sustainably.

Scaling, and doing it aligned with the EU's commitments to address climate change, was the second challenging aspect across these sectors.

3.9.2 Sustainability requirements emerge as backbone in most of the signals detected and assessed

Given the EU's commitment to the twin green and digital transition, it should come as no surprise that many conversations across the Horizon Scanning workshops included some discussion points relating to the topic of sustainability. However, approaching this topic was quite different for each of the sectors.

For example, **Solar Fuels & Chemicals** and **Responsible Electronics** are at the leading edge of defining new industries, and have the unique position of following sustainable principles as a guiding force as their respective sectors position themselves for growth. Recognition of this capacity was broadly acknowledged by workshop participants across their respective workshops.

Solar fuels & Chemicals prioritised two clusters with deep connections to sustainability and climate related issues – (1) *Stability of CO_2 reduction processes*, and (2) *Carbon efficiency in the whole process* (a topic highlighted by all breakout groups during the workshop). The CirculAIR project[22] – top priority signal by votes in the workshop – also serves as an example project for how this sector views its future roles to support EU sustainability. Briefly put, the project is focused on producing aviation biofuels from biomass via a process (hydrothermal liquefaction) that also suggests benefits for carbon sequestration.

The **Responsible Electronics** workshop participants also identified their sector's potential contributions to sustainability through numerous priority signal clusters – circular electronics (including sustainable printed circuit boards and biodegradable electronics), and omnipresent flexible electronics (using sustainably sourced

22 https://cordis.europa.eu/project/id/101083944

biopolymers) among others.

During the course of that session, discussion repeatedly returned to the role of *circularity* – as a guiding design principle for research and innovation, as defining the sector's role in closing material loops in chip production, and as driving the development of high-performance, low-power, and readily reusable materials.

In the **Quantum Technologies** context, development pathways with the greatest potential must be identified and this current phase of experimentation can be resource intensive. In many cases, the components needed are being fully designed and created during the experimentation process (e.g. new hardware, engineered materials, laboratory designs, etc. are all required, refined, and replaced at a more rapid rate than established industrial sectors).

While that group of participants' primary sustainability interest was in reference to energy efficiency (as discussed in greater details below), there were some experts who cited the potential for quantum computing technologies to have spillover benefits to other fields (e.g. improved battery chemistry) that relate to sustainability as well.

The three PM portfolios with a longer industrial legacy – **Agriculture & Food, Architecture**, **Engineering & Construction**, and **Space Systems & Technologies** – viewed sustainability from a different perspective, though still marked its importance as a force shaping the futures of their sectors.

The workshop results for **Agriculture & Food** horizon scanning indicated that sustainability was integrated across many of the priority signal clusters. Novel foods and biotechnology for instance included discussion points about agricultural diversification including new protein sources (given the climate impact of meat production). In a similar way, sustainability was integrated into the clusters of ecosystem restoration as coupled with agriculture, the waste-free farm concept, and the sector's potential to contribute to the EU energy mix (e.g. green hydrogen, or ocean-based energy storage)

Space Systems & Technologies is a dynamic sector, and the workshop group acknowledged that at present the space sector is 'very far' from adopting or applying the circular economy concept (e.g. sourcing of raw materials). Several signals clusters such as reusable launch systems[23] and in-orbit recycling[24] indicate recognition of the need to move the sector in this direction. Some participants openly discussed ideas like an 'EU space sustainability compass' and the development of an 'ethical and sustainable code for space activities', both framed as opportunities to shift both the thinking within the sector and public opinion regarding its environmental impacts.

The **Architecture, Engineering & Construction** sector has a similar historical inertia. In the workshop discussions, participants acknowledged both the need for a deep climate-sensitive sectoral transformation, and for awareness regarding specific innovation fields that are aligned with sustainable goals. Materials are a particularly rich vein of research and experimentation, with clear indications from participants that innovations like bioceramic bricks[25, 26], geopolymer concrete[27, 28], or the use of recycled materials such as glass[29, 30], if

23 Dumont, E., Illig, M., Ishimoto, S., Chavagnac, C., Saito, Y., Krummen, S., ... & Reimann, B. (2022). CALLISTO: A Prototype Paving the Way for Reusable Launch Vehicles in Europe and Japan.

24 Fung, T. Y., Roy, S. S., Shi, Q., & DeLaurentis, D. A. (2022, June). Space junk aggregation, neutralisation, in situ transformation, and orbital recycling. In *2022 17th Annual System of Systems Engineering Conference (SOSE)* (pp. 239-245). IEEE.

25 Kumar, T. S., Madhumathi, K., & Jayasree, R. (2022). Eggshell waste: a gold mine for sustainable bioceramics. *Journal of the Indian Institute of Science*, *102*(1), 599-620.

26 https://www.designboom.com/technology/3d-printed-bioceramic-bricks-eggshell-waste-building-materials-manufactura-03-03-2023/

27 Thomas, B. S., Yang, J., Bahurudeen, A., Chinnu, S. N., Abdalla, J. A., Hawileh, R. A., & Hamada, H. M. (2022). Geopolymer concrete incorporating recycled aggregates:A comprehensive review. *Cleaner Materials*, *3*, 100056.

28 Almutairi, A. L., Tayeh, B. A., Adesina, A., Isleem, H. F., & Zeyad, A. M. (2021). Potential applications of geopolymer concrete in construction: A review. *Case Studies in Construction Materials*, *15*, e00733.

29 Robert, D., Baez, E., & Setunge, S. (2021). A new technology of transforming recycled glass waste to construction components. *Construction and Building Materials*, *313*, 125539.

30 Thevega, T., Jayasinghe, J. A. S. C., Robert, D., Bandara, C. S., Kandare, E., & Setunge, S. (2022). Fire compliance of construction materials for building claddings: A critical review. *Construction and Building Materials*, *361*, 129582.

properly scaled and integrated, could help reduce the sector's climate impact.

Initiatives like the Renovation Wave and the New European Bauhaus were referenced as influential in the way that they guide efforts for more rapid adoption of innovations that can drive sustainable transformation.

3.9.3 Energy has become a key issue

The recent EU energy crisis has put this issue at the forefront of every actor group across the EIC PM portfolios covered in this project. With soaring energy costs, the new calculus for return on investments has demanded that many sectors reassess which projects and topics get a renewal, and which must be temporarily postponed or abandoned.

Several of the sectors explored in the workshops have a direct role to play as potential providers in defining the future energy mix. **Solar Fuels & Chemicals**, for instance, might play a central role in the EU's energy futures as a collection of technologies and processes that draw on more sustainable and available material sources (e.g. ocean-water conversion). It can provide a number of different energy products and offers an opportunity to combine that with the much-needed carbon capture.

However, with sunk energy costs now representing a much higher portion of the overall assessment of techniques and processes, these promising fields suffer the pressure to produce results quickly and in demonstrable fashion.

For example, in the **Solar Fuels & Chemicals** workshop, industrial-scale demo projects were viewed as an urgent necessity by some of the workshop participants, particularly research and business representatives. These projects could be a way to differentiate the field from other energy research (e.g. nuclear fusion) that has made similar claims to revolutionise energy production for decades but has failed to deliver.

This means that while next generation processes are being highlighted to address some of the previous technologies' perceived limitations (high-cost production, longevity, geographical factors, etc.), the field is being asked to perform for public validation that it may some day deliver on its promise – thus raising the question as to whether the focus should be put on projects that may not be optimised but are ready for that stage of large-scale demonstration.

The workshops also included fields that have been simultaneously pushing the boundaries of the state of the art, at the cost of significant consumption. The **Quantum Technologies** sector, for example, is faced with high energy demanding tasks at every stage of the technology development cycle. US (United States) experts noted a few signals that might reduce the overall energy efficiency of some quantum systems (e.g. applying machine learning to quantum system). Yet, as it is a critical domain due to the capacities and services it might enable in the future and the need to keep up with competitive nations such as the US and China, its sustainability might be only addressed in a second stage.

Similarly, the energy and other resources being utilised in-**space** assets and applications are not nominal and become more pressing given the most recent economic downturn and the high European energy prices. Developments noted by workshop participants in domains like space solar power might contribute to meeting the sector's growing demand for energy.

In the **Architecture, Engineering & Construction** workshop, participants discussed the topic of energy efficiency as a prioritised cluster of signals including dynamic glazing[31], various heat recovery systems[32, 33], utilisation of the built environment as part of energy collection (like photovoltaic

31 del Ama Gonzalo, F., Zannoni, A. L., Santamaria, B. M., & Ramos, J. A. H. H. (2022). Dynamic Glazing With Higher Thermal and Optical Performance for Zero Energy Building Design. In *Urban Sustainability and Energy Management of Cities for Improved Health and Well-Being* (pp. 44-61). IGI Global.

32 Ratajczak, K., Amanowicz, Ł., & Szczechowiak, E. (2020). Assessment of the air streams mixing in wall-type heat recovery units for ventilation of existing and refurbishing buildings toward low energy buildings. *Energy and Buildings*, *227*, 110427.

33 Wehbi, Z., Taher, R., Faraj, J., Lemenand, T., Mortazavi, M., & Khaled, M. (2023). Waste Water Heat Recovery Systems types and applications: Comprehensive review, critical analysis, and potential recommendations. *Energy Reports*, *9*, 16-33.

rooftop[34] or pavement[35]) and storage systems (e.g. using redbrick supercapacitors)[36]. The sector seems aware that buildings account for the largest share of end energy use (nearly 40%)[37] and that the EC is backing a transformation of this sector through various initiatives – like the Renovation Wave[38], the climate adaptation strategy[39] and indirectly though the RePowerEU[40].

Energy Efficiency discussion was also present in the **Responsible Electronics** workshop, though it was concerned with efficiencies at a smaller scale – the transistors (e.g. gallium-oxide[41], meta-surfaces[42], and novel materials that make up our digital and electric devices). These discussions also included new approaches to analogue computing[43], in-memory computation[44], and new types of optoelectronic devices that can reduce energy needed for information processing. As the sector aligns with the EU's transversal digitalisation initiatives, participants noted the ability for new materials like graphene[45] or other high-performance/low-power materials to also support emergent EU circular economy initiatives.

As shown above, across all the PM portfolios, energy supply, demand, and efficiency of use was a priority topic under which many different signals were gathered and discussed. While each of the sectors has a different role to play in the future of EU energy – integrated as net producers, users, and/or managers – it is also clear that there are challenges ahead with respect to the present-day energy conditions.

Additionally, energy efficiency conversations were often intermingled with considerations of other material inputs that R&D&I required. For instance, with respect to circularity in design (as a way to reduce both material and energy requirements), or the development and use of materials that can play a specific energy and sustainability role.

The issues of energy and sustainability are critical elements of the EU's strategic, future-oriented commitments, and the discussions held around all EIC PM portfolios recognised this. Participants from all stakeholder groups seemed to acknowledge and accept their role in shaping the EU's future potential through the development of clean and efficient deep tech solutions.

34 Martinopoulos, G. (2020). Are rooftop photovoltaic systems a sustainable solution for Europe? A life cycle impact assessment and cost analysis. *Applied Energy*, *257*, 114035.
35 Zhou, B., Pei, J., Nasir, D. M., & Zhang, J. (2021). A review on solar pavement and photovoltaic/thermal (PV/T) system. *Transportation Research Part D: Transport and Environment*, *93*, 102753.
36 Wang, H., Diao, Y., Lu, Y., Yang, H., Zhou, Q., Chrulski, K., & D'Arcy, J. M. (2020). Energy storing bricks for stationary PEDOT supercapacitors. *Nature communications*, *11*(1), 1-9.
37 https://ec.europa.eu/commission/presscorner/detail/en/fs_21_6691
38 COM(2020) 662 final.
39 COM/2021/82 final.
40 https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en
41 Dahiya, S., Kaur, D., Ghosh, A., & Kumar, M. (2022). A strategic review on gallium oxide based power electronics: recent progress and future prospects. *Materials Today Communications*, 104244.
42 Yoon, G., Tanaka, T., Zentgraf, T., & Rho, J. (2021). Recent progress on metasurfaces: applications and fabrication. *Journal of Physics D: Applied Physics*, *54*(38), 383002.
43 Zhang, W., Gao, B., Tang, J., Yao, P., Yu, S., Chang, M. F., … & Wu, H. (2020). Neuro-inspired computing chips. *Nature electronics*, *3*(7), 371-382.
44 Flebus, B., Rezende, S. M., Grundler, D., & Barman, A. (2023). Recent advances in magnonics. *Journal of Applied Physics*, *133*(16).
45 Sang, M., Shin, J., Kim, K., & Yu, K. J. (2019). Electronic and thermal properties of graphene and recent advances in graphene based electronics applications. *Nanomaterials*, *9*(3), 374.

Results – drivers, enablers and barriers

In the context of the ANTICIPINNOV project and a wider perspective in technology foresight exercises, the Horizon Scanning process can be adapted and complemented to meet the specific needs of insights from the 'end-consumer'. This often implies running a process that touches on elements of stakeholder consultation and goes beyond revealing novelty by, for example, highlighting topics that are relevant for ecosystem development and policy implementation. These insights may include (but are not limited to):

- Identifying drivers and enabling conditions that could foster the successful takeaway of an emergent technology and/or its innovative use, as well as identifying barriers and challenges that we might face in pursuing that aim.
- Assessing which technologies and/or their innovative uses could have potentially more impact and/or be strategic for the European Union.
- Unveiling the most impactful areas where the EU institutions should position its funding instruments, to complement and not overlap with other sources that aim to foster European R&D&I.
- Suggesting policy initiatives and other complementary actions, such as non-financial support (e.g. mentoring, pairing, and consultancy) or indirect financial support (e.g. funding of facilities or supporting organisations such as testbeds or digital innovation hubs).

At the conclusion of each workshop, the participants were asked to identify drivers, enablers and barriers to the future of the sector. This activity roughly aligns with the futures triangle method that is used to 'map the environment' with respect to present-day perceptions on what is influencing the future(s)[46]. An adaptation of this framework as used, as previously explained in Chapter 2.

Taken individually, the results from this exercise might be useful in assessing sector-specific stakeholder perceptions regarding the broader STEEP (social, technological, economical, environmental and political) environment. This more granular approach can be helpful for each of the EIC PMs with respect to policy implementation and funding decisions. Each workshop report included the contributions made by participants in the context of each PM portfolio approached.

46 Inayatullah, S. (2007). Alternative futures of occupational therapy and therapists. *Journal of futures studies*, *11*(4), 41-58.

Moreover, when the results of these activities are taken in aggregate, the emergent common themes across the sectors can serve as an important guiding constellation of STEEP factors that are shaping the view of researchers and innovators across fields. This can be a fruitful result with respect to concurrent strategic foresight work for more anticipatory R&I at policy level.

Below we present the most common discussion points across the Horizon Scanning workshops. While some nuance of sector-specific discussions might be lost, the following common themes - shared by two or more of the portfolio sectors - were identified during analysis (illustrated in Chapter 2 - Figure 6):

Drivers (pull)

- Green deal and climate change responsive policy
- Decarbonisation of systems
- Societal motivation for change (esp. climate issues)
- Strategic autonomy and geopolitics
- Resource security (e.g. food, raw materials)
- Reduce consumption of raw materials
- Material waste minimisation
- Europe's interest in tech sovereignty
- Startup-based innovation ecosystems
- Energy resilience and security
- Minimising energy consumption

Enablers (opportunities, push)

- Standards
- Cheap and renewable energy
- Circular economy
- New business models
- Access to data
- Cybersecurity
- AI at the edge
- Education and skills development
- Legislation - CO2 supply, carbon tax
- Consumer demand

Barriers (challenges, weight)

- Geopolitical tensions
- Lack of updated standards or regulations
- Limited access to raw materials or resources
- Lack of private investment and funding opportunities
- Engineering challenges for scalability
- Incompatibility with legacy technologies
- Unaddressed research gaps
- Fragmentation or limited coordination
- Skills scarcities or retention
- Limited societal awareness or acceptance

These aggregated results should be considered as initial indicators of cross-sectoral aspirations and concerns and can be used to trigger further discussions and analytical activities.

Conclusions and recommendations

5.1 Overview

The EIC is tasked with overseeing EU funding across a broad spectrum of policy and economic domains, reaching a significant number of actors and ecosystems from researchers to startups.

Adding to this complexity, it has responsibilities to address three distinct bands of the TRL spectrum in its Pathfinder, Transition, and Accelerator programmes. Lastly, and perhaps more importantly to the current Horizon Scanning project, in using these instruments the EIC plays a key role in shaping the future business and innovation European landscapes through its support to the most cutting-edge topics.

All this requires identifying technologies and innovations that are believed to be ready for further development and market deployment, and possibly world leading actors that can ensure their successful development. This alone is extremely significant, but it is also paired with a second component – fostering the future-oriented technologies that should help define Europe's strategic autonomy while influencing global policies on trade, technology standards, social justice and ethical concerns, and ecological and environmental issues related to climate change.

Accessing already existing expert communities from business to policy or creating new anticipatory-centric working groups linked with future Horizon Scanning activities might facilitate the coordination of such complex responsibilities. The difficulty in Horizon Scanning, without the benefits of comprehensive strategic foresight exercises, is that the signals gathered can and do have wildly different implications depending on the perspective from which they are viewed. Therefore, a major recommendation is that the exercise continues to be participatory and follows a multi-stakeholder approach.

The following recommendations aim to streamline Horizon Scanning activities in the specific context and needs of the EIC in light of a bigger ambition of turning it into a systematic and institutionalised intelligence-gathering process. This Section is divided into broader recommendations that consider the scope and strategic integration of Horizon Scanning in the EIC, and more specific suggestions to improve the design and flow of workshops. In this last group, we consider not only the role of the JRC (or any other partner delivering such exercises) but most specifically the conditions that the EIC needs to guarantee internally for a more impactful exercise.

5.2 Process scope and strategy and workshop preparation

5.2.1 Timeline

There are a few additional recommendations that might be suggested as the EIC assesses its future use of strategic foresight in the wake of the current Horizon Scanning exercises. However, perhaps most important among these suggestions is to ensure that the exercise and the results are delivered in a timely fashion, on a schedule that aligns with the EIC's internal drafting and work programme deadlines.

For results to be useful, ample time must remain available for the EIC's PMs to properly integrate insights from foresight work into their calls, including time and resources to conduct any follow-up information gathering or internal checks and assessments.

If the results from this Horizon Scanning project are any indicator, there may certainly be broad areas for investment that cut across different PM portfolios and compliment those areas that are more sector-specific. However, if these potential synergies are not recognised with enough time to coordinate across drafting efforts, then capitalising on these opportunities becomes more difficult.

5.2.2 Expert panels

To facilitate the timely deployment of strategic foresight activities, namely Horizon Scanning workshops, the EIC could consider the creation and support of one or more standing expert panels that would be available on short notice to create, review and discuss strategic foresight-derived knowledge and insights.

A single panel pool might be created, allowing diverse and relevant expertise to be brought to bear on a given area on an ad hoc basis. Alternatively, PM portfolio-specific standing panels might be created and regularly convened at prescribed intervals. Membership of such panels or expert pool might be decided via peer recommendation, or open to a more voluntary process, with sensitivity to diversity and inclusion parameters, and reflect the representativeness of different stakeholder profiles and demographic categories. Potential targets might range from leading scientific experts to EIC beneficiaries.

Furthermore, membership might have strict term limits, or be temporary and based solely on the needs of the EIC within its present PM portfolio mix. There are many ways to conceive of the expert panel institution, and certainly more time should be committed to understanding the optimal structure for such panels given the unique and dynamic needs of the EIC and the role played by EIC PMs in mobilising and capturing the most valuable resources in their respective ecosystems.

5.2.3 Comprehensive EIC PM portfolio coverage

In this project, the Horizon Scanning process was applied to six of the EIC's PM portfolios, and the analysis of the results of this process revealed potential synergies that might guide EIC decision-making as to its internal organisation. As mentioned previously, robotics & automation, artificial intelligence, biomimicry and biological processes, and materials sciences were all identified as research and innovation areas that offer benefits across the PM portfolios.

Briefly looking at the portfolios that were not included in this Horizon Scanning exercise, we might already see some synergies reinforced and new fields for cross-sector opportunities. Absent from this Horizon Scanning were the following four PM portfolios:

- Health and biotechnology
- Medical technologies and medical devices
- Energy systems and green technologies
- Advanced materials for energy and environmental sustainability

The European Health Union has been the guiding document in prioritising the health of EU citizens and creating a more prepared and resilient European health system, implying that an anticipatory approach to health is valued and necessary. In combination with Europe's commitment to the global One Health Joint Plan of Action (put forth by the FAO (Food and Agriculture Organisation), WHO (World Health Organisation), (UNEP (United Nations Environment Programme), UNEP (United Nations Environment Programme), and WAOH (formerly OIE) which supports environmental health as a key component of human and animal health, it has become clear that there is momentum in taking a proactive and anticipatory approach to identifying and nurturing areas where crossover benefits might be found. As an example, the EIC's *Food Chain Technologies, Novel & Sustainable Food* programme portfolio would be able to contribute to overall European health and the One Health initiative, but it might also benefit from some of the medical advances that are also being pursued in research labs across the EU.

Similarly, a brief analysis of the Energy Systems and Green Technologies, and the Advanced Materials for Energy and Environmental Sustainability PM portfolios would seem to compliment the cross-cutting areas revealed during this Horizon Scanning process. It is easy to imagine that both the Space and AEC PM portfolio's interest in both novel materials and energy systems would align well with that of these programmes.

Extending Horizon Scanning and sense-making activities across EIC would seem to offer a more robust set of identified signals and offer the opportunity to capitalise on cross-cutting R&I areas. Horizon Scanning and sense-making can help foster beneficial communication across the EIC PM portfolio teams and continue to build an organisational culture of shared wins and collective vision.

Having all of this in mind, the extension of Horizon Scanning to the full scope of the PM portfolios does not necessarily mean replicating the exercise individually for each one. An alternative and/or complementary approach could be to run these workshops following thematic clusters, joining PM portfolios that share bigger policy and technology domains (e.g. Health, Energy, Sustainability, etc.) or approach it through the angle of common enabling technologies. Additionally, through discussions with experts from across PM portfolios, new synergies might be identified that outline novel areas or fields in which R&I might be fostered via the EIC or other instruments.

Finally, new PM portfolio areas could be identified through Horizon Scanning or other anticipatory processes and established within the EIC programme. This was already demonstrated by the cross-cutting or enabling technologies that were highlighted in this report, as well as in the literature review also developed for the ANTICIPINNOV project[47] where thematic fields not explicitly covered by PM portfolios were identified (e.g. Mobility and Blue Economy).

5.2.4 Participatory scanning and analysis

As noted in Chapter 2 when outlining the state of the art of Horizon Scanning, the shift toward automation has had mixed results. Text and data mining techniques allow for greater breadth of scanning in a short amount of time – enabling analysis of a large corpus of textual resources that would be impossible for a team of humans. However, when engaging in the sense-making process of these analyses, it would seem that a more nuanced and expert human perspective remains invaluable to the process of Horizon Scanning.

During these Horizon Scanning exercises, the text and data-mining activities consistently matched or exceeded the number of signals discovered via the expert-based submissions. That said, there seemed to be a discrepancy between the signals being used from the two competing research modes. In

47 Farinha, J., Vesnic Alujevic, L., Alvarenga, A. and Polvora, A., Everybody is looking into the Future! A literature review of reports on emerging technologies and disruptive innovation, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/144730, JRC134319.

many EIC PM portfolio groups, participants noted that TIM (tools for innovation monitoring) results occasionally:

- were a bit vague or too much high-level,
- represented technological advancements that were either already well known or had very high TRLs (technology readiness levels),
- did not capture the most recent developments within a specific sub-field.

Given that the expert submitted signals enabled most workshop discussions, participatory scanning should continue to be carried out often and by a larger and more diverse pool of experts relevant to each field. Therefore, while automatic scanning of signals is a useful complementary tool, at this moment, it should not be seen as a replacement.

Nevertheless, this approach does not mean that there is no room for progress in data and text-mining outputs, which could be achieved by both improving the digital process through AI integration (see next recommendation) and providing a reinforced layer of expert analysis of results in advance to the workshops (as also suggested later in this chapter).

5.2.5 Integrating AI into horizon scanning processes

Horizon Scanning processes have been used to chart the potential of AI in fields of education and development[48], and to foster effective and ethical development of the field[49]. More recently, a new generation of AI systems are being deployed to support Horizon Scanning itself.

Generative algorithms based on large language models (LLMs) are currently shifting the way humans interact with text, including in activities such as searching for information and creating new statements (e.g. Chat GPT, Bard, etc.). While generative capacities built from foundation models are expanding the applications of AI systems, we should consider the possibilities of what they might be able to produce if trained on an EIC data set and other relevant sources of signals:

- Could the system reliably identify weak signals from a given corpus?
- Could they be useful as novelty engines - scanning the extreme spaces of R&I and dreams for radical innovations just over the horizon?
- Could such a system help generate new types of expert prompts for horizon scanning activities?
- Or even rapidly iterate 'innovations' from its own generative ideation process - ideas that could then be checked by human expertise for feasibility, existing literature, etc.?
- Are these technologies more than just stochastic parrots50?

While generative AI adds another tool to Horizon Scanning's signal collection and analysis processes, it also introduces a new layer of complexity. We know that these generative systems are still prone to 'hallucinating' - and in cases like ChatGPT this can include the fabrication of facts, events and evidence51 to support whatever claims it has already produced.

Nevertheless, it is worth recommending the experimentation of such tools in the context of the EIC foresight exercises. While the generative aspect of these systems may prove valuable in creative and speculative activities such as imagining combinations of innovations across multiple fields of research, it seems that for the time being these system applications will be most useful as tools to inspire or provoke humans, but not replace them fully.

5.3 Workshop deployment

The Horizon Scanning workshops were clearly appreciated by participants from across six stakeholder groups, with positive feedback

48 Nemorin, S., Vlachidis, A., Ayerakwa, H. M., & Andriotis, P. (2022). AI hyped? A horizon scan of discourse on artificial intelligence in education (AIED) and development. *Learning, Media and Technology*, 1-14.

49 Hollenberg, L (2018). Quantum Machine Learning. Input paper for the Horizon Scanning Project 'The Effective and Ethical Development of Artificial Intelligence: An Opportunity to Improve Our Wellbeing' on behalf of the Australian Council of Learned Academies, www.acola.org.

50 Bender, E. M., Gebru, T., McMillan-Major, A., & Shmitchell, S. (2021, March). On the Dangers of Stochastic Parrots: Can Language Models Be Too Big?. In *Proceedings of the 2021 ACM conference on fairness, accountability, and transparency* (pp. 610-623).

51 Choi, Jonathan H. and Hickman, Kristin E. and Monahan, Amy and Schwarcz, Daniel B., ChatGPT Goes to Law School (23 January 2023). Journal of Legal Education (Forthcoming), Available at SSRN: https://ssrn.com/abstract=4335905 or http://dx.doi.org/10.2139/ssrn.4335905.

received from participants and EIC PMs alike. While some recommendations might be entertained in designing future Horizon Scanning activities, these are to be considered as additional to an already streamlined process.

The objective of this last set of recommendations goes slightly beyond the role of the EIC, when partnering with external entities such as the JRC to deploy Horizon Scanning. But being aware of these factors, and contributing to improve the process, would foster the quality and take-up of the outputs and outcomes.

5.3.1 Time constraints

At the end of some of the workshops, some participants would regularly state that the conversation would benefit from more time allocated to each of the discussion rounds. This is a common comment to hear when engaging in foresight workshops, and generally is viewed as signifying that participants find value in the activities being conducted.

It should be acknowledged that the time of each participant is valuable, and that a 3-hour workshop is already a rather large commitment of personal resources. But further reflection could also emerge on the possibility of extending workshops to an entire day or two half days (7-8 hours). This last option could entail having the workshops set apart by a significant period to allow the results of the first workshop to be analysed and factored into the second.

5.3.2 Categorisation/clustering

One design change to explore is greater participation in the arrangement of clusters and categorisation of the collected signals. This might be done by having the EIC PM more actively engaged at this stage and/or inviting more than one expert to review pre-clustering work before the workshop, or in a separate workshop activity that assumes a longer workshop format.

A clustering exercise for the expert participants, or a collective review of initial categorisations derived from the Horizon Scanning team, can accomplish a few things.

For one, a clustering exercise conducted by the PM and/or the expert participants would confer the benefit of creating categories or clusters that are labelled with titles that clarify the most relevant areas and sub-areas of different research and innovation directions. Potential categories might be gathered as early as the initial scanning survey and could be the initial inputs for the cluster/categorisation activity.

A second benefit of engaging with this activity is that it is a chance to remind participants that the Horizon Scanning method is undertaken to look for signals that bear larger promise or peril in the time horizon indicated. This message cannot be overstated during the Horizon Scanning process and can help reinforce the longer-term focus of the participants in the activities that follow.

While the act of clustering can help to organise the results of various scanning modes, the discourse around naming clusters/categories and using these as an information organisation scheme is also a future-oriented activity - particularly if these discussions and clustering actions begin outlining novel areas where research and innovation streams intersect and reinforce one another. Allowing for more than one round of signal clustering/categorisation is therefore recommended.

Finally, a third benefit directly associated with increased engagement of the PM at this stage would be to help to clarify and reinforce the scope of the PM portfolio itself, as well as to explore potential synergies with other PM portfolios or focus each exercise on smaller set of issues encompassed in the PM portfolio. This last option was already tested in the Solar Fuels and Chemicals workshop by excluding for instance certain fields related to hydrogen use.

5.3.3 Drivers, enablers, barriers – ‘futures triangle’

This exercise was introduced after the two pilot workshops to distinguish the signals and discussions connected directly with concrete technologies and innovations, and the inputs more connected with contextual factors (usually linked to larger domains).

As this last set was not the priority output, the EIC and JRC agreed that it is nevertheless important to capture and summarise discussions around these topics, as they allowed important policy issues to be traced. Therefore, the first and more overarching recommendation is to explore in further exercises how these outputs could enrich the feedback for policy processes that the EIC aims to provide to the EC.

Additionally, there are a couple of more methodological comments to be made on this part of the workshop process. Firstly, this activity was introduced as a derivation of the futures triangle - a methodological approach first devised to engage a group with a 'mapping of the future' or an environmental scan[52]. During stakeholder deliberations, participants discuss their view of the future through three dimensions - topics that are pushing, pulling, and weighing down the future[53].

This process aims to build a collective and more comprehensive view of the future from the present perspective. The *image of the future* is that which pulls the present towards a more specific future state[54]. This is not necessarily a preferred state, it is the image(s) of the future held by the group being engaged[55]. Quantitative measures and trends make up the pushing factors that are also influencing the direction of STEEP factors as they change. Lastly, weights are identified aspects of the present that are usually specific to the image of the future (the *pulling* aspect) - these can be framed as barriers, obstacles, or inertia, but they are consistently identifiable in the present (or at least they can be agreed upon as such by some of the stakeholder participants).

While the version of the triangle presented in the workshop does acknowledge these terms in the visualised activity board, the concept of the image of the future was left unmentioned. Given the time constraints that were already faced in the Horizon Scanning workshop, and the focus of the workshop on signal prioritisation, it is understandable that the concept of the *image of the future* was not introduced.

However, given that Horizon Scanning is not itself sufficient to create anticipatory policy or decision-making[56], it would be important to mention that both the triangle and the Horizon Scanning process are components of a larger alternative futures and foresight procedural approach to anticipation. Such an admission would foster an understanding of the current Horizon Scanning process and its relation to the goals of the EIC and their alignment with the Commission's strategic foresight activity.

As the triangle in these workshops has been introduced as a redesign of the initial futures triangle, then locating the activity within this larger process would also honour the methods initial conception. Indeed, even recent publications that claim to have redesigned the futures triangle method situate it as the activity with respect to the processes of scenario planning, not as a standalone activity[57].

Recommendations for the futures triangle activity would be to include it as part of the initial workshop, as an initiation activity to help frame the discussion of signal clustering (and the Horizon Scanning results). This relocation of the activity reinforces the extended time horizon and allows for some portion of time in the Horizon Scanning workshop series to discuss the images of the future.

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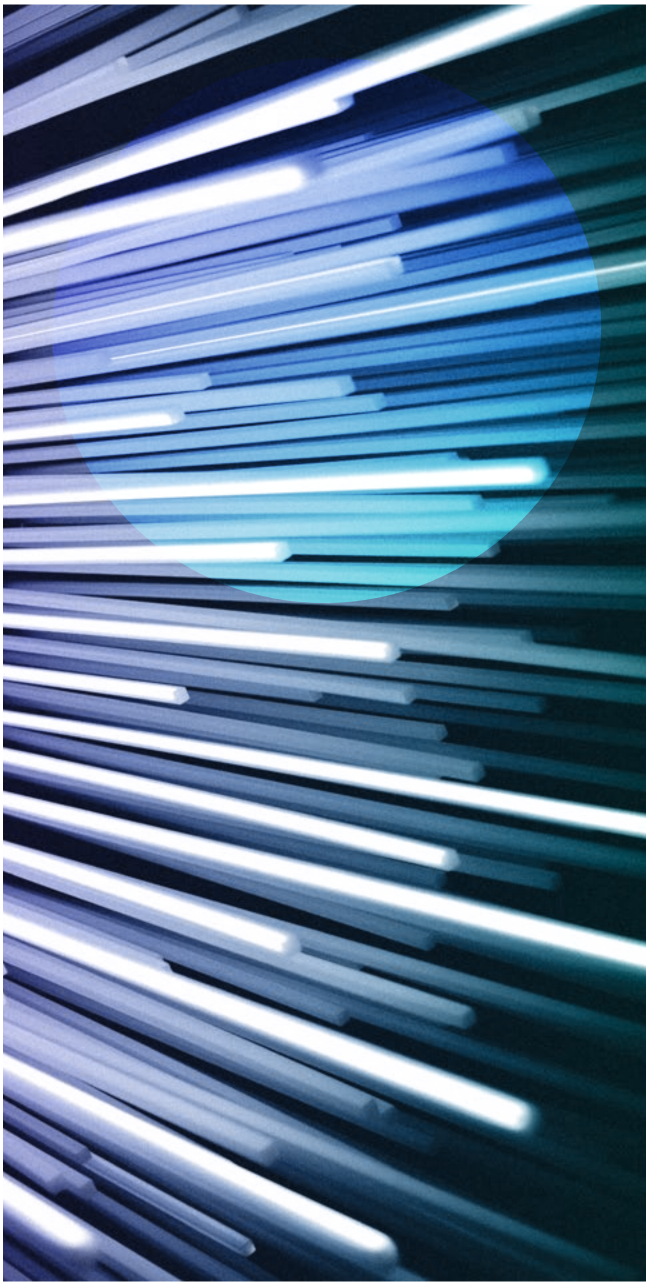
5.3.4 Further foresight methods

As mentioned above, Horizon Scanning and the futures triangle activities are not sufficient to enable productive strategic foresight by themselves. While Horizon Scanning activities by themselves do not necessarily hinge on one or more images of the future, when the sense-making process of the collected signals begins, images of the future begin to play an important role[58]. If they are unacknowledged, their role is likely to be implied by the sense-making, but not clearly stated, thus giving the results of the horizon scan a particular future-oriented bias. As a way to counter this, it is recommended to give some practical overview of the alternative futures perspective that is at the heart of all strategic foresight activities. This could be accomplished through:

- An introduction of archetypal images of the future.
- The use of reference foresight scenarios with potential wide application across the Commission and several policy domains[59].
- A simpler scenario process that can introduce the need for thinking in alternative futures with respect to sense-making of Horizon Scanning results.

While the typical Horizon Scanning project does not encompass additional foresight activities like scenario building, a simpler approach opening up the idea of possible alternative futures and the agency that stakeholders have in shaping a preferred future could be pursued. For that purpose, another report provided for in the ANTICIPINNOV project[60] raises possibilities of other foresight activities in the specific context of the EIC.



58 Könnölä, T., Salo, A., Cagnin, C., Carabias, V., & Vilkkumaa, E. (2012). Facing the future: Scanning, synthesising and sense-making in Horizon Scanning. Science and public policy, 39(2), 222-231.

59 Vesnic-Alujevic, L., Muench, S., Stoermer, E., Reference foresight scenarios: Scenarios on the global standing of the EU in 2040, Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/490501, JRC132943.

60 Vesnic-Alujevic, L., Farinha, J., Polvora, A. (eds). Technology Foresight for Public Funding of Innovation: Methods and Best Practices, Publication Office of the EU, Luxembourg, 2023, doi: 10.2760/759692, JRC134544

List of abbreviations

AEC	Architecture, Engineering and Construction
AI	Artificial Intelligence
ANTICIPINNOV	Anticipation and monitoring of emerging technologies and disruptive innovation
CCFOR	JRC's Competence Centre on Foresight
CCTMDA	JRC's Competence Centre on Text Mining and Data Analysis
ChatGPT	Chat Generative Pre-trained Transformer
CO_2	Carbon Dioxide
EC	European Commission
EIC	European Innovation Council
ERCEA	European Research Council Executive Agency
EU	European Union
GDP	Gross Domestic Product
IoT	Internet of Things
JRC	Joint Research Centre
ML	Machine Learning
PATSTAT	Patent Statistical Database
PM	Programme Manager
R&D&I	Research, Development and Innovation
R&I	Research and Innovation
SCOPUS	Elsevier's abstract and citation database of peer reviewed scientific journals
STEEP	Social, Technological, Economical, Environmental and Political
TIM	Tools for Innovation Monitoring
TRL	Technology Readiness Level

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