Myllylä and Kaivo-oja
European Journal of Futures Research (2024) 12:2
https://doi.org/10.1186/s40309-023-00223-z

European Journal of Futures Research

RESEARCH ARTICLE

Open Access

A hybrid foresight study of the environmental reference laboratory system in Finland: a foresight study for the Government of Finland

Yrjö Myllylä[1*] and Jari Kaivo-oja[2]

Abstract

This article presents a hybrid foresight study using the Delphi methodology. The study is part of a strategic research project of the Finnish state named "Foresight in Environmental Reference Laboratory Operations." The main starting point for this study was the Policy Delphi method, which was supplemented with other Delphi variants and decision support methods. In this hybrid foresight application, Delphi methodology was combined with decision-making and strategic planning tools, namely (1) SWOT analysis, (2) Boston Consulting Group Matrix, (3) research infrastructure (RI) analysis, (4) platform analysis, and (5) integrative foresight workshop. This article draws strongly on the hybrid foresight methodology perspective of foresight tool orchestration. The authors argue that the Delphi methodology gains reliability and appeal with hybrid methodological orchestration. The function of reference laboratories includes services for the verification and maintenance of the quality and validity of environmental measurements, such as the maintenance of reference measurement equipment, expertise, and training, and the organization of national reference measurements as well as participation in international reference measurements, method development, and standardization. The study shows the importance of environmental reference laboratories addressing the following challenges by 2030: (1) new measurement targets, such as the diffusion of nanomaterials, microplastics, and drugs in both nature and the food chain and the environmental impact of recycled materials and indoor air issues; (2) automation of measurement activities and transition to technologically advanced measurement systems; (3) citizens' opportunities to participate in the production of information about their environment through new technologies; (4) preparing for the incorporation and internationalization of laboratory operations; and (5) the concentration of measurement service business.

Keywords Hybrid foresight, Delphi method, SWOT analysis, Boston Consulting Group Matrix, Research infrastructure (RI) analysis, Platform analysis, Integrative foresight workshop, Decision-making and strategic planning tools, Reference laboratory

*Correspondence:
Yrjö Myllylä
yrjo.myllyla@utu.fi
[1] Finland Futures Research Centre, Turku School of Economics, University of Turku, Turku FI-20014, Finland
[2] Finland Futures Research Centre, Turku School of Economics, University of Turku, Tampere Office, Åkerlundinkatu 2A, Tampere 33100, Finland

Introduction

Foresight supports decision-making. It is important to find suitable methods for each decision-making situation and need. When foresight data is collected and interpreted using various foresight methods, a more reliable picture of the factors affecting decision-making is obtained. This constitutes so-called hybrid foresight. The Delphi method and its variants are widely used and increasingly common in foresight research. However, there is relatively little scientific literature on hybrid foresight in general and especially on the Delphi method as a part of hybrid foresight.

This hybrid foresight study presents a challenging decision-making situation, where maintaining the reliability of environmental measurement operations in the long term is essential as various change trends, such as (1) technological development, (2) maintenance of supply security, and (3) internationalization challenge the reference laboratory field. The focus of the foresight study was to promote the reliability and quality of measurement operations as part of the environmental measurement ecosystem. This research paper presents five different combinations of foresight methods or foresight and analysis methods to anticipate developments in the field and to identify priorities for further action to support decision-making. In these methodological combinations, the Delphi method and its different variants are one of the key methods. The research paper presents why and how different combinations of methods have been used and what are the key results obtained with these combinations. Based on the study and results, recommendations for the development of environmental reference laboratory activities in Finland will be presented.

A project "Foresight in environmental reference laboratory operations" was included in the Finnish Government's study and research plan in 2018. The objectives of the project were to (1) identify the key change factors affecting reference laboratory activities, (2) identify the impact of key factors on the role of reference laboratory operations in the future, (3) clarify the common intention of different actors in their future roles, (4) identify central value sites in reference laboratory operations now and in the future, (5) identify different operational models by which the pressure of operational change factors can be solved, and (6) present the impact of reference laboratories now and in a planned time set in future. The review time span was set at 10–15 years, practically by 2030.

Key concepts are *reference laboratory*, *hybrid foresight methodology*, and *environmental measurement*. *Reference laboratories* serve other laboratories in maintaining quality and competence. The tasks of reference laboratories include, among other things, the maintenance of reference measurement equipment and expertise. *Foresight* can be crystallized as a visionary view of the future that supports decision-making. *Hybrid foresight methodology* combines two or more methods used in foresighting (see for example [37, 46]). Hybrid foresight is also related to triangulation, where a phenomenon is studied with multiple foresight methods in order to reach a more reliable picture of the phenomenon. The study makes use of a wide definition of "environment," encompassing both the natural to the built environment.

Research material was produced by a hybrid foresight application. The Delphi methodology was augmented with tools used in decision-making and strategic planning: (1) SWOT analysis [49], (2) Boston Consulting Group Matrix [4, 37, 56], (3) research infrastructure (RI) analysis [15, 27], (4) platform analysis [59], and (5) integrative foresight workshop [30]. The 1st interview round of the Delphi panel was conducted face-to-face as themed interviews with open questions, with the themes largely consisting of the research questions. Sixteen people participated in the 1st round. The 2nd Delphi interview round was conducted using a structured interview form (Table 1). Half the experts were interviewed face-to-face, the rest by phone or in written form. Thirty-four top experts participated in the 2nd round. After this, 29 experts participated in active work in a foresight workshop.

Chapter 1 highlights the research goals and the problems to be solved, key concepts, review time span, and the composition of the material. Chapter 2 introduces ten research questions. Chapter 3 discusses the methodology used, with emphasis on the Delphi method as a means to obtain and further develop expert knowledge. Chapter 4 introduces applied variants of the Delphi method as well as other used decision-making and strategic planning tools within the framework of Rafael Popper's Futures Diamond model. In addition, justification for the use of each method is given.

Chapter 5 presents the key results of method hybrids used: 5.1 results of SWOT analysis, 5.2 results of BCG Matrix, 5.3 results of RI analysis, 5.4 results of platform analysis, and 5.5 results of integrative and interactive workshop: key scenario analysis. In Chapter 6.1, Delphi variants and other methods used are brought together as a summary of methodological solutions. Chapter 6.2 provides key STI policy recommendations. Also, the key results in terms of technological development are discussed, and recommendations related to innovation policy are made. Chapter 7, "Summary," brings the research together using Snowden's model of fully-fledged foresight.

Research questions

In foresight research, there must be a clear need for decision-making, which is supported by foresight research. Because the starting point for the study was a mandate from the Finnish Prime Minister's Office, technology foresight deviated from mainstream requirements. Based on the research questions, combinations of foresight methods were selected to best answer each question. If the questions are not asked in more detail, there is always

Table 1 The interest-competency matrix to select Delphi panelists and the participants of the second Delphi round

Interests **Competence**	**Business operators** (technology suppliers, equipment suppliers, software suppliers, operators, laboratories engaged in service business)	**Reference laboratory representatives** (IL, SYKE, THL, STUK, VTT Oy, LUKE, Evira, GTK, TTL)	**Public actors** (e.g., ministries, ELYs, National Emergency Supply Agency, parliament)	**In total panelists**
Air, water, living nature, non-living nature, built environment, environmental health	11	12	11	34

IL Finnish Meteorological Institute, *SYKE* Finnish Environment Institute, *THL* Finnish Institute for Health and Welfare, *STUK* Radiation and Nuclear Safety Authority, *VTT Oy* VTT Technical Research Centre of Finland Ltd., *LUKE* Natural Resources Institute Finland, *Evira* Current Finnish Food Authority, *GTK* Geological Survey of Finland, *TTL* Finnish Institute of Occupational Health, *ELYs* (Regional) Centres for Economic Development, Traffic, and the Environment a risk that the research challenges in the foresight project will not be answered or cannot be answered, because they are simply not known among the research implementers. The foresight study sought answers specifically to the following research questions.

Question 1 Do National Reference Laboratories produce results and effectiveness, where the activity is aimed at different customer groups' viewpoints (e.g., citizens, business, administration)?
Question 2 Have potential impact benefits been ignored or not realized? Why?
Question 3 Do activities have conflicting impacts and effects that eliminate positive outcomes?
Question 4 In what ways are new technologies and societal changes expected to affect the industry and thereby the role of reference laboratories? What is the time horizon?
Question 5 Which factors support development? What can be seen as future challenges for the industry? Which emerging topics deserve attention?
Question 6 What are the requirements for responding to changes in the operational environment (organization, ways of working, forms of cooperation, adaptation to measurement paradigm changes)? Is there a need for the industry to create its own platform economy models?
Question 7 How do Finnish reference laboratory activities and their development relate to other EU countries' efforts and organizations? Could the Finnish reference laboratory cluster be profiled as a key research infrastructure in the EU? Does the Finnish reference laboratory cluster meet the new EU GSO criteria?
Question 8 How have foreign actors prepared for the operational changes brought along by new technologies or new global value networks and platforms?
Question 9 Is it possible to see disruptive operating models emerging in the industry, for example, due to the development of platform economy, globalization, and digitalization?
Question 10 Do alternatives for contemporary legal forms of organization exist? Can new business and management innovations be found in this area?

The list of research problems was long. The questions show that decision-making needs were relatively well structured. This list of questions helped the research team to design a hybrid foresight study. The Cynefin Framework is a decision-making model by Snowden and Boone [54], which is a useful sense-making and knowledge management framework that shows that a versatile use of research methods is well suited to such a complex research problem. According to the Cynefin Framework, there are four decision-making situations: (1) simple decision-making (simple systemic contexts: the domain of best practice), (2) complicated decision-making (complicated contexts: the domain of experts, identifying cause-and-effect relationships), (3) complex decision-making situation (complex contexts: the domain of emergence—where this article focuses), and (4) chaotic systemic contexts (chaotic contexts: the domain of rapid response, where you should not anticipate but act) (see [26, 28, 54]). When scenario analyses are presented, they are typically linked to complex contexts.

Of the foresight methods used in the research, the Policy Delphi method produced answers especially to research questions 1–5, 8, and 10. The Delphi-SWOT method produced answers especially to research questions 1–2, Future workshop-BCG to research questions 4 and 9, and the Delphi-RIA to question 7. The Delphi-Platform analysis produced answers especially to question 9 and the Delphi-Futures workshop to questions 1, 4–6, 9, and 10. The methodological advantage of hybrid foresight is that it provides comprehensive answers to broad research questions.

Hybrid foresight study

The Delphi method served as a core methodology of the hybrid foresight method, which was combined with other methods or analytical tools to form a full family of hybrid foresight tools. The Delphi method was like an operating system for other prediction methods and analysis tools. Therefore, it is worth taking a closer look at the origins and different variants of this method. Why is the hybrid Delphi approach needed? To get a reliable picture of phenomena, triangulation is needed. The phenomenon needs to be viewed from several different expert perspectives (e.g., [22], (Kaivo-oja and Roth: Strategic foresight for competitive advantage: a future-oriented business and competitive analysis techniques selection model, forthcoming), [46]). A diversity of perspectives is needed in information acquisition, methods, and theories.

In the so-called Arenas project in 2010 and 2011, the EU assessed regional foresight practices in 27 countries [9]. The so-called Labour Force and Education Needs Survey from Southwest Finland was highlighted as an exemplary regional foresight practice [9]. There were four factors in this foresight practice that influenced the choice of approach. First, companies were connected to the process through interviews. Second, educational institutions and other necessary actors were connected to the process through a sector-specific foresight workshop. Third, the survey used the Hybrid Delphi approach. Fourth, value was given to the productization of the method so that it could be done in public-private collaboration (see [39]).

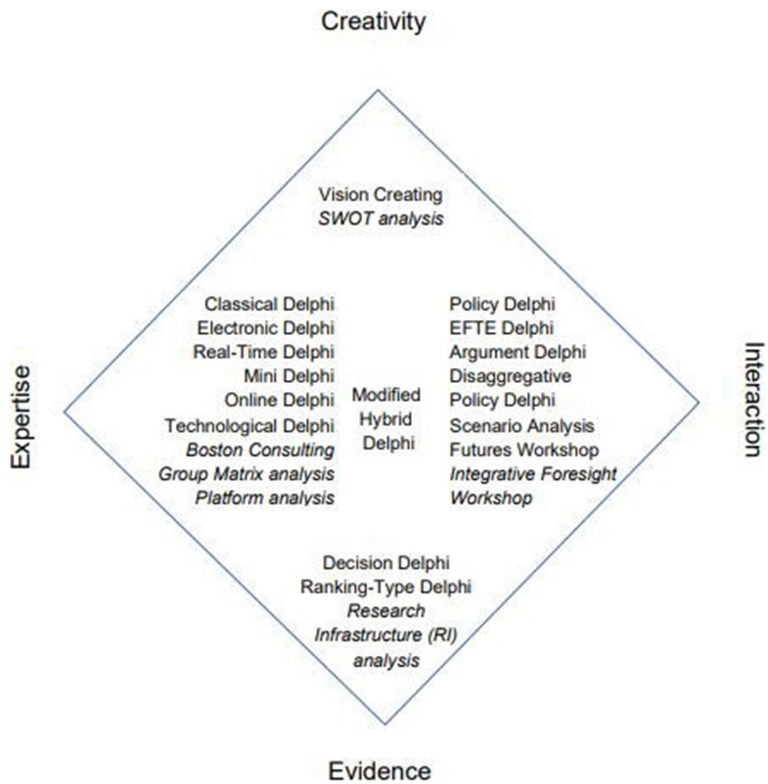

Fig. 1 Futures diamond model applied in this study. Foresight methods used in the project "Foresight in Environmental Reference Laboratory Operations" (compare to [3]; see also Table 4)

Figure 1 shows the project foresight methods and their location in the different dimensions of the Futures Diamond model (see (Kaivo-oja and Roth: Strategic foresight for competitive advantage: a future-oriented business and competitive analysis techniques selection model, forthcoming), [46]). This practice increases the transparency of this study. In this study, we considered the Delphi method and foresight workshop as so-called operating systems that allow the sharing of very different methods, i.e., hybrid foresight. Methodologically, we did not rely solely on Delphi. Other methods used were the Boston Consulting Matrix, the SWOT analysis, the platform method, and the research infrastructure evaluation method. In the participatory foresight workshop, experts carried out scenario-building analyses and vision creation with the facilitators' support. The key results and findings are reported in this article. Next, we shortly explain additional hybrid foresight methods applied in this study.

The Delphi method

Rauch [50] has suggested a distinction between three kinds of Delphi method variants: (1) Classical Delphi [7, 18], (2) Policy Delphi [20, 31, 32, 41, 60], and (3) Decision Delphi [50]. He describes Classical Delphi as the "well-known basic Delphi approach to obtain a group opinion through an anonymous, multilevel group interaction" (see [50], p. 160). The classical Delphi method serves as a forum for facts to seek a consensus among homogeneous groups of experts.

In contrast, the Policy Delphi method serves as a forum for ideas seeking to generate the strongest possible opposing views. It is a tool for the analysis of policy issues and not an approach for decision-making [31]. According to Seker [53], other known Delphi variants are electronic Delphi [36], modified Delphi, ranking-type Delphi [52], real-time Delphi [14], disaggregative Policy Delphi [58] EFTE Delphi [29, 42, 53], mini Delphi, online Delphi, technological Delphi, and argumentation Delphi.

Typical methodological elements of Delphi studies have been trend analysis, scenario analysis, and cross-impact analysis (CIA) (see, e.g., [5, 44]). Delphi applications typically form the core of the expertise component in the Futures Diamond method selection framework, the other components being interaction, creativity, and evidence [46]. A good survey about the integration of Delphi methodology and prediction market analyses has been created by Prokesch et al. [48]. When we studied relevant Delphi studies in scientific journals, we noticed that scenario analysis was most often used in connection with the Delphi method (for example, [8, 23, 34, 45, 61]).

It is essential to carefully choose the operating system for the SWOT analysis, the PESTEV/STEEPV analysis, megatrend analysis, weak signal analysis, scenario analysis, Boston product matrix analysis, etc. Real-Time Delphi variant allows combining most of the above into a single process while gaining the benefits of the Delphi process to influence the outcome. The stakeholder analysis performed at the beginning of the process guides the selection of Delphi panelists and participants in the foresight workshop. In particular, the so-called interest-competency matrix (e.g., [17]) (Table 1) is of note.

The SWOT analysis

The SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis assesses the strengths of organizations. The SWOT analysis was originally developed by Albert S. Humphrey [21] in the early 1960s. It is a quadrilateral method used to formulate a strategy and to identify, evaluate, and develop learning or problems. It is a useful and simple tool for planning organizational activities and projects. The SWOT analysis records analyzed issues: internal strengths, internal weaknesses, external opportunities, and external threats.

The Boston product portfolio matrix approach

The starting point for the Boston product portfolio analysis is that products have a life cycle (see [19, 37]). This can also be seen in the case of technologies and the products and services based on them. The product name, service, technology, cluster, or similar can be substituted for the word "product" in BCG analysis. The following theory text is not directly targeted to the reference laboratory context. For example, no reference laboratory involved in this research is a company, and the results of the study do not indicate that this would be desirable even according to the entrepreneurs who participated in the second Delphi panel.

(1) "Question mark" (sunrise area, "start up"), emerging, market share or volume is slight from the operator's viewpoint, but growth is fast. Next, the product may change into
(2) *a* "Star". Its market share is high, it means a lot to the operator, and its growth rate is high. However, the product is not necessarily productive yet but demands external financing, cash flow that comes from
(3) "Cows" (sources of cash flow). Products included in this category are large clusters or industries which have great market share or volume from the operator's perspective. Margins are small but the volume generates the most important cash flow for the operator at that moment, among other things for the development of the star products and question mark products. Star cluster products will eventually become cow products if the development efforts are properly targeted. The fourth group is
(4) "Pets" or "Stray Dogs," with a small market share or volume and growth rate. These products should not necessarily exist, they represent the end of the product's life cycle and a timely waiving of them could be justified.

The National Reference Laboratory approach

The activities of the National Reference Laboratory (NRL) and its development appear to be largely parallel to other EU countries examined (France, Germany, Sweden). Reference laboratory activities in these countries are government-funded, feasible in research institutes, and networked with each other [38]. In most countries, the starting point has been to name a specialized (research) institute as a reference laboratory for a sub-sector (e.g., surface water, groundwater, and waste water), but some reference laboratories have been chosen through competitive tendering.

In France, the AQUAREF Consortium of five institutes (www.aquaref.fr) is the reference laboratory for aquatic environmental chemistry. The mandate of the AQUAREF Consortium is written into national legislation, and the majority (70–80%) of the reference laboratory activity costs are financed from the state budget. In Germany, the reference laboratory system is distributed to several state institutions in environmental chemistry. The mandate of these state-run institutions is based on national legislation. In Sweden, also universities are involved. The Atmospheric Science Unit (ATM) of the Department of Environmental and Analytical Chemistry, University of Stockholm, has been designated as the reference laboratory for air quality. On a broader level, Sweden has introduced a platform called "Kvalitetslandet" to facilitate discussion and cooperation between different quality management actors (https://kvalitetslandet.se/).

The platform approaches

The development of open-minded business is nowadays particularly linked to agile management and development of platform economy models (see, e.g., [25]). Five sub-sectors of the platform economy have been identified (see [6]), where changes are worth following in order to anticipate possible developments in the platform. They are (1) data, (2) networks, (3) infrastructure, (4) community(s), and (5) marketplaces.

Questions about data include the following: From where is data collected? Where is data stored? Who Owns Data (cf. EU Open Data Strategy and Finnish Open

Data Service, www.avoindata.fi). In addition, the reliability of data (also cybersecurity), the availability and sharing of data (e.g., in machine-readable form), and the harmonization of data are essential. Networks often operate between hierarchies and markets and are a little more formal than communities. Questions linked to infrastructure: Where are the laboratories located? Are they firm or mobile? The community is a community of everyday social interaction, which includes, among other things, subcontracting and development cooperation. Marketplace questions: Where to buy products? Where are they sold? Here, the laboratory activity in environmental measurements is examined in general. The development of laboratory activities in terms of operating models will also have an indirect impact on reference laboratory activities.

Participatory foresight workshops linked to the hybrid foresight process

The experts of the research group used the Delphi-SWOT analysis to create scenario dimensions based on six themes. These dimensions served as pre-scenarios and were used as a starting point for an integrative future workshop. During the workshop, the content and vision of the scenarios were developed.

Participatory foresight workshops feature innovation. The initial brainstorming session produces ideas from which, based on the working group's vote, a topic is selected for further work. Experts can also partly differ between the Delphi panel and the expert workshop. For example, the time of employers and company representatives is more easily managed through conventional expert interview methodology. In the foresight workshop, the choice of participants will have a bit more emphasis on public sector actors. Combining various foresight methods will best involve all parties in the review. The workshop also supports the networking of actors, which is necessary for anticipating the future to implement results and strategic choices (see Table 2).

Justification for the Delphi methodology as an operating system combined with other analytical tools (Hybrid Delphi)

Answers to the research questions were sought by integrating Policy Delphi with other foresight and analysis tools. The Delphi method was used as an operating system for expert knowledge. In the applications, the Delphi methodology is combined with expert knowledge analysis tools: SWOT analysis, BCG Matrix, Research Infrastructure analysis, Platform analysis, and Integrative Foresight Workshop. This procedure is called the Hybrid Delphi Method or, more broadly, the Hybrid Foresight Method. The authors argue that the results of the Delphi method thus used are more reliable than without the described methodological combination. Still, many of today's foresight studies rely on a single methodology, which can be considered a questionable approach.

Fully fledged hybrid foresight model

The use of hybrid methods is a valid procedure as judged by this study. The evolution of the Delphi method and Delphi variants should be taken into account in Delphi studies. When Delphi managers design research and questionnaires, they should be aware of various Delphi variants. All but one (Disaggregate Delphi) of the variants [12] were covered in this study.

When planning Delphi studies, it would be worthwhile to learn from the numerous studies that have been carried out over the years. When talking about Delphi variants, it is legitimate to use the hybrid foresight method. If a hybrid foresight study is made, multiple Delphi variants should be orchestrated. The Hybrid Delphi approach is connected to the mixed method approach. In this study, methodological triangulation has taken place in practice [24].

The basic idea in fully fledged foresight is that the three pillars must be thought through carefully, or the foresight project will almost certainly fail. The fully fledged foresight model supported the success of this study (Fig. 2).

In this study, the methodological pillars of fully fledged foresight are (1) Hybrid Foresight model, which combines Delphi variants and other strategic working methods; (2) network analyses: networking took place particularly in connection with the Delphi expert panel, but also in the foresight workshop; and (3) decision-making process: the challenge was systemic complexity, the starting point was the Cynefin framework [54]. In addition, there were obvious other methodological elements, as some issues were compared with each other, especially as regards the review of the platform economy and the European research infrastructure elements.

Regarding networking, it was challenging to produce a SWOT analysis. The analysis provided some interesting results. Usually, a SWOT analysis is done from the perspective of one organization. In this case, the evaluation was done as a joint evaluation of many actors. Building a vision is usually challenging because it is a manifestation of a state of will. Lack of a clear vision in an organization often leads to unfruitful strategic work. In the research, it was possible to create common thematic visions for reference laboratory activities in the Finnish environmental sector. The research provides a good basis for the long-term development of reference laboratory operations.

The key themes in the research were research infrastructure (RI) and the platform issue, which has not been studied much in general with forecasting methods,

Table 2 Hybrid foresight study with integrated Delphi methods

	Why?	How?	Goals and process
Delphi-SWOT	A reliable picture of the factors of the SWOT analysis is obtained. The authors are ranked in order of importance in the final analysis according to the Delphi panel. The alternative strategies created based on the SWOT analysis thus created are on a reliable basis.	In the first round of the Delphi panel interview, SWOT factors are devised, which are prioritized in the second round of the Delphi panel in order of priority. The Delphi-SWOT analysis also influenced the selection of themes and dimensions of the scenarios to be worked on for the Futures Workshop.	Goals: support expert workshop implementation and link comprehensive expert discussions with the SWOT analysis. Process: follow the logic of various Delphi variants and research questions.
Future workshop-BCG	In the 2030 situation, radical technologies affecting environmental measurement activities could be grouped into product baskets according to the BCG analysis: sunrise, star, dairy cow, and pet product baskets. Based on the joint assessment of several experts, the result is on a more reliable basis than the result of the reflection of an individual expert.	In the BCG analysis, the Futures Workshop participants selected the most important issues from the list of 100 radical technologies identified by Linturi and Kuusi [33] affecting Finland.	Goals: help experts in technology foresight discussions in the project. Identify the most important radical technologies. Process: combine the most important radical technologies and then implement a comprehensive Boston Consulting Matrix analysis.
Delphi-RIA	With the help of the Delphi method, the most important factors are selected from the RIA factors that are the most relevant to be developed in the context of the research theme for the development of environmental measurement activities.	The factors given in the second round of the Delphi panel interview based on the first Delphi round were prioritized by the panel.	Goals: combine the RIA factors with the expert assessment of Delphi panel experts. Report all critical RIA assessment results to the expert foresight workshop. Process: combine the RIS assessment with the Delphi expert panel assessments.
Delphi-platform analysis	The aim was to find out how important the five aspects of the platform economy presented by Choudary [6] are: (1) data, (2) networks, (3) infrastructure, (4) community, and (5) marketplaces are important for environmental measurement activities.	Five factors were placed for evaluation by the three interest groups in the Delphi panel and the Delphi subpanel, and the results of the groups were compared with each other. The groups included representatives of reference laboratories, private actors, and public administration actors.	Goals: combine the platform analysis to expert assessment of Delphi panel experts. Report all critical platform analysis results to decision-makers. Process: combine the platform analysis with the Delphi expert panel assessments.
Delphi-Futures Workshop	The Delphi method reveals real problem areas, which will be deepened in a future workshop.	The six key themes that emerged in the Delphi panel were raised as scenarios to be worked on in the future workshop and further as visions chosen by the workshop groups.	Goals: support scenario analysis and strategic SWOT discussions with expert knowledge of the Delphi panel. Process: combine the Delphi expert panel assessments and results with all hybrid foresight studies and results.

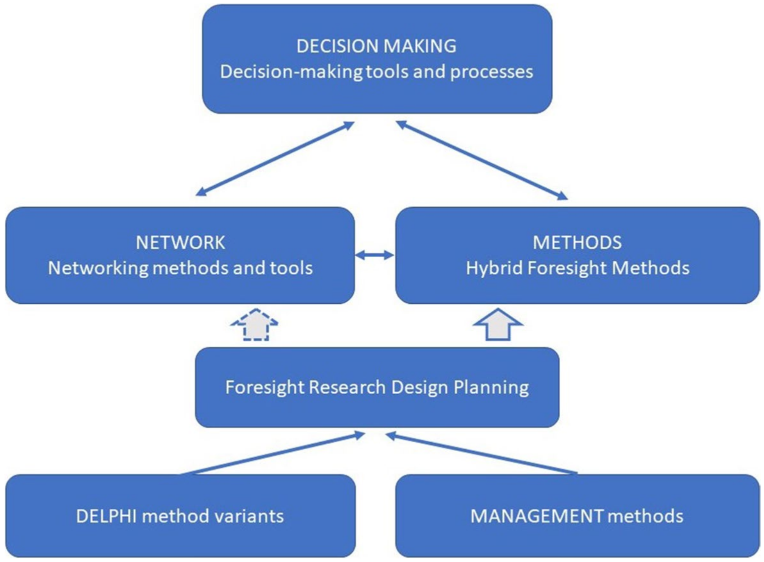

Fig. 2 Fully fledged hybrid foresight model

especially in relation to laboratory functions. Also, according to our knowledge, the BCG model has not been previously applied to reference laboratory operations in the environmental field in this way (compare [37]).

The results answered the research problems that were set. Answers were received to questions related to complexity, which were the challenges of environmental reference laboratory operations in Finland. As a result, it was possible to produce strategic action plans and crystallize them into thematic statements. We gained more strategic understanding and defined visions. The effectiveness of the method is also demonstrated by the fact that the policy recommendations raised have led to action. This can be seen as a specific goal of foresight research in general (see, e.g., [13]) and in particular in this Prime Minister's Office foresight study, which aimed to solve practical problems using foresight information.

Projects in line with the policy recommendations have been launched, e.g., in the measurement of microplastics, in environmental measurement monitoring related to the circular economy, and in indoor air measurements. Efforts have been made to promote new rapid measurement technologies by reference laboratories, taking the reliability of new measurement activities into account.

The COVID-19 pandemic has also demonstrated the validity of supply security scenarios and the chosen vision with security awareness. At the national level, there must be reference laboratory activities at measurement sites that are critical to supply security, so that the volume of measurement activities can be scaled up relatively quickly with expertise.

The Laboratories 2030 project and its background

Foresight into environmental reference laboratory functions has been carried out as a part of the Finnish Government's implementation of the 2018 Survey and Research plan (VN TEAS project, Dnro, PMO/1804/48/2017). In the plan, proposals were sought under the heading *The social change of reference laboratory function in environmental measurement.*

Reference laboratories have a service mission that includes quality and competence validation and maintenance services such as education, consultancy, quality assessment, method development, infrastructure maintenance, and standardization. National Reference Laboratories (NRLs) are set up by ministries for specific administrative needs. NRLs exist in several research institutes and public authorities. Central government reform and digitalization will bring additional changes. According to Pouru et al. [47], we need more foresight looking into alternative future developments and desirable futures. We should actively seek and promote desired systemic changes.

Methods and key results

This section provides answers to research questions 1–10. As already noted above, the core methodological elements of the hybrid foresight study were the Delphi methodology variants combined to other carefully selected and relevant methods (see Fig. 1).

Key results of Policy Delphi Study

The Policy Delphi method was applied in the PESTEV analysis of strong prospective trends and in identifying

STRENGTHS		OPPORTUNITIES	
The quality of the operation and reliable information	4,96	Ensuring reliable environmental information.	4,63
Low level of corruption, neutrality.	4,48	Responding to new measurement needs.	4,38
Knowledge and its tradition.	4,43	Increasing knowledge and laboratory infrastructure.	4,08
Impact on environmental knowledge and reliability.	4,26	Utilizing digitalisation and new technologies.	4,04
Long reliable time series on the state of the environment.	4,22	Education and communication to bring about change.	3,92
International appreciation.	3,96	Utilization of cumulative (eg Big data) data.	3,92
National matrices (sampling types).	3,78	Navigating at the interfaces and importing new information.	3,79
Mutual cooperation.	3,74	Strengthening the role in environmental health measurements.	3,71
Finnish way of working, culture.	3,13	Business support / ecosystem thinking.	3,54
		New profile as a clear public function (service).	3,46
		Utilizing county reform, communication.	2,92
WEAKNESSES		**THREATS**	
Lack of resources.	3,96	Confirmation/ absence of resourcing.	4,21
Slow response to customer requests.	3,63	Uncritical, non-alternate corporate incorporation.	4,00
Managing new methods and technologies.	3,63	Decrease in practical know-how.	3,71
Cost/ expences of operation.	3,63	Monopolisation of environmental laboratory activities.	3,67
Lack of communication.	3,46	Disaster/ Supply Maintenance.	3,63
Alienation of experimental culture.	3,00	Doors open outwards - the challenge to recruite talent.	3,58
		Tendering of reference laboratories.	3,33
		Political policies.	3,25
		Reference laboratories do not recognize their role.	3,17
		Provincial reform is breaking ties.	2,67

Fig. 3 SWOT analysis of a reference laboratory for environmental measurements. The results are based on the evaluation of the second round of the Delphi panel, respondents 23–24—(weight 1–5, where 1 = not important, 2 = slightly important, 3 = moderately important, 4 = fairly important, 5 = very important)

weak signals and wild cards and their impacts on the most important measurement targets. For example, the most significant change trends were corporatization, privatization, and concentration of laboratory operations, new measurement needs, the prevalence of on-line measurement, and big data. On the other hand, identified wild cards were environmental disasters and the development of artificial intelligence. Microplastics in the environment, the environmental effects of recycled materials, and indoor air issues emerged from the new measurement targets [38]. The following presents more detailed results of Delphi methodology having been combined with other analysis tools used in decision-making and strategic planning: (1) SWOT analysis, (2) Boston Consulting Group Matrix, (3) research infrastructure (RI) analysis, (4) platform analysis, and (5) Integrative Foresight Workshop.

Key results of SWOT analysis

In the pilot interview phase, Delphi panelists carried out a free-form reference laboratory operation SWOT analysis. The highlighted variables were listed for the second Delphi interview round. The panel gave the factors a value of 1-5, 1 being non-important and 5 being very important. Based on this, a SWOT analysis was created in which the factors were prioritized. In both interview rounds, verbal arguments were also collected as justifications for the SWOT factors using the eDelphi platform, and the SWOT factors with their justifications were sent to expert panelists, who evaluated them critically for final justifications. The key results of the SWOT analysis are presented below and summarized in Fig. 3.

Strengths

The reference laboratories' influence on producing environmental information was considered very important. The low level of corruption as well as knowledge and tradition gained importance. Quite important strength factors were also the impact on the environmental status information and its reliability, more generally reliable time series of environmental status information, international appreciation, national matrices (sampling types), and mutual cooperation. The collaboration between reference laboratory actors is a noteworthy strength.

Weaknesses

The following factors were highlighted as relatively weak: lack of resources, slow response to customer needs, lack of control over new methods and technologies, and cost of operation. Government austerity measures have also been seen as an ongoing uncertainty and are also reflected in laboratory activities and functions.

Opportunities

Ensuring reliable environmental status information continued to be the single most important opportunity factor. Quite important opportunities included responding to new measurement needs, increasing expertise and laboratory infrastructure, utilizing digitalization and new technology, collaborating with device manufacturers, exploiting cumulative (e.g., Big Data analytics) knowledge, navigating interfaces, bringing new knowledge to actors, and strengthening their role in environmental health measurements. For example, research programs (including EU programs) and participation in them were seen as important opportunities for increasing knowledge.

The data also highlights the importance of public-private partnerships from many different angles. Public-private partnerships are useful and efficient for innovation ecosystems and value networks. In Finland, Harmaakorpi and Rinkinen [16], Ståhle and Pirttivaara [55], and Santonen et al. [51] have investigated the emergence of new ideas, inventions, and innovations. New innovations, products, and services increasingly emerge through global value networks and innovation ecosystems as co-creations of numerous actors. As a result of the development of global value networks, the importance of national clusters has diminished and the need for cross-regional and sectoral cooperation has clearly increased. Innovation ecosystems are dense, dynamic, and self-directed networks where openness, interaction, and interdependence are stronger than in conventional networks and clusters.

Threats

Uncertainties in resourcing were seen as the main threat. Other threats included uncritical and discriminatory incorporation of laboratory activities, loss of practical know-how as service business moves to private organizations, monopolization of environmental laboratory activities, uncertainties in maintaining supply security, and challenges in recruiting experts. Supply security refers to the continuation of high-quality and adequate measuring operations in exceptional circumstances such as nuclear disaster, bankruptcy of an international metrology company, bioterrorism, or the like. Lack of resources or challenges in securing them can lead to a declining attractiveness of the sector and present a threat to knowledge. This in turn affects, inter alia, the maintenance of supply security. On the other hand, as the service business shifts more and more to private companies, there is a threat of practical know-how being reduced.

SWOT analysis makes it possible to draw up clear strategic guidelines for decision-makers and stakeholders. It also provides an updated assessment of the status quo. Typically, there is a desire to further strengthen strengths and to eliminate weaknesses. We usually want to seize opportunities and combat threats. Because there were several stakeholders in the project, the SWOT guidelines had to be tailored and, of course, not all stakeholders could be given the same strategic guidelines. Therefore, the foresight workshop wanted to openly discuss a possible vision with six different themes. The SWOT analysis influenced which themes were taken into the Integrative Foresight Workshop for scenario review. This critical choice was made in the researchers' workshop before the Integrative Foresight Workshop.

Key results of the Boston Consulting Matrix

Linturi and Kuusi [33] presented 100 radical technologies that will have the greatest impact on Finnish society by 2037. Of all these, the Delphi panel prioritized 14 key technologies that are most essential in environmental reference laboratory operations. Based on the Delphi panel's mentions, the most important radical technologies were (1) new differentiation techniques and the circular economy and (2) radical increase in computing power. Cloud computing and storage services came third. The production of fresh water was mentioned fourth. The foresight workshop ranked these 14 technologies according to the BCG analysis. Due to the pre-selection of key technologies, no factor entered the pet category (see [37]).

According to the foresight workshop, by 2030, the most obvious widespread, employable, and financial surplus technologies relevant to reference laboratories are computational power growth, cloud computing and storage services, freshwater production, quadcopters and other flying drones, real-time 3D perception techniques of environment, new commodity/substance manipulation techniques, and the ubiquity of the environment and the Internet of Things (Fig. 4).

In order for the above technologies to be in a position consistent with this analysis by 2030, there is a current need for development measures to support them. Similarly, star products, i.e., rapidly growing technologies that are relatively widespread already in 2030, will require investment today. Star products may not be fully profitable due to growth efforts. These technologies include new separation technologies and circular economy, biochips or Lab on chip technology, nano cells, neural networks,

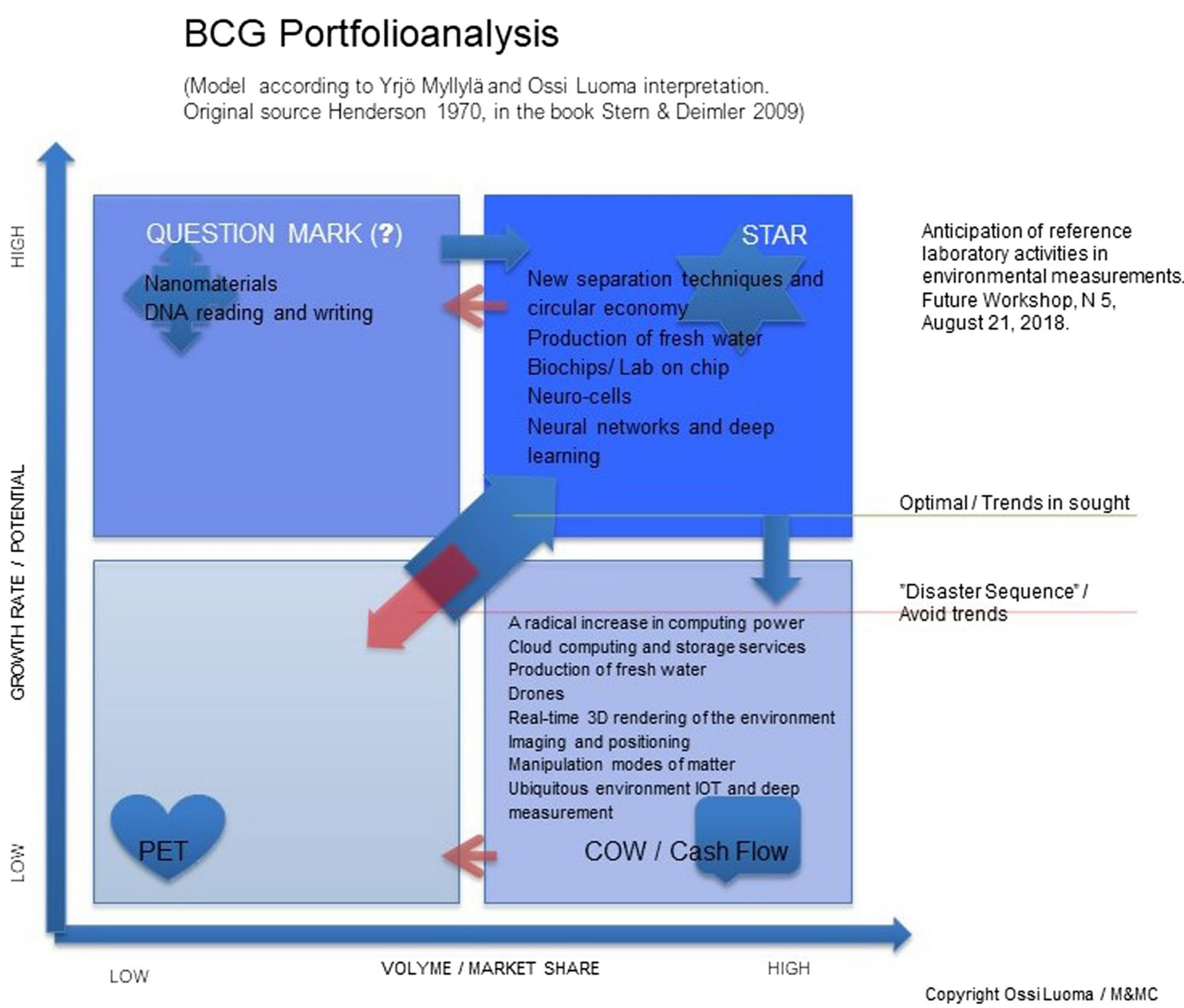

Fig. 4 Boston Consulting Group (BCG) product portfolio analysis of radical technologies affecting the reference laboratory for environmental measurements. Analysis done at Future Workshop

and deep learning. The detailed content of these technologies was described during teamwork based on the study by Linturi and Kuusi [33].

Key results of European research infrastructure analysis

The Delphi panel tested the importance of meeting the 14 GSO criteria in Finnish laboratory infrastructure by 2030. Of these criteria, the following were considered at least fairly important: data exchange procedure, core purpose, integrated financial planning, international mobility, partner agreement, existence of e-infrastructure and development area, scheduling, and cost model.

In Table 3, we report the results of GRI questions [15]. These are key results of European research infrastructure (RI, the GSO Framework) analysis.

Table 3 provides decision-makers with a priority list of development needs related to research infrastructure. The most strategically important are (1) data exchange procedure, (2) the core purpose for networks, (3) financial planning (integrated), and (4) international mobility and communication. In addition, fairly important are (5) partner agreements for networks, (6) the existence of e-infrastructure, and (7) the development area, scheduling, and cost model. No issue was classified as an area of great importance. This study used the EU's official RI criteria for the 1st time ever in the evaluation of Delphi panel experts. The evaluation showed that the criteria worked properly. The list could be used more widely in the development of science and innovation policy in the RI agencies of the European Union.

Table 3 Development needs research infrastructures by expert evaluation ($N = 7$)

Laboratory infrastructure components	Index
Data exchange procedure	4.29
The core purpose for networks	4.29
Financial planning (integrated)	4.14
International mobility and communication	4.00
Partner agreement for networks	3.71
Existence of E-infrastructure	3.57
Development area, scheduling, and cost model	3.57
Clustering of research infrastructure	3.29
Evaluation procedure at regular intervals	3.29
Project management model	3.29
A systematic framework for assessing socio-economic effectiveness	3.00
Technology transfer and IPR management procedure	3.00
Admission procedure for potential new members with GEA criteria	3.00
Preliminary agreement on a possible...	3.00

Index explanations: 1 = not important, 2 = little important, 3 = moderately important, 4 = fairly important, 5 = great importance

Osmo Kuusi has presented that even a very small group of experts can be a working solution in a Delphi expert panel study. In a Delphi study, anonymity is important, but even a group of three people can be sufficient [29]. Few experts think about the fact that there are often only two reviewers in scientific article review processes as well.

Key results of platform analysis

According to the second Delphi round, by 2030, most (or at least quite a bit of) environmental measurements will include changes in the way data is collected, with further changes expected in networks and laboratory infrastructure. Some stakeholders also see changes in the community. By contrast, no significant changes are seen in marketplaces (see results in Fig. 5). These questions were addressed by three different interest groups. The groups were reference laboratories, private operators, and public operators. In data collection, public operators see less changes than private operators or reference laboratories, but the differences are not very big. In networks, on the other hand, public actors see more changes by 2030 than private operators. This could be explained by the fact that operators emphasize changes in their operations, indicating that public sector operators have the greatest pressure for changes in their networking.

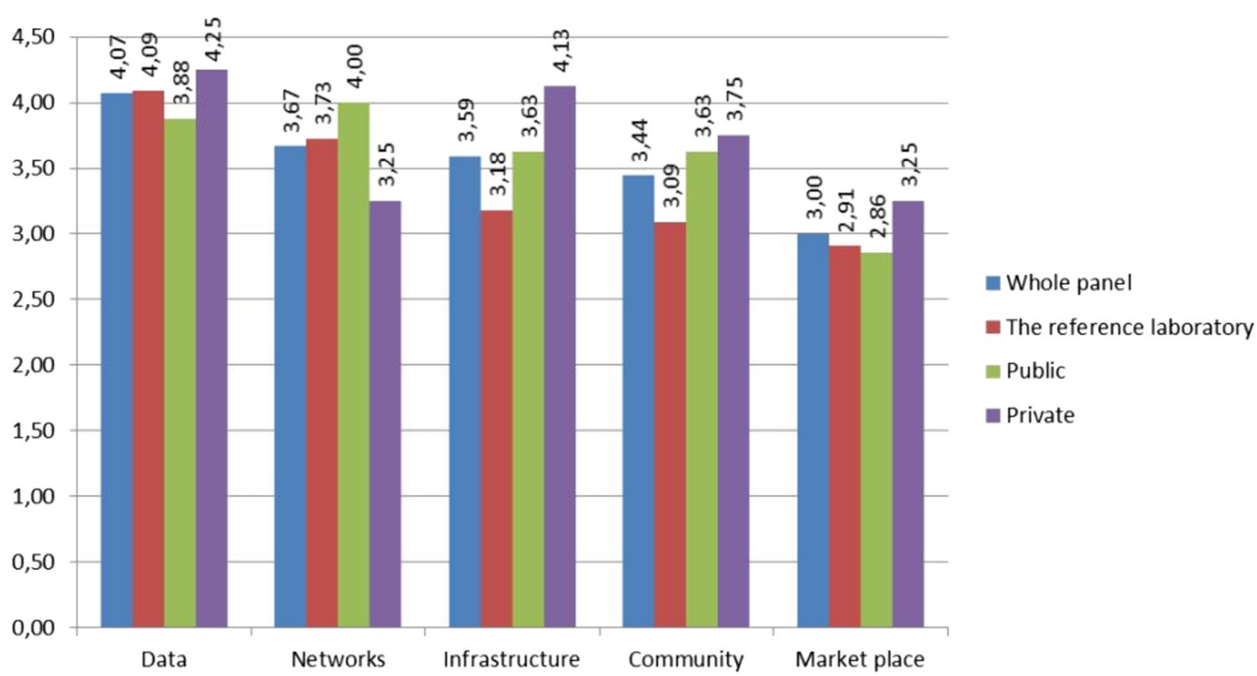

Fig. 5 Disruptive operating models in environmental measurement reference laboratories. The results are presented on the basis of the Delphi expert-panel 2nd round interview estimates (weighting 1–5 with 1 = no change, 2 = little change, 3 = moderate change, 4 = fairly change, 5 = very much change)

The importance of the platform economy cannot be overlooked when developing reference laboratory operations. Digital platforms and the platform economy are seen as significant changes that also affect companies operating in Finland. They can be divided into three groups: broader policy actions, specific actions by public authorities to promote the platform economy, and industry-specific interventions [2]. Five elements (pillars) form the fundamentals of the platform economy (Fig. 5).

According to the panel, the biggest changes are in data (Where is data collected? Where is data stored? Who owns data?), in networks (national and international), and thirdly in infrastructure (Where are the laboratories located, mobility, etc.?).

The reference laboratory interest group in the Delphi panel estimates that changes to the industry by 2030 relate especially to data collection and ownership. Secondly, the reference laboratory operators highlighted the changes in national and international networks. The private sector interest group also estimates that the biggest changes are related to data and secondly to infrastructure and thirdly to communities, such as development community, subcontracting and customer networks, and other communities like daily network and work relationships. The panel's public actors emphasized changes in national and international networks, secondly in everyday networks (development community, subcontracting, customer networks), and thirdly in infrastructure (location of laboratories, mobility, etc.).

Ville Miettinen [35] divides business platforms according to Gawer's [11] typification into (1) internal company platforms, (2) supply chain platforms, (3) multi-party platforms, and (4) industry platforms. An internal platform addresses a company's internal needs. The purpose of a supply chain platform is usually to increase cost efficiency and supplier options. Multi-sided platforms connect two or more user bases and enable cooperation between them. Industry platforms connect companies in the ecosystem. The main purpose of industry platforms is to stimulate innovation in companies operating on the platform.

Key results of Integrative Foresight Workshop: key scenario analysis and vision analysis results

From the 1st and 2nd Delphi rounds, themes relevant to the future development of reference laboratory activities emerged. The key issues related to the themes were crystallized and thematic scenario dimensions were developed on the basis of the material and questions. The task of the foresight workshop was to produce key content for scenario dimensions in three stages. The first phase utilized the Futures Wheel method. The applications of the Futures Wheel included brainstorming on the group's theme and brainstorming on the preliminary content of the scenarios. The aim was to outline the overall picture in thematic working groups. A case example is the visual image produced by the coordination theme group based on the application of the Futures Wheel (see Fig. 6).

In the second phase, the idea/theme produced by the futures wheel was refined using the ACTVOD future table. The ACTVOD table was used to select a possible and desired scenario related to the theme. The scenarios were tentatively structured for the thematic groups according to Table 3. The purpose of the work phase was to complete an ACTVOD Table. The ACTVOD analysis examines Actors (A), Customers (C), Transformation (T), Values (V), Obstacles (O), and Drivers (D) in relation to the scenario (see details of this methodology in [30]).

In the third phase, a vision of the selected scenario option and related follow-up measures were developed. The goal was to create a desirable and possible scenario or a vision of the chosen scenario. Vision and the path leading to it were described as a result.

The vision of reference laboratory activities in environmental measurements can be summarized as follows: Versatile (public-private, national-international, research-training-administration) and coordinated cooperation ensures reliable environmental measurements. Reference laboratory activities are desired (and achievable) as publicly owned subject and phenomenon-based networked activities. The reference laboratory system has the capacity to acquire and cover new technologies and new measurement objects (incl. indoor air), especially regarding automation and digitalization. Close and natural cooperation between reference laboratories contributes to supply security, which must be actively promoted.

The scenario process was done in the workshop as an interactive, systematic process. The six main themes raised in the Delphi rounds were placed on two scenario dimensions (Table 4). In the workshop, the thematic groups strived to define a theme-specific vision. Figure 7 shows an example of maintenance reliability. A vision normally refers to a mental image of a desired future state or outcome. It can also refer to a statement that articulates an organization's or individual's aspirations, goals, and targets for the future. In both cases, a vision provides a guide or a roadmap to help people stay focused and aligned in pursuing their goals. Visionary leadership is needed in the implementation of strategies with missions (see, e.g., [1]).

Next, we present six thematic visions, that is, subvisions of six themes.

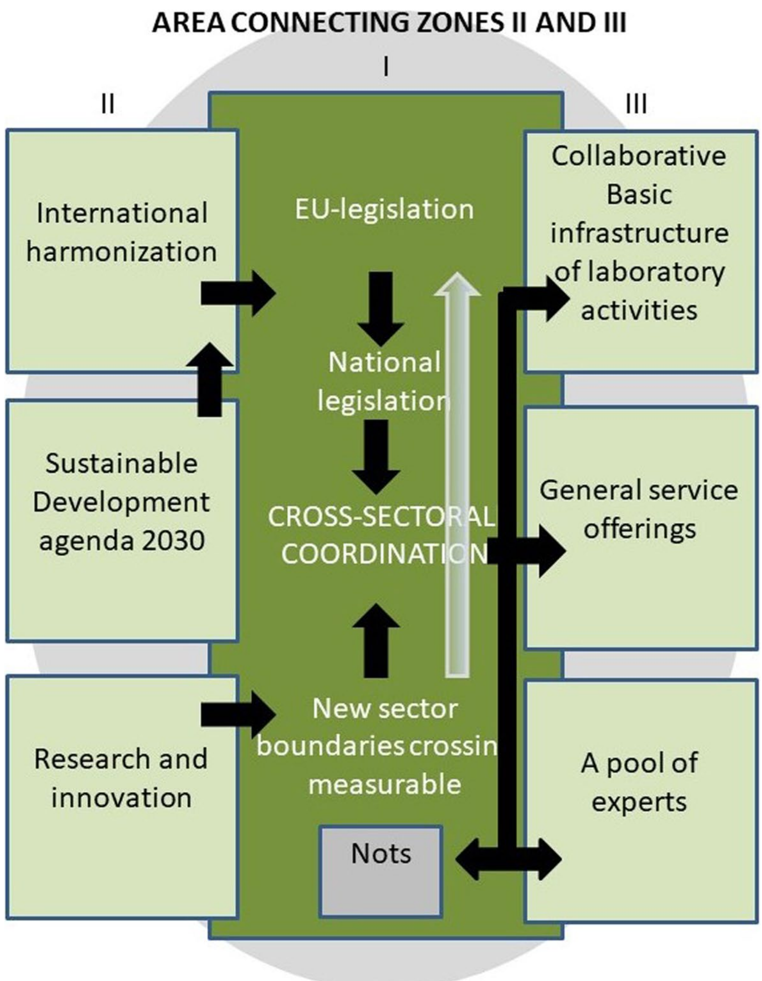

Fig. 6 Coordination of environmental measurement reference laboratory activities in 2030 according to the Future Workshop, Futures Wheel Analysis

Theme 1: Coordination. Coordination of reference activities for environmental measurements in 2030 (see Fig. 5):

Given current and future status options, the dimensions of coordination were decentralized-centralized and weak-strong. The current situation was positioned in a weak-decentralized state. Desired future: Important themes for coordination are legislation (including EU legislation), cross-sectoral coordination, and new measurable cross-sectoral boundaries. The key players are central government (which directs) and agencies and research institutes (which implement). The vision is “a sector-independent, centrally managed and case- and phenomenon-based network.”

Theme 2: Ownership. Ownership of reference laboratory operations for environmental measurements in 2030:

Given current and future status options, the dimensions of ownership were public-private (owners) and national-global. The current situation was positioned in the public-national state. The group ended up with the following desired and perceived future vision and scenario: important key themes are independence, identification of spearheads and focusing, public-private collaboration, and international collaboration. The actors are the public body with a more centralized and internationally respected status and “designated institutes.” The vision is “a more centralized public owner creates Finnish export products from quality.” Developing the export of reference laboratory expertise as a government top project. Resources and activation of political actors.

Theme 3: Technologies. Response of the Reference Laboratory for Environmental Measurements to Technology change until 2030:

Table 4 Themes, key issues, and main dimensions of scenario analysis for the Futures Workshop

Themes	Key questions of workshop topics	*X*-axis/the main dimensions of the scenarios	*Y*-axis/the main dimensions of the scenarios
Coordination	Coordination of reference laboratory activities for environmental measurements in 2030	Distributed or centralized?	Strong or weak coordination?
Ownership	Ownership of reference laboratory operations for environmental measurements in 2030	Owners: public vs. private	Ownership: national vs. global
Technologies	Response of the reference laboratory function for environmental measurements to technological change by 2030	Focus on measurement data collection vs. interpretation	Technology solutions are device-based vs. system-based
BCG-analysis 2030, radical technologies	Ranking of new technologies affecting reference laboratory operations in 2030 in terms of growth rate and scope of operations	Technology volume small vs. large	Technology growth rate high vs. low
New measurement targets	The most important new measures to be taken into account in environmental activities in 2030 in various technology and measurable volume options from the point of view of reference laboratories	Measurable amount small vs. large	Emphasis on technological development: current technologies as a rule vs. new technologies as a rule
Security of supply	How to prepare for the preservation of environmental measurement capabilities in the event of a crisis, what is the role of reference laboratories in 2030?	Readiness to measure: immediate readiness vs. delayed readiness	Taking measurements nationally vs. internationally

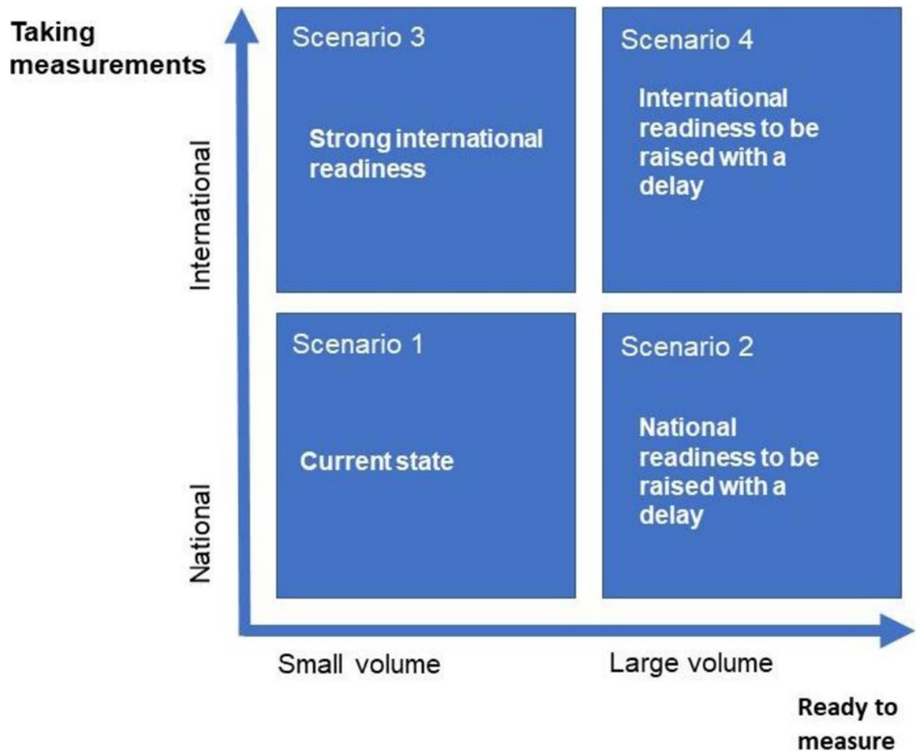

Fig. 7 Security of maintenance scenarios in environmental measurements. The scenario dimensions given as a starting point for the foresight workshop

Given current and future status options, the dimensions of technological change are (1) device-based vs. system-based and (2) data collection vs. data interpretation in data processing. For example, online measurement and automation form a trend that seems to lead in many cases from device-based solutions to system-based ones. The current situation is built for device-based data collection. The group came to a desired and perceived future vision and scenario, where key themes are the ability to identify and take over technologies, ensuring the primary outcome to support decision-making. The actors include equipment manufacturers, companies, surveyors, CSC-type data analytics experts, research institutes, and universities. Vision: "automated decisions for reference laboratories based on measurement results."

Theme 4: Boston Consulting Group Matrix Analysis 2030. Results: Environmental measurement laboratories will be affected by certain radical technologies in which the reference laboratories must have expertise. The significance of these by 2030 was clarified by Boston Consulting Group (BCG) product portfolio analysis. The review dimensions of the BCG analysis were growth rate and volume/penetration of technology diffusion. The idea is that products and technologies have a life cycle; to be successful, operations must have products elsewhere than in the so-called pet group. The options are the so-called sunrise products (or technologies), star products (or technologies), cash flow sources, that is dairy cow products (or technologies), and pets/stray dog products (or technologies). The task of the group was to place the 14 technologies with the greatest impact on reference laboratories by 2030, as identified by the Delphi panel, to the right product group in the analysis. Based on the analysis, it is possible to design measures to promote the adoption of the technologies.

According to the workshop, actors in the introduction of technology are data producers, sensor developers, equipment developers, method developers, reference laboratories, service business laboratories, educational organizations, data users, authorities, and the general public (e.g., cottagers). According to the analysis (vision), new technologies (in the analysis "sources of cash flow") that reference laboratories must be able to meet in 2030: cloud computing and storage services, quadcopters and other drones, real-time 3D visualization of the environment, imaging and positioning, methods of manipulating the substance, producing fresh water, and ubiquitous environment/IOT. In particular, work is now needed to promote and take over these technologies. There is also a need to promote star technologies, such as new separation technologies and circular economy technologies.

Theme 5: New measurable. The most important new measures to be taken into account in environmental activities by 2030 in various technology and measurable volume options from the viewpoint of reference laboratories:

Given current and future status options, the dimensions were current technology vs. new technologies and in measurable quantities small volume vs. large volume. The current situation was positioned with current technologies as a rule and measurable low volume.

The group ended up with the following desired and considered possible vision and scenario: The most important thing in the core circle is need. The actors are legislators, the research community, citizens, companies (equipment manufacturers), and the reference laboratory. The vision is (indoor air as an example) that in 2030, we will manage indoor air problems in homes—understanding the toxin effects, reliable measurement methods, and the national indoor air reference laboratory framework. General vision: collaborative reliable measurements.

Theme 6: Supply security. How to prepare for the preservation of environmental measurement capabilities in the event of a crisis? What is the role of reference laboratories in that in 2030?

Given current and future status options, future dimensions are immediate readiness vs. upgradable readiness and national vs. international measurement. The current situation was positioned in the national-immediate readiness state.

The group ended up with the following desired and possible vision: The network of laboratory operators and the officials are proud and happy. A key part of supply security. The first step is in Finland and then to the world (EU, etc.). Happiness and pride at work make laboratory work so attractive that real experts want to work. As a follow-up measure, building and strengthening the network (e.g., the KELO network). The COVID-19 pandemic showed in Finland that the vision worked. With the help of the research infrastructure and the Finnish Institute for Health and Welfare (THL) reference laboratory expertise, it was possible to scale the need for the volume of measurement activities. Finland survived the pandemic with the least damage (see also [43]).

Future foresight of the reference laboratory in Finland—methodological hybrid machinery and key recommendations

Summary of methodological *solutions*

The Policy Delphi has been used as the main method. Other variants of the Delphi method have also been included. This poses a challenge to the synthesis. The role of different methods in the study is examined in Table 5. The table is based on the classification created by Artur Strasser [57] for Delphi variants. The use of the methods was guided by the research questions and, secondly, by placing Policy Delphi and the foresight workshop in the role of the operating system for the use of other methods.

The Delphi method is often discussed at too general a level. When designing Delphi studies, it is essential to be aware of Delphi variants and how they could be utilized in the study.

When using the Policy Delphi approach and hybrid foresight, it is important to strive for the clearest possible policy brief. The study presented results that serve all relevant stakeholders. There were also results that were specific to certain actors engaged in laboratory activities.

Popper's Diamond model provides a framework for choosing hybrid methods in foresight. One important criterion for hybrid foresight is to consider all four dimensions of Popper's model: expertise, creativity, interaction, and evidence. The hybrid foresight model covers these dimensions, although there are some differences in coverage. The areas that are best covered are expertise and interaction. However, the Diamond model helps ensure that the methods chosen are versatile and capable of meeting all dimensions of the model.

Key science technology and innovation policy recommendations

Technological developments such as online measurement and new measurement targets challenge the internationalization of reference laboratory operations. Online measurement draws attention to the quality of the measurement system as a whole, big data, and the opportunities and challenges posed by mass aggregation. For example, a COVID-19-type pandemic could have been and future pandemics could be averted by systematically analyzing the early signs of the pandemic using, for example, Google's trend analysis tools (see [40]). It is also possible to develop a tsunami-type warning system through the qualifications and training provided by the reference laboratory.

New measurement targets include the need for long-term monitoring of environmental impacts resulting from the circular economy, microplastics in the environment, and indoor air quality. In new measurement areas, such as indoor air quality measurements, it is also possible to develop new ways of organizing reference laboratories, for example, as network-like virtual organizations. As measurement activities become more international, measurement activities take place extensively in the field and the analysis of results is centralized at various points.

Table 5 Hybrid foresight tools. Delphi method variants and other management methods in the hybrid foresight study

Delphi variants and other methods	Used in study	Not used	Comments
Delphi variant			
Classical Delphi [7]	x		The Delphi questionnaire included various key elements of the classical Delphi method like trend assessment, importance assessment, and analysis of weak signals and wild cards.
Policy Delphi [31]	x		Three interest groups were identified in the stakeholder analysis: reference laboratory operators, companies, and administration operators.
Decision Delphi [50]	x		A final policy brief was reported.
Electronic Delphi [36]	x		Using digital Delphi e-tool: www.edelphi.org.
Modified Delphi	x		See Popper's foresight method diamond (Fig. 1).
Ranking-type Delphi [52]	x		In many special research questions, like rating the objects of the measurement activity.
Real-time Delphi [14]	x		Using digital Delphi e-tool: www.edelphi.org.
Argument Delphi [29]	x		In some special research questions, like processing of future images.
Disaggregative Policy Delphi [58]		x	Not used in this study.
EFTE Delphi [42]	x		There were various feedback loops.
Mini Delphi	x		Mini-Delphi was organized to analyze research infrastructure (RI) criteria. Mini Delphi was motivated by the availability of a limited expertise group in this special issue.
Online Delphi [14]	x		Using environment www.edelphi.org.
Technological Delphi	x		Especially in the context of research infrastructure analyses and the Boston Consulting Group Matrix.
Other methods			
SWOT-analysis	x		Combined with Delphi methods.
BCG Matrix	x		Combined with Delphi methods and foresight workshop.
Research Infrastructure analysis	x		Combined with Delphi methods.
Platform analysis	x		Combined with Delphi methods.
Integrative Foresight Workshop	x		Combined with Delphi methods.

These challenges, e.g., national reference laboratories and, in some cases, may dictate joint reference laboratory activities between countries, unless reference laboratory activities are identified as being of particular importance for national supply security and efforts are made to ensure their competence.

Measurement targets must be defined separately, where it is worth maintaining the supply security of measurement activities that are important for society. For example, Finnish test results during the COVID-19 pandemic were initially sent to Asia and later to Estonia as the pandemic continued. How to ensure supply security in crises is an important question. In conclusion, coordination of measurement activities can be recommended. The measurement points where reliability is to be maintained should be defined. In these measurement areas, such as virus and pandemic preparedness, expertise should be maintained to the extent that measurement activities can be scaled as the crisis becomes more widespread. It is also important that the representatives of reference laboratories have sufficient opportunities to participate in international cooperation within the framework of their resources, e.g., technology standardization committees.

The greatest cooperation should be increased with reference laboratories and privately owned laboratories engaged in service business, with publicly owned enterprises engaged in service business. Secondly, cooperation between research institutes and universities should be increased. This is especially important in Finland, as research resources have been transferred from reference laboratories operating in connection with state research institutes to universities.

The service provider or technology manufacturer qualified by the reference laboratory thus obtains the necessary reference required when selling the service or technology. Reference laboratories are such an important part of export and quality assurance from a business perspective. More broadly, they act as quality assurance agents when they are part of, for example, the environmental permit process, so that companies that carry out measurement activities can be trusted. Decisions are then based on correct information, which increases trust in the authorities and other actors.

Reference laboratories have an indirect impact on the quality and safety of our environment. For example, according to data published by the WHO in 2018, air quality in Finland is the best in the world [10]. Confidence in food purity requires reliable measurement activities, where reference laboratory activities play a key role. Finland is also known for its clean waters and the export of water technology, where reference laboratory activities have a key impact. According to an interviewee of the Delphi panel, Finnish reference laboratory activities are currently being exported to a country that has given up reference laboratory activities about 10 years ago. The argument at the time was that private competition was enough to maintain quality. As a result, companies' measurement results became uncertain, environmental permit processing dragged on for years, and investment in the country declined. Now the state took action to reverse the direction and ended up with Finnish reference laboratory expertise.

Research infrastructure analysis and platform analysis showed that the Delphi panel is a good tool for prioritizing the importance and weight of different factors for the phenomenon under study. We conclude that SWOT analysis, BCG product portfolio analysis, research infrastructure analysis, and platform analysis as well as the Integrative Foresight Workshop method improve the reliability, quality, and usability of results in decision-making when combined with the Delphi method.

In the use of expert knowledge, the interest and competence of experts in the phenomenon under study is a key starting point. Experts in the Delphi method should be consciously selected using the interest-competence matrix, in which case the versatility and appropriateness of the expert information for the phenomenon under study can be assessed, as this has a significant impact on the outcome. It is justified to use the same method when selecting participants for foresight workshops and assessing the quality of the workshop results.

Acknowledgements
Foresight into the environmental reference laboratory functions has been carried out as a part of the Finnish Prime Minister Office's implementation plan of the 2018 Survey and Research plan (VN TEAS project, Dnro, PMO/1804/48/2017). In the PM office plan, proposals were sought under the heading *The social change of reference laboratory function in environmental measurement*.
We would like to express our gratitude to the Finnish Prime Minister's Office for giving us the opportunity to acquire the essential material for our research article, which is part of the foresight research project. We also extend our thanks to Dr. Jouko Inkeröinen, the coordinator from the University of Oulu's Kvantum Institute, for being a part of the research planning and implementation during the government commission phase. Additionally, we would like to acknowledge the involvement of the experts who participated in the steering group work of the Finnish Ministry of the Environment and the Ministry of Transport and Communications.
Furthermore, we would like to thank Mr. Leo Westerlund for doing the language check.

Authors' contributions
JK-a was involved in the planning of the study, while YM played the main role as a researcher responsible for the practical implementation of the research and the acquisition of empirical material. YM is the main author of the article and the main presenter of the results, while JK-o's role was primarily focused on writing the theoretical basis. They both jointly wrote "Key science, technology and innovation policy recommendations."

Funding
The acquisition of the research's basic material has been done as a part of the Finnish Prime Minister's Office's implementation plan of the 2018 Survey and Research plan (VN TEAS project, Dnro, PMO/ 1804/48/2017).

Availability of data and materials
The summary material used in the research article is available from the publication "Myllylä et al. [38] Ympäristöalan vertailulaboratoriotoiminnan ennakointi, Tutkimusraportti. Valtioneuvoston kanslian julkaisuja (2018-11-19) [Foresight of reference laboratory operations in the field, Research report, Prime Minister's Office]. From: http://urn.fi/URN:ISBN:978-952-287-612-6."
The interview material is entered into the www.edelphi.org software platform to generate summary data. The platform produces anonymous summary material which is then edited with the Excel software. However, the Excel tables do not add any special value to the graphic form in which the material is presented in the Prime Minister's Office report. The authors can provide the Excel material to the questioner upon request. Please contact the corresponding author, Yrjö Myllylä, for more details.

Declarations

Competing interests
The authors declare that they have no competing interests.

Received: 18 June 2023 Accepted: 17 December 2023
Published online: 31 January 2024

References
1. Abrahamsen MH, Halinen A, Naude P (2023) The role of visioning in business network strategizing. J Bus Res 154:113334. https://doi.org/10.1016/j.jbusres.2022.113334
2. Ailisto H, Collin J, Juhanko J, Mäntylä M, Ruutu S, Seppälä T, Halén M, Hiekkanen K, Hyytinen K, Kiuru E, Korhonen H, Kääriäinen J, Parviainen P, Talvitie J (2016) Onko Suomi jäämässä alustatalouden junasta? Valtioneuvoston selvitys- ja tutkimustoiminnan julkaisusarja 19/2016 From:(http://urn.fi/URN:ISBN:978-952-287-253-1). Accessed date: 7.5.2021
3. Andersen PD, Rasmussen LB (2014) The impact of national traditions and cultures on national foresight processes. Futures 59:5–17. https://doi.org/10.1016/j.futures.2014.01.01
4. Barksdale HC, Harris CE (1982) Portfolio analysis and product life cycle. Long Range Plan 15(6):74–83. https://doi.org/10.1016/0024-6301(82)90010-3
5. Chen K, Ren Z, Mu S, Sun TQ, Mua R (2020) Integrating the Delphi survey into scenario planning for China's renewable energy development strategy towards 2030. Technol Forecast Soc Change 158:120157. https://doi.org/10.1016/j.techfore.2020.120157
6. Choudary SP (2015) Platform Scale: How a new breed of start-ups is building large empires with minimum investment. Platform Thinking Labs, Boston
7. Dalkey N, Helmer O (1963) An experimental application of the Delphi method to the use of experts. Manag Sci 9(3):458–467. https://doi.org/10.1287/mnsc.9.3.458
8. Darkow I-L, von der Gracht HA (2013) Scenarios for the future of the European process industry - the case of the chemical industry. Eur J Futures Res 1(10). https://doi.org/10.1007/s40309-013-0010-9
9. EU Synthesis Report (2011) 27 National Seminars Anticipating & Managing Restructuring. ARENAS-project. European Commission Employment, Social, Affairs and Equal Opportunities, p 159
10. Finnish Meteorological Institute (2018) Finland tops WHO air quality statistics. Press release 7.5.2018. From: https://en.ilmatieteenlaitos.fi/press-release/524196421. Accessed 7 May 2023

11. Gawer A (2009) Platforms, markets and innovation. An introduction. https://api.semanticscholar.org/CorpusID:54173848
12. Glaser B, Strauss A (2017) Discovery of Grounded Theory: Strategies for Qualitative Research. Routledge, London
13. Godet M (1994) From anticipation to action. A handbook of strategic prospective UNESCO Publishing Vendome: Presses Universitaires de France France
14. Gordon T, Pease A (2006) RT Delphi: an efficient, "round-less" almost real time Delphi method. Technol Forecast Soc Chang 73(4):321–333. https://doi.org/10.1016/j.techfore.2005.09.005
15. Group of Senior Officials on Global Research Infrastructure (2017) GSO Framework. Presented to the G7 Science Ministerial Meeting, 27-28 September 2017. Turin, Italy
16. Harmaakorpi V, Rinkinen S (2015) Kohti ekosysteemiperustaista innovaatiopolitiikkaa. Policy Brief 10/2015, Tekes. Helsinki https://cris.vtt.fi/en/publications/kohti-ekosysteemiperustaista-innovaatiopolitiikkaa. Accessed 7 May 2023
17. Heinonen S, Kuusi O, Salminen H (2017) How do we explore our futures?: methods of futures research, vol 10. Acta Futura Fennica, Somero
18. Helmer O (1967) Systematic use of expert opinions, report no. P-3721. The RAND Corporation, Santa Monica. From: https://www.rand.org/pubs/papers/P3721.html. Accessed 7 May 2023
19. Hendersson BD (1970) The product portfolio. In: Stern CW, Deimler MS (eds) (2009) The Boston consulting group on strategy. Classic Concepts and New Perspectives. Second Edition. John Wiley & Sons, New Jersey, pp 35–37
20. Hilbert M, Miles I, Othmer J (2009) Foresight tools for participative policymaking in inter-governmental processes in developing countries: lessons learned from the eLAC Policy Priorities Delphi. Technol Forecast Soc Chang 15(2):880–896. https://doi.org/10.1016/j.techfore.2009.01.001
21. Humphrey AS (1986) Gearing up for change. Manag Decis 24(6):12–15. https://doi.org/10.1108/eb001419
22. Jackson EA (2018) Triangulation. Afr J Econ Manag Stud 9(2):266–271. https://doi.org/10.1108/AJEMS-01-2018-0034
23. Julsrud TE, Uteng TP (2015) Technopolis, shared resources or controlled mobility? A net-based Delphi-study to explore visions of future urban daily mobility in Norway. Eur J Futures Res 3(10). https://doi.org/10.1007/s40309-015-0069-6
24. Kaivo-oja, J., Lauraéus, T. (2017) Knowledge management and triangulation logic in the foresight research and analyses in business process management. In Lorna Uden, Wei Lu, I-Hsien Ting (Eds.) Knowledge Management in Organizations. 12th International Conference, KMO 2017, Beijing, China, August 21-24, 2017, Proceedings. Communications in Computer and Information Science book series (CCIS, volume 731), Springer International Publishing AG, Cham, Switzerland, 228-238
25. Kaivo-oja, J., Lauraéus, T. (2018) Disruption management and the orchestration of dynamic capabilities: seeking dynamic smart disruptor profile. 10th International Scientific Conference "Business and Management 2018" May 3–4, 2018, Vilnius, Lithuania Section: Contemporary Business Management Challenges and Opportunities https://doi.org/10.3846/BM.2018.39
26. Kaivo-oja J, Stenvall J (2013) Foresight, governance and complexity of systems: on the way towards pragmatic governance paradigm. Eur Integr Stud 7:28–34. https://doi.org/10.5755/j01.eis.0.7.4236
27. Knudsen MS, Ferreira-Aulu MB, Kaivo-oja J, Luukkanen J (2021) Energy research infrastructures in Europe and beyond: mapping an unmapped landscape. Eur Integr Stud 15:111–124. https://doi.org/10.5755/j01.eis.1.15.28840
28. Kurtz CF, Snowden DJ (2003) The new dynamics of strategy: sensemaking in a complex and complicated world. IBM Syst J 42(3):462–483. https://doi.org/10.1147/sj.423.0462
29. Kuusi O (1999) Expertise in the future use of generic technologies. VATT Research Reports 59. VATT, Helsinki
30. Lauttamäki V (2016) ACTVOD-futures workshop – a generic structure for a one-day futures workshop. Foresight 18(2):156–171. https://doi.org/10.1108/FS-01-2015-0003
31. Linstone HA, Turoff M (1975) The Delphi method: techniques and applications. Wesley Publishing Company, Reading, Massachusetts, Addison
32. Linstone HA, Turoff M (2002) The Delphi method: techniques and applications (Digital version From: https://web.njit.edu/~turoff/pubs/delphibook/index.html. Accessed date: 7.5.2021)
33. Linturi, R., Kuusi, O. (2018) Societal transformation 2018–2037 100 anticipated radical technologies, 20 regimes, case Finland. 487 p. Publication of the Committee for the Future 10/2018. From: https://www.eduskunta.fi/FI/naineduskuntatoimii/julkaisut/Documents/NETTI_TUVJ_10_2018_Societal_transformation_UUSI.pdf. Accessed date: 3.6.2023
34. Mateu M, Cobo C, Moravec J (2018) Plan Ceibal 2020: future scenarios for technology and education—the case of the Uruguayan public education system. Eur J Futures Res 6:6. https://doi.org/10.1186/s40309-018-0134-z
35. Miettinen V (2017) Arvonluonti alustataloudessa. Pro Gradu tutkielma, Tampereen yliopisto, johtamiskorkeakoulu (From http://urn.fi/URN:NBN:fi:uta-201702061088. Accessed date: 3.6.2023)
36. Mitchell VW (1991) The Delphi technique. Tech Anal Strat Manag 3(4):333–358. https://doi.org/10.1080/09537329108524065
37. Myllylä Y, Kaivo-oja J (2015) Integrating Delphi methodology to some classical concepts of the Boston consulting group framework: arctic maritime technology BCG Delphi foresight—a pilot study from Finland. Eur J Futures Res 3:2. https://doi.org/10.1007/s40309-014-0060-7
38. Myllylä Y, Kaivo-oja J, Inkeröinen J (2018) Ympäristöalan vertailulaboratoriotoiminnan ennakointi, Tutkimusraportti. Valtioneuvoston kanslian julkaisuja (2018-11-19) [Foresight of reference laboratory operations in the field, Research report, Prime Minister's Office] (From: http://urn.fi/URN:ISBN:978-952-287-612-6. Accessed date: 7.5.2021)
39. Myllylä, Y., Marttinen, J., Kaivo-oja, J. (2012) Ennakointi demokratian vahvistajana. Esimerkkinä EU:n palkitsema TKTT-konsepti ja muut kansainvälisessä arvioinnissa esille nostetut suomalaiset ennakointikäytännöt. [Anticipative action as strength for democracy: EU-best practice winner, the TKTT-concept as an example and other best practice foresight models of Finland]. Futura 4/2012. 38-49. From: http://urn.fi/URN:NBN:fi:ELE-1568315. Accessed date: 7.5.2021
40. Myllylä Y, Sajeva M, Kaivo-oja J, Aho S (2011) iKnow Delphi 2.0 Country Report Finland. 104 p. October 2011. iKnow Project, Finland Futures Research Centre FFRC (From: http://urn.fi/URN:NBN:fi-fe2019052216519. Accessed date: 7.5.2021)
41. Needham RD, Robert C, de Loë RC (1990) The Policy Delphi: purpose, structure, and application. Can Geogr 34(2):133–142. https://doi.org/10.1111/j.1541-0064.1990.tb01258.x
42. Nelms KR, Porter AI (1985) An interactive Delphi method. Technol Forecast Soc Chang 28(1):43–61. https://doi.org/10.1016/0040-1625(85)90072-1
43. OECD (2021) OECD Science, Technology and Innovation Outlook 2021. Times of crisis and opportunity https://doi.org/10.1787/75f79015-en
44. Panula-Ontto J, Luukkanen J, Kaivo-oja J, Mahony T, Vehmas J, Valkealahti S, Björkqvist T, Korpela T, Järventausta P, Majanne Y, Kojo M, Aalto P, Harsia P, Kallioharju K, Holttinen H, Sami R, S. (2018) Cross-impact analysis of Finnish electricity system with increased renewables: long-run energy policy challenges in balancing supply and consumption. Energy Policy 118:504–513
45. Poli R (2018) A note on the classification of future-related method. Eur J Futures Res 6(15). https://doi.org/10.1186/s40309-018-0145-9
46. Popper R (2008) How are foresight methods selected? Foresight 10(6):62–89. https://doi.org/10.1108/14636680810918586
47. Pouru, L., Minkkinen, M., Auffermann, B., Rowley, C., Malho, M., Neuvonen, A., (2020) Kansallinen ennakointi Suomessa 2020. Valtioneuvoston selvitys- ja tutkimustoiminnan julkaisuja 2020: 17. [National Foresight in Finland 2020. Publication series of the Government's analysis, assessment and research 2020: 17]. From: http://urn.fi/URN:ISBN:978-952-287-948-6. Accessed date: 7.5.2021
48. Prokesch T, von der Gracht H, Wohlenberg H (2015) Integrating prediction market and Delphi methodology into a foresight support system — insights from an online game. Technol Forecast Soc Chang 97:47–64. https://doi.org/10.1016/j.techfore.2014.02.021
49. Puyt RW, Lie FB, Wilderom CPM (2023) The origins of SWOT analysis. Long Range Plan 56(3):102304. https://doi.org/10.1016/j.lrp.2023.102304
50. Rauch W (1979) The decision Delphi. Technol Forecast Soc Chang 15(3):159–169. https://doi.org/10.1016/0040-1625(79)90011-8
51. Santonen T, Kaivo-oja J, Antikainen M (2011) National open innovation systems (NOIS): defining a solid reward model for NOIS. Int J Innov Reg Dev 3(1):12–25. https://doi.org/10.1504/IJIRD.2011.038060

52. Schmidt RC (1997) Managing Delphi surveys using nonparametric statistical techniques. Decis Sci 28(3):763–774. https://doi.org/10.1111/j.1540-5915.1997.tb01330.x
53. Seker SE (2015) Computerized argument Delphi technique. IEEE Access 3(2):368–380. https://doi.org/10.1109/ACCESS.2015.2424703
54. Snowden DJ, Boone ME (2007) A leader's framework for decision making. Harv Bus Rev 85(11):68–149. https://hbr.org/2007/11/a-leaders-framework-for-decision-making
55. Ståhle, P., Pirttivaara, M., (2015) Rikastuttava yhteistyö ja uudet toimintamallit. Innovaatioekosysteemi yhteiskunnan ajurina. [Enriching cooperation and new operating models. The innovation ecosystem as a driver of society.]. Tekes Review 317/2015. Helsinki Finland
56. Stern CW, Deimler MS (2009) The Boston Consulting Group on Strategy. Classic concepts and new perspectives, 2nd edn. Wiley, New Jersey
57. Strasser A (2017) Delphi method variants in information systems research: taxonomy development and application. Electron J Bus Res Methods (EJBRM) 15(2):120–133 (From: https://academic-publishing.org/index.php/ejbrm/article/view/1362/1325. Accessed date: 7.5.2021)
58. Tapio P (2003) Disaggregative Policy Delphi: using cluster analysis as a tool for systematic scenario formation. Technol Forecast Soc Chang 70(1):83–101. https://doi.org/10.1016/S0040-1625(01)00177-9
59. Tiwana A (2017) Platform ecosystems. Aligning Architecture, Governance, and Strategy. Morgan Kaufman. Elsevier
60. Turoff M (1970) The design of a Policy Delphi. Technol Forecast Soc Chang 2(2):149–171. From: http://www.elsevier.com/locate/issn/00401625. Accessed 7 May 2023
61. von der Gracht HA, Darkow I-L (2010) Scenarios for the logistics services industry: a Delphi-based analysis for 2025. Int J Prod Econ 127:46–59. https://doi.org/10.1016/j.ijpe.2010.04.013

Publisher's Note