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Interactive Horizon Scanning of the Forest Bioeconomy With a Nested Business Environment Framework

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ABSTRACT

In sectors based on renewable resources, foresight studies have often been macro-scale, quantitative outlook studies. As a result, in the complex operating environment of the forest bioeconomy, the organizations and professionals of the emerging bioeconomic sector have not been able to fully utilize futures information in their decision-making processes. This study sought to find solutions to this issue by utilizing a nested business environment framework (NEST framework) in signal interpretation as part of piloting interactive horizon scanning of the forest bioeconomy. In interaction with a diverse group of forest bioeconomy stakeholders, the horizon scanning exercise collected and interpreted signals of change. The aim was to increase forest bioeconomy actors' sense of ownership towards signals information. This study discusses strengths and weaknesses of interactive horizon scanning in the context of the forest bioeconomy and raises awareness of the opportunities and challenges of using a NEST framework in signal interpretation. The study contributes to the analytical tools and has practical implications for interpreting signals of change in the forest bioeconomy and other sectors based on renewable resources. According to the results, the NEST framework used in signal interpretation has strengths, but revealing its full potential requires further development. These developments may include the application of the framework in concrete, timely stakeholder contexts, both involving forest bioeconomy actors and a necessary outside-in perspective from other sectors.

1 | Introduction

Strategic foresight aims to observe and recognize emerging information that is likely to cause future changes, and to deal with these changes by reacting to them with appropriate organizational responses (Iden et al. 2017; Fergnani 2022). This is particularly important in sectors based on renewable resources, where the transition towards sustainability can be considered a structural change at present (Patterson et al. 2017). However, in the complex operating environment of the forest bioeconomy, the sector has been dominated mainly by quantitative foresight methods (Hetemäki and Hurmekoski 2016). In the forest sector, for example, many outlook studies, statistics-based forecasting, modeling, and strategies based on these methods have been carried out in the past (Hurmekoski and Hetemäki 2013; Näyhä et al. 2015; Heiskanen et al. 2022). In strategic planning based only on quantitative data, there is a risk that macro-level trends, scenarios, and quantitative modeling may remain separated from micro-level decision-making processes and orientation towards the future. New approaches are needed to enable individuals, organizations, and groups of organizations, such as the emerging bioeconomic sector based on renewable resources, to identify and assess complex, interconnected signals of change.

This study focuses on developing forest bioeconomy actors' (individuals and organizations) sense of ownership towards future signals information by interactive horizon scanning. Horizon scanning is a systematic process to detect and collect early signs and weak signals of potentially important developments (Amanatidou et al. 2012; Konnola et al. 2012; Cuhls et al. 2015; Cuhls 2019). However, the outcome of a horizon scanning exercise is usually used in strategic foresight as a collection of emerging trends beyond the strategy horizon, thus, the individual signals are usually connected with a wider analysis of the operating landscape (Cuhls 2019). In interaction with a diverse group of stakeholders, this study's horizon scanning exercise attempts to develop forest bioeconomy actors' capability to connect future signals with their own operating environment and decision-making processes. In sectors based on renewable resources, the bioeconomy can be defined in several ways, and the sustainability of using natural resources is often understood ambiguously (Kleinschmit et al. 2014; Pülzl et al. 2014; Giurca 2020; Ranacher et al. 2020). In this study, forest bioeconomy means tangible and intangible value creation based on forests in the transition from the current production-based forest bioeconomy towards a sustainable biosociety that combines the well-being of society and the environment.

Several analytical frameworks show how signals can be set into a wider landscape. Such frameworks include the Three Horizons framework, which highlights three separate ways (Horizons 1, 2, and 3) of looking to the future (Sharpe and Hodgson 2006; Curry and Hodgson 2008; Hodgson and Midgley 2015; Sharpe et al. 2016). Another example is the multi-level perspective (Geels 2002; Geels and Kemp 2007; Geels and Schot 2007) to structure analysis across macro–meso–micro system levels of change. Despite such analytical frameworks, connecting signals to actors' decision-making processes has remained difficult. Therefore, this study aims to find solutions to this issue by interpreting collected signals of change through the Möller et al. (2020) nested business environment framework (NEST framework). The NEST framework stems from business studies with the aim to better understand complex systems, such as the forest bioeconomy, and has been used previously, for example, in value creation studies of the forest sector (Laakkonen et al. 2023). The NEST framework consists of the socioeconomic-technological (SET) system, the Meso layer, and the Actor layer (Möller et al. 2020). In this study, the signals collected through interactive horizon scanning are interpreted through these layers with the aim of piloting how the approach helps forest bioeconomy actors make better use of future signals in their decision-making processes.

The aim of this study is to contribute to the analytical tools and practice of interpreting signals of change by testing the utilization of the NEST framework in signal interpretation as part of an interactive horizon scanning exercise. This study discusses the strengths and weaknesses of interactive horizon scanning in the context of the forest bioeconomy and seeks to raise awareness of the opportunities and challenges of such methods. There are three research questions: (i) What kind of signals of change does interactive horizon scanning of the forest bioeconomy produce? (ii) What kind of perspectives can be produced for different NEST layers of the forest bioeconomy through interactive interpretation of collected signals? (iii) How does the utilization of the layers of the NEST framework work in signal interpretation? The research questions are a continuation of each other: the purpose of the first research question is simply to collect the signals for the interpretation phase. Thereafter, the purpose of the second research question is to answer the third research question, which aims to test the utilization of the NEST framework in signal interpretation.

The article is structured as follows: First, the elements of the proposed analytic framework are presented. Second, we detail how the interactive horizon scanning of the forest bioeconomy was organized, and analyze the data collected in the exercise with the proposed framework. Third, the results of the horizon scanning pilot are shown, focusing on its different phases and experiences gained during the process. Finally, the results are discussed, and conclusions about the usefulness of the NEST framework in interpreting signals of change are made.

2 | Analytical Framework

2.1 | Horizon Scanning in the Context of Forest Bioeconomy

Horizon scanning, also known as environmental scanning, is a process for detecting and interpreting the consequences of emerging issues and other signals of change both inside and outside a field or organization (Gordon and Glenn 2009; Amanatidou et al. 2012; Konnola et al. 2012; Cuhls 2019). In strategic foresight, horizon scanning is generally done at the beginning of a foresight project and thus, is considered as a set of methods or a combination of methods, rather than an actual method itself (Cuhls 2019). Therefore, horizon scanning can be the first step in action-taking processes (Cuhls 2019), which is what this study also aims for.

Horizon scanning can be conducted in many ways, and its nature can be divergent depending on the subject being studied and the goals of the project (Amanatidou et al. 2012; Bengston et al. 2024). For example, horizon scanning may be: (1) exploratory or issue-centered; (2) ongoing, periodic, or one-time; (3) automated (AI, text-mining) or manual; (4) expert-based, team-based, crowd-sourced, or individual; (5) in-house or outsourced; (6) short- to long-term; (7) regional to global; (8) predefined or open (Amanatidou et al. 2012; Bengston et al. 2024). Regardless of the field of study, horizon scanning processes commonly follow four steps: (1) scoping and framing; (2) scanning and collecting; (3) analyzing and synthesizing; and (4) communicating and using results (Gordon and Glenn 2009; Amanatidou et al. 2012; Bengston et al. 2024).

In the forest sector, horizon scanning has previously been used in forest-related research projects (e.g., Hines et al. 2019), but the extent of its use in forest-based organizations and businesses is unknown. Although horizon scanning studies related to the bioeconomy have previously been conducted (e.g., Taylor et al. 2019), horizon scanning studies to explore signals of change which could affect the forest bioeconomy operating environment have been minimal. In this study, the forest bioeconomy operating environment is defined as a broad internal and external environment that can be affected by possible signals of change. The internal operating environment refers to the immediate working environment, which includes community, partners, customers, and competitors. Correspondingly, the external operating environment refers to the contextual environment, which shares broad driving forces such as social values, geopolitics, governance, and technology (Alkhafaji 2003; Scearce and Fulton 2004).

Fundamentally, collaborative horizon scanning is, by definition, interactive. However, interactivity in this study means coproduction of knowledge, which has been used in participatory forest planning studies (Pykäläinen et al. 2007; Khadka et al. 2013). Previous studies have found that stakeholders' sense of ownership has promoted the implementation of plans through stronger commitment and co-productivity (Khadka et al. 2013). In addition, the participation of stakeholders has been shown to increase the legitimacy and richness of foresight results (Bas and Guillo 2015; Kaivo-oja 2017; Heiskanen et al. 2022). Using open foresight approaches, where organizations share their understanding of future developments with other organizations (Hansen et al. 2021), this study's interactive horizon scanning searches for weak signals of change that may have an impact on the forest bioeconomy.

2.2 | How to Search for (Weak) Signals Affecting the Forest Bioeconomy

In addition to looking for broad emerging trends, individual weak signals can also be searched for through horizon scanning (e.g., Hiltunen 2010; Hines et al. 2019). Weak signals are signs of a potentially emerging issue that could disrupt current trends and megatrends (Ansoff 1975; Hiltunen 2010). The definition of weak signals has been problematic because the concept has been characterized in different ways in the literature (Hiltunen 2008; van Veen and Ortt 2021). However, all definitions share the basic idea of the first definition created by Ansoff (1975) that weak signals describe the first sign or symptom of a change that can be relevant to the operating environment under consideration (e.g., Hiltunen 2008, 2010). Recently, a unified definition of weak signals has been proposed (van Veen and Ortt 2021), emphasizing the relationship of the signal perceiver to the weakness of the signal. This definition of weak signals is used in this study:

> *"A weak signal is a perception of strategic phenomena detected in the environment or created during interpretation that are distant to the perceiver's frame of reference."*
>
> (van Veen and Ortt 2021)

But what is "weak" for some is not necessarily so for others. According to van Veen and Ortt (2021), the "weakness" is defined as the distance of information to prior knowledge of the signal interpreter. Thus, the role of the signal interpreter is significant in the forest bioeconomy, as many actors have no previous experience with weak signals. Theories and frameworks on how signals can be seen as part of the complex systems and how they can be set into a wider landscape, for example, the Three Horizons framework (Sharpe et al. 2016) and the multi-level perspective (Geels and Schot 2007)—can help build theoretical understanding of where to first focus thoughts when searching for weak signals of change affecting the forest bioeconomy. Since there are no comprehensive guidelines for the identification of weak signals in the forest bioeconomy, these frameworks suggest that it is essential to look both inside and outside the forest bioeconomy (Mauno et al. 2023) or the organization (e.g., Hines et al. 2019). This divide of a system can also be viewed through the framework of strategic foresight research concepts of internal and external environments (Alkhafaji 2003; Scearce and Fulton 2004; Mauno et al. 2023). Analyzing individual signals of change as well as surprises and discontinuities, such as weak signals, could help forest bioeconomy organizations develop their sense of ownership towards future information.

2.3 | NEST Framework and Further Interpretation of Signals of Change

Simply piloting an open and interactive horizon scanning exercise to collect signals of change is not enough to generate useful information for planning and decision-making. For forest bioeconomy organizations to benefit more from signal information, methodological advancements in foresight practices and a wider application of diverse approaches are needed. In addition to searching for weak signals of change affecting the forest bioeconomy, their further interpretation is needed to connect signal information to the actors' (individuals and organizations) decision-making processes.

Further interpretation, sense-making, and deepening the understanding of signals of change is a vital step before utilizing the collected signals in decision-making processes (Cuhls 2019). In this study, the collected signals of change are interpreted using the NEST framework (Möller et al. 2020), which conceptualizes the connection between the signal interpreter and the wider landscape. The NEST framework enables forest bioeconomy actors (organizations, individuals) to visualize the interpretation of future information in the forest bioeconomy.

The complex operating environment of the forest bioeconomy can be considered as an entity formed by nested layers, where actors and the activities they perform at different layers have interconnections and influence each other (Möller et al. 2020; Laakkonen et al. 2023). This approach can be illustrated using the Möller et al. (2020) NEST framework, which consists of the socioeconomic-technological (SET) system, Business Field, Focal Ecosystem, and Actor Layer (Figure 1). In the framework of Möller et al. (2020), the SET system describes the macro layer of the operating environment, Business Field and Focal Ecosystem illustrate the meso layer (upper and lower meso layer) of the environment, and the Actor Layer and its actors describe the micro layer of the business environment (Figure 1).

The widest layer in the Möller et al. (2020) model is the SET system. The socioeconomic-technological system (SET system) is a global, regional, or national established socioeconomic system which shares the same political and legal courses of action, technological regimes, economic structures, and cultures. The complex socioeconomic forest bioeconomy (consisting of interrelated technological business fields) can be considered a SET system, under which its meso and micro layers are situated. However, Möller et al. (2020) do not go deeply into the ecological dimension of their NEST framework. This study, which is related to renewable resources, emphasizes the importance of the ecological dimension of the forest bioeconomy and thus, the SET system of this study is called the SETE system (socioeconomic–technological–ecological system). In the case of forest bioeconomy, the SETE system refers to the broad internal and external forest bioeconomy operating environment, which now covers universal ecological driving forces such as changing climate and degrading biodiversity. However, when these broad ecological factors cannot be classified as a social, economic, or technological element, it forces the actor to look for and interpret signals also from beyond the normal operating environment. For example, planetary boundaries and the goal of strong sustainability guide the forest bioeconomy's SETE system and its inner layers. When anticipating weak signals of change in the forest bioeconomy, the SETE system can be considered a "well" of futures information, from which micro-layer actors (signal interpreters) can find signals of change for their operations (Figure 2).

After the macro level (SETE system), the forest bioeconomy can be viewed through the meso layer. Möller et al. (2020) divided the meso layer into Business field and the Focal ecosystem (Figure 1). In this study, the upper and lower meso layers are merged into one, describing the forest bioeconomy's fields of activity. The meso layer in this study is considered a unified layer, so that signal interpretations do not go into highly specific business fields. On a practical level, the meso layer in this study consists of interconnected business networks and actor constellations and networks. At this level, an example of forest bioeconomy fields of activity is primary production or industry (Figure 2).

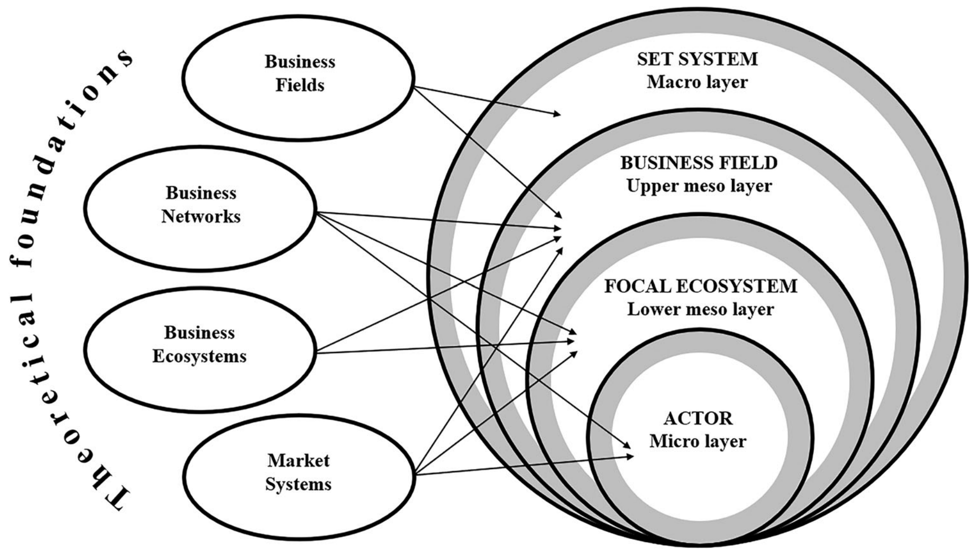

FIGURE 1 | Original nested business environment (NEST) framework, redrawn based on Möller et al. (2020).

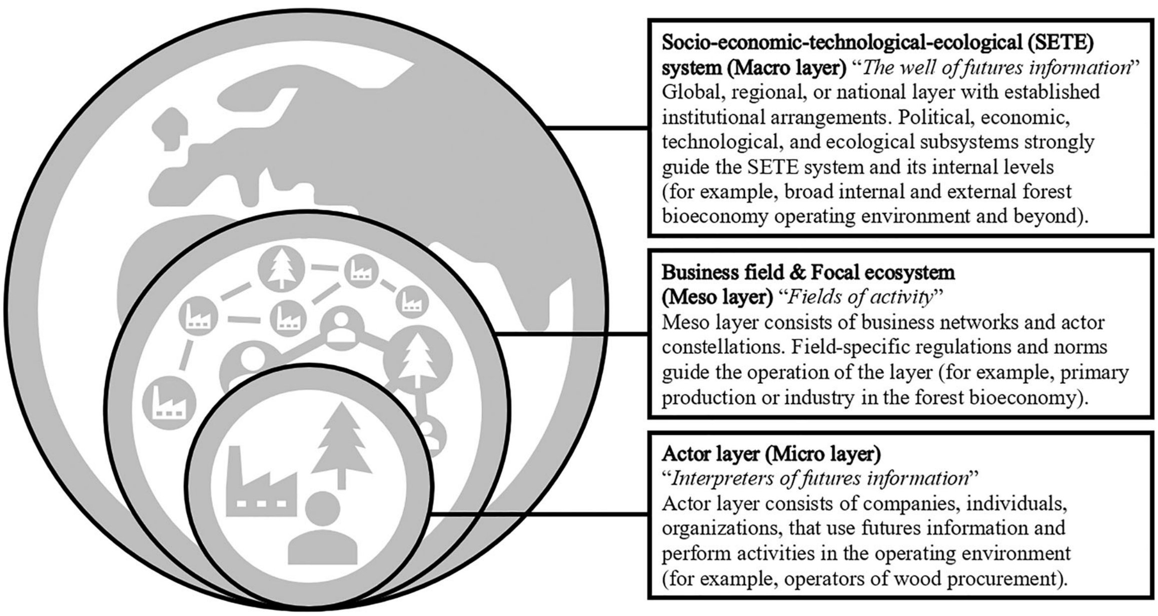

FIGURE 2 | Signal interpretation through the nested layers of the forest bioeconomy. Modified from Möller et al. (2020).

The innermost layer in the NEST framework is the Actor layer, which can be seen as the micro layer of the forest bioeconomy operating environment. The Actor layer describes companies, individuals, and organizations that perform activities in the operating environment. For example, operators of wood procurement firms could be actors and individuals in the Actor layer of the forest bioeconomy. These actors use futures information, which could be found in the SETE system, and perform activities in the operating environment (Figure 2).

In the horizon scanning exercise of this study, interpretation of the signals takes place gradually from the SETE system to the Actor layer, with the aim of increasing understanding of the possibilities for utilizing signal information in the activities of forest bioeconomy actors. More precisely, the purpose is to bring signals that seem distant to organizations closer to actors' own daily operations and activities and to illustrate their sense of ownership towards futures. Signal interpretation using the NEST framework combined with interactive horizon scanning could develop forest bioeconomy actors' (individuals and organizations) coproduction of knowledge of futures.

3 | Interactive Horizon Scanning

3.1 | Scoping and Framing

Due to the interactive nature of this study and its focus on developing forest bioeconomy actors' sense of ownership towards signal information, this horizon scan was performed as an exploratory, one-time exercise with a regional (Finnish) scanning team searching for weak signals of change that could affect the forest bioeconomy. The horizon scanning campaign in this study followed the typical steps of the scanning process (described in Section 2.1). The process first included recruiting and training a team of scanners, followed by the scanning, and collecting signals of change online. An on-site signal interpretation workshop was then held, followed by analysis of the collected data (Figure 3). The phases of the horizon scanning campaign (data collection, analysis, results) are presented in more detail in the next section.

3.2 | Pre-Scanning and Preparations

Before the interactive horizon scanning campaign, a pre-scanning exercise was performed in Autumn 2023. The aim of this pre-scanning was to find out how non-timber forest products, that is, NTFPs (Sheppard et al. 2020), and nature-based tourism could change in the future. The search for weak signals was focused on articles (both science and popular articles), news, and social media posts. The objective of defining the topic purposefully aside from the forest bioeconomy was to test how a more targeted topic would work when searching for signals of change.

In the pre-scanning, seven researchers collected signals in the bookmarking tool Diigo (http://diigo.com) for 4 weeks starting in mid-August 2023. Before beginning, the researchers were instructed to use tags, that is, key words related to (1) business field, (2) topic focus, and (3) time frame. Business-related tags were, for example: NTFPs; nature-based tourism; recreation; or ecosystem services. Focus-related tags were, for example: innovation; business model; product; service; technology; governance; or values. Lastly, researchers were guided to use H1, H2, and H3 as time frame tags according to the Three Horizons framework. This study uses the approach of Garnett et al. (2025) to divide signals into three horizons. In this exercise H1 described the present status of the business environment (Foreseeable domain, 1–3 years), H2 described the business environment in the near future when alternative futures are already starting to appear ("Cross-scale" domain, 3–10 years), and H3 described the business environment in the far future and the weak signals that might seem marginal in the present but significant in the future ("Out of the blue" domain, +10 years) (Garnett et al. 2025). Using this protocol, a total of 46 signals were collected. Of the collected signals, 17 were tagged as H1 signals, 22 as H2 signals, 3 as H3 signals, and the remaining scanning hits had no tags attached.

The pre-scanning using Diigo provided lessons for the interactive horizon scanning campaign. First, the collection of signals requires clear instructions (this is particularly important for scanners who are not familiar with weak signals). Second, the collected signals or their impacts need to connect with the participants' own work and processes to keep them motivated. Finally, it is important for participants to fully understand the meanings of the different horizons in the Three Horizons framework. This is particularly important when understanding Horizon 3 is set as the target; searching for and interpreting H3 weak signals requires an open mind and mindset for exploring the most distant and uncertain futures.

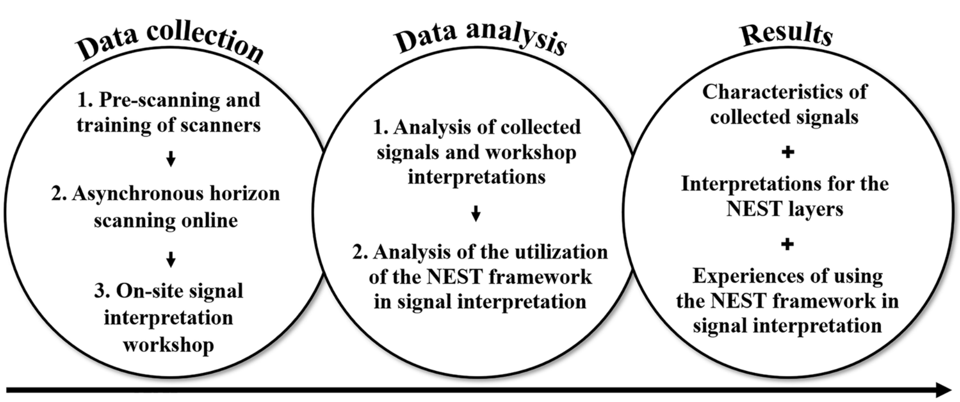

FIGURE 3 | Timeline of the study.

3.3 | Recruitment of the Scanning Team

The pre-scanning activity served as a starting point for the selection of the horizon scanning team. However, the selection of members of the scanning team first involved the creation of an expert matrix, which is a useful basis for participatory study in futures research. For example, expert matrices have been especially used in Delphi studies (e.g., Rintamäki et al. 2016). In addition to science and education institutions like the participants of the pre-scanning, the stakeholders of this study's expert matrix also included private firms and businesses, as well as publicly funded and nonprofit organizations (Table 1).

This study's central principle was to divide the forest bioeconomy into primary production (forests and forestry), industry (processing, refining, and products), and markets and consumers, so that a large part of the forest bioeconomy would be covered by the horizon scanning team (Table 1). For this study, it was also important that the scanning team included diverse people with different backgrounds. Thus, the purpose was to recruit participants from different parts of the forest bioeconomy operating environment nationwide across Finland. The aim was to recruit a more diverse group than the pre-scanning one and to observe a wider research area. As learned in the pre-scanning, the recruitment was conducted so that the theme of the study (forest bioeconomy) would be related to the experts' own work. It was also important that experts with previous futures and foresight experience were recruited to motivate those who were not familiar with different phenomena of the future (Table 1).

A total of 42 Finnish experts were compiled in the expert matrix, of which 28 were contacted by email, and 15 agreed to participate in the study. Of these 15 experts, 10 participated in searching for signals of change (Table 1). The remaining 14 experts in the matrix were not contacted when it was felt that sufficient expertise had agreed to participate in the study. Sufficient expertise was obtained when all rows of the matrix were covered, and each column also had experts represented. The specific expertise of those experts included: forest economics and forest-related markets, wood materials science, wood procurement, social science, cooperation, youth organization activities, and regional planning and development. In addition, three participants had previous experience in futures and foresight activities (Table 1).

3.4 | Training of Horizon Scanners

Before horizon scanning and searching for weak signals of change, training events were organized for the participants. Three 1-h online training meetings were organized in December 2023, and all assigned 15 participants of the study took part in those sessions. The purpose of the training sessions was to teach the basics of futures studies and how to search for, identify, and interpret weak signals that could affect the forest bioeconomy. In addition, the protocol for horizon scanning and how to save the identified scanning hits to the database were covered in the training.

Participants were explained that the use of weak signals can be divided into perception, signal interpretation, and enactment (van Veen and Ortt 2021). This weak signal process is contextual, thus, it takes place in an operating environment where the signal can be divided into three more specific components: (1) the phenomenon itself; (2) the signal that indicates a phenomenon (i.e., news, image, service, product, or event); and (3) interpretation, that is, how the signal is received, and how it is used (Heinonen and Hiltunen 2012; Ilmola-Sheppard 2014; Lesca and Lesca 2014; van Veen and Ortt 2021). Common features of weak signals, including novelty, surprise, challenge, relevance, and delay, may challenge the interpreter's worldview, and therefore weak signals may be missed as they are hidden among other information (Hiltunen 2010; Lesca and Lesca 2014). The training of horizon scanners was an important part of this horizon scanning campaign, as it has also been found to be important in previous studies (Hines et al. 2019).

3.5 | Asynchronous Scanning of Weak Signals (Padlet)

Padlet (http://padlet.com) was used as the database for this horizon scanning exercise. The interaction between users and, if desired, the possibility of anonymity were important criteria in the selection of the database. These criteria were best met by Padlet, which is an interactive whiteboard application for collecting, posting, sorting, and sharing findings.

The exploratory, one-time horizon scanning of this study lasted 9 weeks from January 2024 to March 2024. During that time, participants had the opportunity to save their own scanning hits and comment on and like each other's posts. During 9 weeks, a total of 10 horizon scanners participated in Padlet's activities: 42

TABLE 1 | Anonymized expert matrix for interactive horizon scanning of the forest bioeconomy. A total of 10 experts participated in searching for signals of change (asynchronous horizon scanning). The expertise of these experts covered the indicated cells in the matrix.

	Stakeholders		
Area of expertise	**Science and education institutions**	**Private firms and businesses**	**Publicly funded and nonprofit organizations**
Forests and forestry		✓✓	✓✓
Processing, refining, and products	✓		
Markets and consumers	✓		✓
Previous futures and foresight experience	✓	✓	✓

scanning hits were saved, 29 comments were identified, and 47 likes were given to the scanning hits.

During the first 2 weeks of scanning, the participants were able to familiarize themselves with Padlet's functions and the search for signals of change. As taught in the training sessions, participants were reminded to write the reasoning and the pre-interpretation of the signals they found. As the target was to search for weak signals of change, questions such as: "*Why exactly could this signal be the first symptom of change?*", "*Why is the signal relevant for the forest bioeconomy?*", "*What could be the effect of the signal on the future operating environment of the forest bioeconomy?*" helped horizon scanners to get started with their scanning. The purpose of the first 2 weeks was to collect the basis for commenting on Padlet.

For the following weeks, participants were given the opportunity to comment on each other's posts. Usually, we only recognize signals that already fit our worldview; with the help of commenting, the participants were able to challenge each other. Questions such as: "*What thoughts does someone else's saved scanning hit evoke?*", "*Do you think the scanning hit saved by someone else is weak enough or is it more like a signal of an already known trend?*", "*Does a scanning hit evoke emotions?; What kind?*" helped horizon scanners to start discussing each other's posts. Although commenting was enabled, the search for signals of change continued as in the previous weeks.

For the last 2 weeks of the horizon scanning exercise, a "like button" was opened for the participants. The task was to give a like (i.e., a point) to every post that met the following characteristics: "*The saved signal is surprising in some way (it evokes emotions in you, makes you think, etc.)*", "*The signal describes an issue that may have an impact on the forest bioeconomy in the future*", "*(Extra) The signal comes from outside the forest bioeconomy*". The task was meant to be quick to complete; the purpose was not to analyze the saved scanning hits too closely, but to give the points with intuition and "gut feeling". The purpose of this phase was to highlight the signals that received the most reactions and debate that would be further discussed in the workshop.

3.6 | Interactive Interpretation of Signals of Change (Workshop)

As a follow-up to the online horizon scanning performed on Padlet, a 3-h on-site signal interpretation workshop was held in mid-March 2024. The workshop was attended by six participants from the scanning phase and three of the present authors, who facilitated the workshop. In the workshop, the six participants were divided into two groups of three, and the facilitators followed the working in groups from an outside perspective. The purpose of the workshop was to interpret Padlet's signals that received the most reactions and debate during the scanning phase.

In the workshop, previously collected signals of change were interpreted through three different levels with the help of three assignments. First, signals were interpreted through the broad operating environment of the forest bioeconomy. Second, the purpose was to interpret signals through the forest bioeconomy's various fields of activity (primary production, i.e., forests and forestry, and industry, i.e., processing, refining, and products) (Table 1). However, since there were only six participants and only two groups, the workshop did not interpret signals through the field of activity of markets and consumers. Lastly, participants had the opportunity to interpret signals from the perspective of their own work/company/organization. The first two assignments were group tasks, while the last interpretation assignment was done independently by each participant. At each level of interpretation, the purpose was to answer two questions: (1) *Why might the signal in question be considered significant in terms of the future of this interpretation level? Where could the signal lead to?* (2) *What should the reaction be to this signal at present: What action should be taken at this level of interpretation?* The questions were presented in printed templates where the participants could write their answers during the discussions (Appendix A).

In the first interpretation assignment, the task of the groups was to explore possible implications of two signals through the broad operating environment of the forest bioeconomy. Since the signals collected by the participants were not the "weakest" signals from outside the normal forest bioeconomy operating environment, the groups were given an H3-tagged signal observed in the pre-scanning phase as a common signal. The chosen signal "*Orcas (Orcinus orca) are attacking boats in Southwestern Europe*" was intended to stimulate the participants' thoughts and encourage them to interpret other signals boldly. In addition, this signal was chosen because it comes from beyond the normal operating environment of the forest bioeconomy, and it is an ecological signal connected to this SETE system. After interpreting the common signal, Group 1 was given a signal "*Europe is suffering from a gunpowder shortage 'The main raw material for gunpowder is usually nitrocellulose, which can also be produced from wood-based products'*" to interpret. Correspondingly, Group 2 was given a signal "*The researcher suggests adding cellulose to food as one solution to hunger*" to interpret. Although these signals were not from outside the forest bioeconomy, these signals were selected on the basis that they were discussed and commented on during the scanning phase. Also, these signals were chosen because they could be seen as temporally significant and debatable signals of change.

In the second interpretation assignment, the purpose was to interpret signals through the forest bioeconomy's various fields of activity. Group 1 was given the interpretation level of primary production (i.e., forests and forestry, and industry), and it interpreted the signal "*The electric car brand BYD overtook Volkswagen as the most popular car in China*". Correspondingly, Group 2 was given the industry interpretation level (i.e., processing, refining, and products), and it interpreted the signal "*Composite products can replace current wood products (e.g., guitars)—Composite becomes the new 'wood'*". These signals were selected on the basis that they were easily discussed signals of change. For example, the Group 1 signal can be considered a signal of a wider change which comes from the external operating environment or outside the forest bioeconomy operating environment and can affect the forest bioeconomy in the longer term. Correspondingly, the Group 2 signal was based on the idea that over a long period of time, a certain product could become the "new wood" and did not necessarily have to be a composite. In addition, these signals were selected on the basis that they were liked, discussed, and commented on during the scanning phase.

In the third and last interpretation assignment, participants could choose from the signals collected on Padlet those they thought were most significant from the perspective of their own work or organization. This was an individual task where participants wrote their answers on a template. Unlike the group assignments, this individual task had one extra question: "*What kind of feelings does this chosen signal evoke in you?*" The assignment ended with a common discussion, where participants shared the signals of change they considered most important through their own work or organization (Appendix A).

3.7 | Analysis

The interactive horizon scanning campaign ended with the analysis of the collected data (collected signals of change and workshop interpretations). The data collected in this study have been analyzed in accordance with the principles of qualitative research (Strauss 1987; Miles and Huberman 1994; Coffey and Atkinson 1996) with NVivo qualitative data analysis software (Lumivero 2025). The theories of this study (Three Horizons and the NEST framework) supported the data-driven analysis, the purpose of which was to code and classify the data into predefined categories.

Before qualitative analysis and coding in NVivo, semi-quantitative analysis was performed according to Garnett et al. (2016, 2025) semi-quantitative signal risk assessment. However, instead of assessing risks, the signals were only analyzed based on their potential importance for the future forest bioeconomy. Importance was obtained in the analysis by first giving each signal an impact score (the signal's possible impact on the broad forest bioeconomy operating environment) on a scale of 1–5 (i.e., 1 low to 5 high); then, the signals were given likelihood scores (possible likelihood of the signal's implied outcome) on the same 1–5 scale. The final importance classification of a signal was obtained by multiplying the impact and likelihood scores together. The scored signals were then placed on the Three horizons table based on when the outcome suggested by the signal could occur (H1 = 1–3 years, H2 = 3–10 years, H3 = +10 years). Following the semi-quantitative analysis, the signals in each Horizon were further annotated and coded in NVivo based on what can be said about each signal and their characteristics. The goal of this analysis was to answer the first research question (What kind of signals of change does interactive horizon scanning of the forest bioeconomy produce?). After the analysis of the collected signals of change, all of the data (pre-scanning signals and signals collected by the scanning team) were anonymized and permanently stored with open access principles in the Zenodo data archive (http://zenodo.org).

The second phase of analysis focused on signal interpretations of the workshop (Step 2 in Figure 4). In this phase, the NEST framework was used as the basis for the analysis to answer the second research question (What kind of perspectives can be produced for different NEST layers of the forest bioeconomy through interactive interpretation of collected signals?). First, the signal interpretations of the first and second interpretation assignments made in the workshop were analyzed with NVivo by dividing the written answers into the layers of (1) the SETE-system and (2) the Meso layer. In this study and in analysis, the SETE-system describes the broad operating environment of forest bioeconomy (Macro layer), and the various fields of activity of the forest bioeconomy can be placed in Meso layers. After dividing the signal interpretations into the two layers of the NEST framework, the written answers by the participants were coded into two categories based on the questions asked in the interpretation assignments: (1) *Why might the signal in question be considered significant in terms of the future of this interpretation level? Where could the signal lead to?* (2) *What should the reaction be to this signal at present: What action should be taken at this level of interpretation?* These steps were the interim stage of the analysis, from which the interim stage tables (Supporting Information S1: Supplementary material A and B) were compiled for finalization of the analysis.

Correspondingly, the written answers to the third interpretation assignment of the workshop, the individual task, were coded directly to the Actor layer of the NEST framework (Step 2 in Figure 4). After this step, the written answers by participants were coded into three categories based on the questions asked in the third interpretation assignment: (1) *What kind of feelings does this signal evoke in you?* (2) *Why can this signal be considered significant for your organization in the future? Where could this signal lead to?* (3) *How should you react to this signal today: How would you act in your organization?* Lastly, the categories were compiled into an interim table (Supporting Information S1: Supplementary material C) showing signals

FIGURE 4 | Simplified three steps of the analysis.

that frequently appeared in the participants' answers, which they considered significant in terms of their own work or organization. To conclude the analysis of signal interpretations, all interpretations in the interim tables (Supporting Information S1: Supplementary material A, B, C) were further annotated based on what can be said about signal interpretations made in the workshop. Finally, summary tables of findings were created.

After the perspectives on the NEST layers were obtained, the analysis moved on to evaluating the utilization of the NEST framework in signal interpretation (Step 3 in Figure 4). This was conducted as a SWOT analysis to answer the third research question (How does the utilization of the layers of the NEST framework work in signal interpretation?). SWOT analysis is a method commonly used in strategic management to create a strategy, the purpose of which is to evaluate the company's internal strengths and weaknesses as well as external future opportunities and threats (e.g., Piercy and Giles 1989; Pickton and Wright 1998). SWOT analyses are often criticized for their simplicity in strategic planning (Pickton and Wright 1998), however it was a suitable tool for answering the third research question of this study, as the purpose was simply to explore what are the NEST framework's strengths, weaknesses, and possibilities for application in signal interpretation. In the analysis, all the interpretations made by participants, the interim tables (Supporting Information S1: Supplementary material A, B, C), and the summary tables of the interpretations were considered. In the analysis, all layers of the NEST framework were examined, and a SWOT table was filled out, answering questions about the strengths, weaknesses, opportunities, and threats of each level in signal interpretation.

4 | Results

4.1 | Identified Scanning Hits

The previous stages of the study, asynchronous horizon scanning, and the analysis of the collected signals of change, made it possible to answer the first research question (What kind of signals of change does interactive horizon scanning of the forest bioeconomy produce?). Figure 5 summarizes the results of the semi-quantitative analysis of the collected signals. The figure presents the importance classification of each signal (Importance = signal's possible impact on the forest bioeconomy × possible likelihood of signal occurring), as well as the placement of signals on time horizons (H1, H2, or H3), that is, when an emerging issue provided by the signal is likely to have an impact. Based on the analysis, 18 signals were classified as H1, 22 signals as H2, and 2 signals as H3.

Since the analysis also annotated the signals based on what can be said about each signal and its characteristics, it supported answering the first research question. Based on the analysis, the H1 signals describe the present status of the environment as they can be seen as megatrends (e.g., climate change, urbanization), trends, and drivers of change (e.g., electrification, energy transition, artificial intelligence). Examples of these signals are no. 10 (Europe's air dries up—“Tree growth and carbon sequestration at risk”), no. 11 (In Finland, more than half a million new apartments are needed in large cities by 2040), no. 26. (Artificial intelligence threatens and enables (also in the forest sector)), and no. 34. (Electrification of forest machines). In this horizon scanning exercise, participants recognized H1 signals easily (Figure 5).

Based on the analysis, uncertainty increases in horizon 2 signals: alternative futures occur within a longer time frame than the current H1 signals. Therefore, the importance of interpretation increases. Examples of these are signals no. 8. (Burning may still be the most valuable use of wood in the future), no. 12. (Was it a mistake to prepare for climate change if the Gulf Stream stops?), no. 22. (Composite products can replace current wood products (e.g., Flaxwood's guitars)), and no. 29. (A biotechnology company is building a protein factory in Finland—Production is equivalent to 30,000 cattle annually) (Figure 5). In this horizon scanning exercise, it was easier for participants to find H2 signals than H3 signals, even though the online training guided them to focus on exploring the most distant futures.

In Horizon 3, the uncertainty of signals and the importance of interpretation increase significantly. The signals can be interpreted differently, and they provoke a discussion for and against. Subjectivity of the interpretation increases and therefore signals may also fall into the H2 category. For example, in Figure 5, H3 signals are set to lean more towards H2, even though they are classified as Horizon 3 signals. Finding H3 signals may be highly subjective, and what is new to one interpreter may already be a trend in another context, and vice versa. In this analysis, signals no. 16 (Europe is suffering from a gunpowder shortage “The main raw material for gunpowder is usually nitrocellulose, which can also be produced from wood-based products”) and no. 42 (The researcher suggests adding cellulose to food as one solution to hunger) were marked as H3 signals, as they may seem new to an interpreter from outside the forest bioeconomy. In this pilot, participants had difficulty looking far enough outside the forest bioeconomy, which could have yielded more H3 weak signals for the forest bioeconomy.

4.2 | Perspectives for NEST Layers (Interactive Interpretations)

The on-site interpretation workshop and the analysis of the workshop interpretations, made it possible to answer the second research question (What kind of perspectives can be produced for different NEST layers of the forest bioeconomy through interactive interpretation of collected signals?). Tables 2a and 2b summarize the analysis. To create the summary tables and make findings from the data, the results of the interim tables have been used as a basis for the analysis (Supporting Information S1: Supporting material A, B, C).

Since the Actor layer interpretations in the workshop were an individual task and the interpretations were divided into several different signals, a final summary table was not created. Instead, an Actor layer interim table (Supporting Information S1: Supporting material C) was further annotated based on what can be said about signal interpretations made by the participants. Based on these findings, the signals selected as the

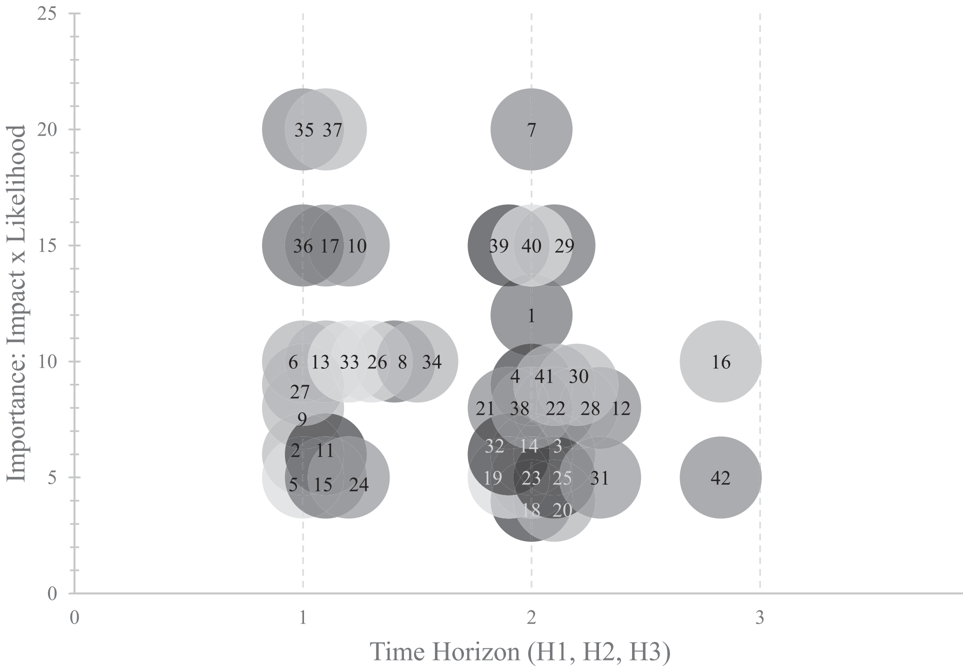

FIGURE 5 | Summary of collected signals of change and their analysis: (1) Finland's transmission system operator predicts an almost 50% increase in electricity production and consumption by 2030 in Finland; (2) China's growth and exports increasingly rely on the "new trio" (solar panels, batteries, electric cars); (3) The (energy) transition could be achieved; (4) Renewable energy capacity increased by almost 50% in 2023 (IEA); (5) Who has the power to define futures (in 2024); (6) Nordic Data Festival 2024; (7) Employer image of the forest industry: Labor shortage in forestry?; (8) Burning may still be the most valuable use of wood in the future; (9) Environmental restoration, where does the money come from?; (10) Europe's air dries up—"Tree growth and carbon sequestration at risk"; (11) In Finland, more than half a million new apartments are needed in large cities by 2040; (12) Was it a mistake to prepare for climate change if the Gulf Stream stops?; (13) The energy sector is in transition; (14) Growing need for housing and wood construction?; (15) Craneworks Oy Ltd. and display communication; (16) Europe is suffering from a gunpowder shortage "The main raw material for gunpowder is usually nitrocellulose, which can also be produced from wood-based products"; (17) There are already a lot of innovations in the forest bioeconomy, but will they ever develop into anything significant?; (18) Viruses and pandemics; (19) Dispelix: XR Waveguide Combiners; (20) Jeff Bezos sold his company shares for $2 billion; (21) Apple Vision Pro VR glasses; (22) Composite products can replace current wood products (e.g., Flaxwood's guitars); (23) The electric car brand BYD overtook Volkswagen as the most popular car in China; (24) A large part of China's forests are natural forests, the cutting of which is currently prohibited—But what if the situation changes in the future?; (25) Could bioenergy produced from wood someday be included in emissions trading?; (26) Artificial intelligence threatens and enables (also in the forest sector); (27) Conflicts and the forest industry; (28) Could ecology be a significant factor in competitive sports in the future?; (29) A biotechnology company is building a protein factory in Finland—Production is equivalent to 30,000 cattle annually; (30) The uncertainty and instability of politics; (31) The collapse of the contract-based system and organizations; (32) Cheap energy; (33) in Finland, 58% would like to live in the countryside, only 11% in city centers; (34) Electrification of forest machines; (35) Deforestation regulation; (36) Protected forest areas are increasing in Finland, how does it affect wood production, employment, etc.?; (37) Legislation of the restoration decree; (38) Energy communities promote the production and distribution of renewable electricity; (39) The increase in the value of the circular economy challenges the traditional use of wood; (40) Does drought during the growing season become a greater factor limiting the growth and well-being of trees than excessive (forest drainaged) moisture?; (41) Bio-based CO2 is a valuable raw material for the hydrogen economy; (42) The researcher suggests adding cellulose to food as one solution to hunger.

most significant by the participants were strongly related to their own work (e.g., related to climate change for someone who works in this area). Examples of signals that frequently appeared in the participants' answers, which they considered significant in terms of their own work or organization, included: "*Was it a mistake to prepare for climate change if the Gulf Stream stops?*", "*Europe's air dries up—'Tree growth and carbon sequestration at risk'*", "*The (energy) transition could be achieved*". Relating to participants' personal feelings, many of the selected signals were perceived as threats rather than opportunities. For example, signals related to climate change aroused fear in some of the participants. However, only a few individual feelings-based interpretations of the signals were made, and the signals were rather interpreted through one's own work. Although the Actor layer interpretations yielded only a few perspectives, other interactive interpretations provided findings for the entire NEST framework. For example, the externally produced signal ("*Orcas are attacking boats in Southwestern Europe*") could not be connected to the forest bioeconomy by the participants. In addition, the interpretations were practical at all layers and followed the forest sector's traditional ways of dealing with the future.

4.3 | Feasibility of the NEST Framework in Signal Interpretation

The previous stages of the study, the on-site interpretation workshop, and the analysis of the workshop interpretations made it possible to answer the third research question (How

TABLE 2a | Interpretations from the perspective of the SETE system: Interpreted signals and their perspectives for the broad operating environment of the forest bioeconomy.

Interpreted signal	Interpretations from the perspective of the SETE system
Orcas (*Orcinus orca*) are attacking boats in Southwestern Europe	• Participants did not find a direct connection to the forest bioeconomy in this signal. • However, the signal was considered a minor threat (Could something similar happen in a forest ecosystem?). • The action proposals were practical (e.g., the cause of the behavior must be investigated). • However, some imaginative action proposals were also considered (e.g., "smelly" boats to prevent Orcas from attacking again).
The researcher suggests adding cellulose to food as one solution to hunger	• This signal was interpreted as having a direct connection to the forest bioeconomy (businesses and organizations). • This signal was interpreted as an opportunity to multiply the MCC (microcrystalline cellulose) market. • The signal was interpreted as an opportunity to improve the image of the forest industry. • A "*MasterChef Forest*" competition was presented as an imaginative action proposal, which could help increase public awareness of the forest sector and its opportunities.
Europe is suffering from a gunpowder shortage. "The main raw material for gunpowder is usually nitrocellulose, which can also be produced from wood-based products".	• This signal was also interpreted as having a direct connection to the forest bioeconomy. • The signal was interpreted as an opportunity; gunpowder was considered a possible use for wood by-products. • Cooperation that breaks the boundaries of the forest bioeconomy was presented as an action proposal. • Although the signal was interpreted as an opportunity, not everything was discussed in the workshop: (e.g., would war be the only factor that would force companies/organizations to change their courses of action?).

does the utilization of the layers of the NEST framework work in signal interpretation?). To answer the third research question, the observations collected in the previous analysis stages were classified into SWOT tables for each of the three layers separately, thus analyzing applicability of NEST framework for signal interpretation. Tables 3a, 3b, and 3c summarize the analysis. In the summary tables, excerpts from the data illustrate the justifications for the classifications.

The main point from the findings is that the NEST framework helps to process signals at both the Macro, Meso, and Actor layers, and improves viewing the forest bioeconomy as a whole. Therefore, a broader phenomenon (e.g., climate change or policy direction) raised by an individual signal could be repeated in an interactive process from one layer to another. This can create information for the actor that the boundaries of the system can be defined in many ways to observe changes in the operating environment, but ultimately these systems all come together, and there is only one system in the process, which is only viewed from different directions and limitations. More precisely, the NEST framework provides an analytical tool for actors to become more aware of one's own information processing to understand a wider field of phenomena, such as the forest bioeconomy and signals affecting it.

5 | Discussion

This study piloted interactive horizon scanning of the forest bioeconomy and aimed to further the practice of interpreting signals of change by testing the utilization of Möller et al.'s (2020) NEST framework in signal interpretation. A horizon scanning exercise was performed with a regional scanning team consisting of Finnish forest bioeconomy stakeholders. The group of scanners were trained to search for weak signals of change which could affect the forest bioeconomy. With the interactive horizon scanning exercise, this study focused on developing forest bioeconomy actors' sense of ownership towards signal information.

The study was divided into three research questions to explore the strengths and weaknesses of the interactive horizon scanning process and the feasibility of the NEST framework as part of signal interpretation. The purpose of the first research

TABLE 2b | Interpretations from the perspective of the Meso layer: Interpreted signals and their perspectives for primary production and the industry of forest bioeconomy.

Interpreted signal	Interpretations from the perspective of the Meso layer
The electric car brand BYD overtook Volkswagen as the most popular car in China (interpreted through primary production (i.e., forests and forestry)	• Participants found a connection to forests and forestry in this signal (e.g., the effects on Finland's forests were identified as such that wider electrification can cause energy infrastructure to be built in forests). • In the discussions, the signal was also perceived as a threat at the industry level (e.g., is growing self-sufficiency in China a threat to Finland's pulp, paper, and sawn wood exports to China?). • As an action proposal, it was suggested that if electrification progresses, more extensive land use planning is needed in Finland. • The participants noticed for themselves that this signal is not necessarily a weak one, but the result caused by trends and drivers of change.
Composite products can replace current wood products (e.g., guitars)—composite becomes the new "wood" (interpreted through industry (i.e., processing, refining, and products)	• A direct connection to industry was found in this signal. • However, the signal was not really perceived as a threat, nor as a great opportunity for the industry (a large part of wood products is already composite products). • As an action proposal, the importance of planning was emphasized (e.g., recycling was perceived as problematic for composites, which can bring a negative image effect, in contrast to the signal "cellulose to food"). • It was not discussed that composites could be a signal of something else: the "new wood" does not necessarily have to be a composite.

question was to find out what kind of signals of change an interactive horizon scanning of the forest bioeconomy produces. However, as the main purpose of the study was to contribute to the analytical tools and practice of interpreting signals of change (using the NEST framework), the collected signals were not analyzed in depth. In this study, semi-quantitative signal assessment (Garnett et al. 2016, 2025) was used in the analysis of the collected signals as it is well-suited for illustrating the differences between signals in terms of time horizons and the importance of the signals for the forest bioeconomy.

According to the results, the scanning team had difficulty finding the weakest signals from the distant future (Horizon 3). The signals found were mostly determined to be near-future signals (Horizon 2). This may indicate two points: First, it emphasizes the difficulty of finding weak signals in general. Second, it illustrates the difficulty for forest experts to find weak signals affecting the forest bioeconomy. As van Veen and Ortt (2021) state, weak signals are distant to the perceiver's frame of reference, which may then indicate that the group selected for the study was too close to the topic itself to identify the weakest signals affecting the forest bioeconomy. In addition, the group may not have had sufficient prior knowledge of the complex nature of weak signals in general, which could have influenced the "distance" between information and the signal interpreter (van Veen and Ortt 2021). The above observations have in common that identifying signals as "weak" can be highly subjective and contextual, influenced by, for example, spatial and temporal scales; a signal that appears strong to some may be weak to others, and vice versa.

In the case of this study, whether or not the signal to be interpreted is really a weak signal (H3) or a stronger signal of a future change may not matter. The important perspective in this study was to increase individuals' awareness of how they use the future information provided by signals of change, and this can also be achieved with stronger signals. Therefore, for forest bioeconomy actors who are not familiar with weak signals or discontinuities affecting the forest bioeconomy operating environment, it may be useful to also look at H2 signals, which could aid understanding of H3 signals and the complex nature of futures.

Although semi-quantitative signal analysis was a structured and repeatable method for finding signal importance for the forest bioeconomy, it also included the issue of subjectivity. Determining the true importance of particularly weak signals may be challenging with knowledge based on current world phenomena. For example, if a signal appears unimportant at present, its importance may increase when moving into the future. Despite the need for development of the method, especially in determining the importance of weak signals, the method has relevance for decision-makers and practitioners of the forest bioeconomic sector, for its simplicity in assessing signals that are closer to the present.

TABLE 3a | SWOT analysis of the SETE system layer for signal interpretation.

Interpretations through SETE system	Excerpts from participants' interpretations
Strengths: • At the wider level of signal interpretation, macro-level phenomena are recognized as connected to the signals (e.g., participants identified different broad ecological driving forces affecting the signals). Weaknesses: • At this level, the effects of the signal on the actor's own work or activities may seem distant (e.g., it was difficult for participants to find a direct connection from signals to the forest bioeconomy businesses and organizations). Opportunities: • Signal interpretation through this layer enables the most imaginative interpretations (e.g., the pilot's group, consisting mainly of forest experts, interpreted the signals more imaginatively than at lower layers). Threats: • Since the "well of futures information" in the SETE system is deep, the threat is that something from the signals remains uninterpreted (e.g., the subject that was not discussed in the workshop: Is war the only factor that would force production of gunpowder from wood?).	• "We should consider what the boundaries could be in the forest ecosystem, the crossing of which could start a similar process". (Signal: Orcas (*Orcinus orca*) are attacking boats in Southwestern Europe). • "MasterChef Forest competition to improve the image/ brand + general recognition and awareness of where to use raw materials". (Signal: The researcher suggests adding cellulose to food as one solution to hunger). • "The governance creates the goals + funding; companies apply and therefore only implement those visions". (Signal: Europe is suffering from a gunpowder shortage "The main raw material for gunpowder is usually nitrocellulose, which can also be produced from wood-based products").

Although finding weak signals was difficult, the scanning team was diverse and came from different fields within the forest bioeconomy. The purpose of the expert matrix (Table 1) was not to fill all the cells but to gather a diverse group of people from the forest bioeconomy operating environment. This was achieved by taking an organizational perspective, rather than mainly including researchers or members of the scientific community, as was the case in the pre-scanning phase. The scanning team of this study included representatives of different types of forest bioeconomy organizations and various levels of futures expertise. However, an even more diverse group, where the participants would be entirely from outside the forest sector, could bring new perspectives to the research topic and facilitate finding weak signals affecting the forest bioeconomy. The problem in that case may be that outside participants may not find participation meaningful. In these questions, the sense of ownership would become a more important topic than it was in this exercise.

One aim of this study was to increase the sense of ownership through interaction. In previous studies related to forest planning, it has been found that stakeholders' sense of ownership has been promoted, for example, the implementation of plans through stronger commitment and co-productivity (e.g., Khadka et al. 2013). This was also the focus of this study; signal interpretation using the NEST framework combined with interactive horizon scanning aimed to develop forest bioeconomy actors' co-production of knowledge of futures. However, the topic still requires further research at the organizational level. For further implications, the collection and interpretation of signals should be able to be carried out within organizations to better utilize the results at a strategic level.

Since Horizon 3 signals were underrepresented in this study, the search for the weakest signals can also be improved in further studies. For example, quantitative methods could be used to find weak signals affecting the forest bioeconomy, and it may be more efficient to collect a large number of signals, unlike this study. These methods may include algorithmic data mining techniques with change or outlier analyses (e.g., Kuosa 2010; Eckhoff et al. 2014; Mühlroth and Grottke 2018). Quantitative methods were not used in this study, as the purpose was specifically to develop the orientation of forest bioeconomy actors towards signal information through interaction. Producing an "outside-in" perspective through the heterogeneity of the participants could facilitate finding weak signals affecting the forest bioeconomy, but when developing participants' awareness of how they could use signal information, external signals could also be beneficial. In this horizon scanning exercise, an externally produced signal ("*Orcas are attacking boats in Southwestern Europe*") was presented to the participants with the aim of broadening the perspective of seeing that even "illogical" and external signals could potentially have a connection with the forest bioeconomy.

The purpose of the second research question was to find out what kind of perspectives can be produced for different NEST layers of the forest bioeconomy through interactive interpretation of collected signals. The scanning team, which consisted mainly of forest experts, did not manage to make very imaginative interpretations of the signals. In addition, the interactive interpretations followed the forest sector's traditional ways of dealing with the future, which was seen, for example, in the case of an externally produced signal. This may be due to two factors: First, the collected signals were mainly H2 signals from

TABLE 3b | SWOT analysis of the Meso layer for signal interpretation.

Interpretations through Meso layer	Excerpts from participants' interpretations
Strengths: • At the Meso layer, interpretation of the signal is focused from an abstract level towards a more concrete level of activity, which can facilitate understanding of future information given by the signals (e.g., in this pilot, participants found the connection from the signal to the Meso layer easily). Weaknesses: • Since the interpretation focuses on a specific field of activity, the interpretation may become too practical (e.g., the discussions in the workshop dealt with practical topics, although there could have been more opportunities for ideation). Opportunities: • Interpretation through the Meso layer enables an interim step between the Actor layer and the SETE system: Gradual interpretation from the SETE system to the Actor layer can improve understanding of the connection between the actor and the broad SETE system. Threats: • Without interpretation through other layers, the benefit of interpretation through the Meso layer is lost: In addition to interpretation through the Meso layer, interpretation through the SETE system and Actor layer is also needed, so that the future information and complexity offered by signals of change can be better illustrated for forest bioeconomy actors.	• "*Self-sufficiency + technology development in China: effect on, for example, Finnish pulp/sawn wood exports*". (Signal: The electric car brand BYD overtook Volkswagen as the most popular car in China). • "*What should the reaction be to this signal?: an ecological electric car as a European concept?*" (Signal: The electric car brand BYD overtook Volkswagen as the most popular car in China). • "*Recycling as a problem with composite products → to what extent can be recycled → collection problem → incineration → image issues*". (Signal: Composite products can replace current wood products (e.g., guitars)—composite becomes the new "wood").

the near future, resulting in interpretations that may be more practical than if the signals were ambiguous H3 weak signals. Second, this study indicated that the recruited forest bioeconomy professionals did not necessarily have sufficient futures capacity for the search for signals of change and their further interpretation. An individual's futures capacity has been studied previously (e.g., Pouru-Mikkola and Wilenius 2021), but the futures capacity of forest professionals in particular has not been studied extensively. Although using the NEST framework for signal interpretation can itself develop the futures capacity of participants, this study shows that futures capacity building of forest professionals is needed to better utilize futures information provided by signals of change. Therefore, in subsequent studies, more emphasis should be placed on building sufficient futures capacity before interactive and interpretative foresight exercises.

In this study, a weak futures capacity of the participants was reflected in the individual task of the interpretation exercise. It was noteworthy in the interpretations at the Actor layer that participants chose signals related to climate change as one of their most important signals. This may be due to the fact that participants were not able to perceive the connection between the "illogical" signals and their own work, or because we usually pay attention to perceived negative aspects more sensitively than to positive ones (e.g., Rozin and Royzman 2001; Vaish et al. 2008). In addition to recruiting a professionally diverse horizon scanning team, subsequent studies should also pay attention to an individual's temperament, world view, and previous experiences as they can affect both the perception of signals and their interpretation. For example, the Myers Briggs Type Indicator (MBTI) has been used to help understand the future orientation of actors (e.g., Morrow 2005; Voros 2018) and it has been shown that different actors perceive and react to novel situations differently.

Although the interpretations for the NEST levels were mostly practical, and the forest bioeconomy or the participants' own activities were not seen far into the future, this exercise succeeded in developing the participants' orientation towards the future in a workshop situation. However, a challenge with using the NEST framework in this study was that different signals were interpreted at different layers. If the same signal had been interpreted at each layer, the differences in the interpretations could have become more visible. Due to the relatively small number of participants, however, the purpose of this study was to interpret as many different signals as possible, to interpret the forest bioeconomy and its different layers

TABLE 3c | SWOT analysis of the Actor layer for signal interpretation.

Interpretations through Actor layer	Excerpts from participants' interpretations
Strengths: • Bringing a seemingly distant signal close to one's own activity, which can improve understanding of the connection between one's own activity and the SETE system. Weaknesses: • Utilizing futures information brought by the signals of change also requires looking outside one's domain (e.g., the systemic nature of the forest bioeconomy is better understood when signals of change are also interpreted through the SETE system). Opportunities: • At this level, the signal is interpreted through the actor's own work/activity, which provides an opportunity to reflect the individual's own feelings, unlike the previous layers. Threats: • Since interpretation through the Actor level gives more opportunities for interpretation through one's own feelings, a lot can be overlooked (e.g., participants of this pilot recognized and interpreted a lot of signals related to climate change, because its effects are clearly visible in the forest sector and in the work of participants).	• "*If the Gulf Stream stops, it arouses confusion and even fear in me.*" (Signal: "Was it a mistake to prepare for climate change if the Gulf Stream stops?"). • "*Policy changes as a result of these signals can affect all aspects of forest use, the economy, etc.*" (Signal: Europe's air dries up—"Tree growth and carbon sequestration at risk"). • "*In signals related to climate change, the availability and usability of wood is questioned, which affects the operations of organizations that utilize wood*" (Signal: "Burning may still be the most valuable use of wood in the future").

through multiple signals. The purpose of the Actor layer interpretations, in particular, was to find as many Micro-layer interpretations as possible by letting participants choose the most significant signals. The Actor layer interpretation of the workshop was an individual task, with individuals documenting their own feelings and reactions. Theoretically, the goal of the Actor layer was to conceptualize the connection between the signal interpreter and the wider landscape (SETE system). The purpose was to make the actor appear as part of the whole, which was accomplished in this exploratory study.

Horizon scanning processes can be extended into the creation of action plans in organizations (Cuhls 2019). The use of the NEST framework in this study in signal interpretation can be thought of as an intermediate step between searching for signals and action taking, as it provides an opportunity to understand the field of forest bioeconomy and the signals affecting it. Thus, the use of the NEST framework in signal interpretation enables the application of the method of decision-making and action plans in private and public organizations. In addition, as is the nature of horizon scanning processes (Cuhls 2019), this study can also be considered a first step in the broader foresight process. In the next steps, the NEST framework could be tested and developed as part of a more continuous horizon scanning process. In this case, it would be possible to return to the observations produced by the interpretation framework, and also the knowledge between the wide field of phenomena offered by the signals and the actor's own operating environment would gradually develop. A larger scanning team outside the forest bioeconomy may be helpful in this broader endeavor.

The purpose of the third research question was to find out how the utilization of the layers of the NEST framework works in signal interpretation. To answer this question, a SWOT table was utilized to structure the observations made from the exercise. Despite the simplicity of the SWOT analysis (Pickton and Wright 1998), it was found to be a suitable tool for answering the third research question as the purpose was simply to explore the NEST framework's strengths, weaknesses, and applicability in signal interpretation. The results suggest that systematic signal interpretation through all layers is needed. Specifically, interpreting the signal through all layers allows the interpreter to be seen as part of the system, in which case reacting to the signal can also be seen as important and valuable. Due to this fact, the NEST framework can be used differently, for example, interpretations can also be made from another direction (from the Actor layer to the SETE system). When the actor has the possibility of seeing themself as part of a bigger system, anticipation of the future can be experienced in a more meaningful way. In the case of the forest bioeconomy and transition studies, this could be done in anticipatory workshop situations where the goal is to anticipate, for example, a sustainable biosociety.

However, organizing a horizon scanning exercise without a real connection to the current issues of the participants' operating environment is challenging, and it could produce difficulties in strategy building and action-taking processes (Cuhls 2019). According to Cuhls (2019), and what was also learned from this horizon scanning exercise, in expert methods, it is only possible to achieve futures knowledge that is within the limits of the knowledge and vision of the experts involved. Therefore, the system delimitation outlined by the NEST framework is needed not only for the interpretation of signals but also for determining and selecting expertise. By viewing the forest bioeconomy as a nested and interconnected entity where the boundaries between "within" and "outside" the system converge, even "completely outside participants" could find participation meaningful. What is outside and what is inside the system depends on how it is viewed. Therefore, using the NEST framework could be a way to make both interpretations and filtering more structured and transparent in the forest bioeconomy and other sectors based on renewable resources.

Methodologically, there is potential in using the NEST framework for the interpretation of signals. Based on the results of this study, the NEST framework enables an analytical tool to conceptualize futures information for companies and organizations in a practical way. However, this study alone is not a sufficient test of the feasibility of the NEST framework. New ways of developing signal interpretation using the NEST framework can be explored in subsequent studies. This may include, for example, linking signal interpretation exercises into the foresight practices and strategies of companies. Further research is still required to learn how to support the interpretation of weak signals of change in a way that utilizes companies in the forest bioeconomy and other sectors based on renewable resources.

6 | Conclusions

This study has contributed to the development of the analytical frame and practice of interpreting signals of change with the help of the NEST framework in the forest bioeconomy. The study provides examples of how the NEST framework can be utilized in foresight processes; first, this study provides an example of how interactive horizon scanning can be performed in the forest bioeconomy operating environment. Second, this study also gives an example of how the utilization of the NEST framework works in signal interpretation as part of the horizon scanning process. Overall, the NEST framework was shown to have strengths and possibilities in interactive horizon scanning processes to interpret signals more effectively. But, revealing its full potential requires further research to successfully utilize it in various foresight practices and in other sectors based on renewable resources.

Furthermore, this study provides implications for business and practice. For business, this study gives an example of how individual signals could be seen as part of a wider field of phenomena. For example, distant SETE layer signals can be considered as much a part of the operating environment as signals occurring near in the internal operating environment. In addition, this study provides an example of how the futures information produced by signals of change can be communicated to micro-level decision-making processes using the NEST framework. Thus, this study provides a piloted example of how the NEST framework could be utilized in foresight practices for private and public organizations in the forest bioeconomy and other sectors based on renewable resources. On a practical level, the findings of this study can also be utilized by individuals; when developing individuals' foresight skills and orientation towards the future, it will also bring a proactive approach to the entire company or organization.

This study lays down a foundation for future research. First, this study shows that the search for the weakest signals of change (H3) remains challenging. However, before improving the search for signals, analytical tools such as the NEST framework and an understanding of the importance of the ecological dimension are needed in the forest bioeconomy to better understand the interconnected nature of signals of change. Second, the results indicate that further research on signal interpretation in the forest bioeconomy is needed; when developing foresight practices in sectors based on renewable resources, such as the forest bioeconomy, it is also necessary to prepare for discontinuities which are difficult to anticipate. In these situations, successful companies can be identified by the fact that they have cooperatively built an ability to react quickly to unanticipated developments with appropriate organizational responses. The piloted interactive horizon scanning campaign of this study provides motivation for the development of strategic foresight in these situations in different organizations in the forest bioeconomy and other sectors.

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Data Availability Statement

Collected data of this study (collected signals of change) can be found online at https://doi.org/10.5281/zenodo.16317286.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.
Supplementary material A: Interim analysis table: Interpretations of selected signals through the SETE system. **Supplementary material B:** Interim analysis table: Interpretations of selected signals through the Meso layer (Forests and forestry; Processing, refining and products). **Supplementary material C:** Interim analysis table: Interpretations through the Actor layer. Examples of signals that participants considered significant for their own work or organization.

Appendix A

Question Templates Used in the Workshop

1. Interpretation assignment: Interpretation through the forest bioeconomy operating environment	
Signal: ____	
Question 1: Why might the signal in question be considered significant in terms of the future of the **forest bioeconomy**? Where could the signal lead to?	Question 2: What should the reaction be to this signal at present?: How should **firms/organizations** in the operating environment of the forest bioeconomy act?
Signal: ____	
Question 1: Why might the signal in question be considered significant in terms of the future of the **forest bioeconomy**? Where could the signal lead to?	Question 2: What should the reaction be to this signal at present?: How should **firms/organizations** in the operating environment of the forest bioeconomy act?

2. Interpretation assignment: Interpretation through the various fields of activity of the forest bioeconomy Field of activity: ____	
Signal: ____	
Question 1: Why might the signal in question be considered significant in terms of the future of **this Field of activity**? Where could the signal lead to?	Question 2: What should the reaction be to this signal at present?: What action should be taken in **this Field of activity**? How would your group act?

3. Interpretation assignment (Individual task): Interpretation through own work/organization		
Signal: ____		
Question 1: From the signals collected in Padlet, choose the one you think is most significant for your organization. What kind of feelings does this signal evoke in you?	Question 2: Why might the signal in question be considered significant in terms of the future of **your work/organization**? Where could the signal lead to?	Question 3: What should the reaction be to this signal at present: **How would you act in your organization**?