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Options for making responsive future strategy to foster sustainability transitions in the German agri-food sector: a Delphi-based approach

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Abstract

In response to pressing global challenges, sustainability transitions research has emerged as an interdisciplinary field focused on fundamental changes, necessitating novel approaches for strategy-making from research and innovation. Foresight practitioners need to extend their well-established methodological toolkit, which can inform subsequent planning processes about managing conflicts and shaping futures, to include the articulation of response options for contributing to the creation of more sustainable future systems. This research aims to contribute to this need by exploring future options characterized by discrepancies. Drawing from the Responsible Research and Innovation (RRI) literature to understand discrepancies between "desirability" and "probability" of future options as missed opportunities to secure social desirability in the future or as threats to it, this research argues for the collective identification and anticipation of discrepancies to reflect on options for making more responsive strategies. Thus, informed by RRI, a Delphi exercise was modified to engage experts from the German agri-food sector ($n=21$) to assess divergent innovation-driven changes in the German agri-food sector that had been collectively anticipated and reflected upon beforehand. The results speak for a reduction of complexity by revealing specific actions necessary to redirect research and innovation processes away from unsustainable paths, as well as identifying determinants of discrepancies to do good or avoid harm.

Keywords Responsible Research and Innovation, Responsiveness, Sustainability transitions, Agri-food, Delphi, Foresight, Desirability and probability discrepancies

Introduction

As the global challenges of climate change, environmental pollution, and resource depletion continue to mount, an expansive interdisciplinary research domain has emerged, focusing on sustainability transitions [26, 48, 61, 75]. Notably, sustainability transitions research has helped to better understand and govern transitions in various sectors [22, 42, 77, 79], to make suggestions for innovation to increase their transformative nature [23, 40, 45], or to identify interdependencies between sectors across different geographies, be it at the local, European or global level, in order to prevent adverse effects in the future [17, 50, 76]. For transition, profound and long-term changes are targeted, encompassing institutions, industries, technologies, and shifts in societal consumption and lifestyle patterns, all aimed at fostering a more sustainable economy [48, 49].

Foresight has evolved as a systematic approach for examining and deliberating upon complex futures, aiding

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sustainability transitions research in exploring alternative approaches to transform existing systems, addressing conflicts and devising strategies for navigating controversies that can result, for example, from different stakeholder expectations about what is desirable and what is not [19, 30, 39, 60, 61, 67]. Specifically, Foresight can play a crucial role in strategic planning by helping science, technology and innovation to proactively prepare for and shape the future with clear imaginaries [33, 53, 57]. In this context, Foresight is regarded as an essential tool for promoting sustainable research and innovation outcomes for sustainable change, by avoiding impulsive reactions to challenging situations or unexpected events [3, 11, 13].

Nevertheless, despite the recognition in the Foresight community of potential discrepancies in future options – including the desirable, the possible and the probable – assessments to inform decision-makers tend to focus on consensus within individual aspects, such as the most desirable and/or probable, and/or impactful [1, 41, 59, 80]. Therefore, there is arguably the risk of sidelining future options characterized by discrepancies to inform strategy-development for research and innovation. This is particularly the case for Foresight-related methods such as the Delphi. Cuhls et al. [16], for instance, suggest moving away from simplistic and isolated assessments of future options and supporting decision-makers with expert advice that captures the complexity of options and the reasons for the assessments. Additionally, even though it has been highlighted several years ago [28], current research still emphasizes the need to focus more on projections that have, for instance, a higher desirability but a lower probability [25]. Furthermore, in studies addressing discrepancies [17, 20, 27], a deeper elaboration of concrete proposals to help decision-makers act on the results remains limited [6, 80]. Consequently, there is a risk that valuable knowledge for promoting sustainable transitions is left undiscovered, such as on how reactions can be encouraged in the absence of consensus [58]. This is, however, critical for Foresight to inform sustaianble change with research and innovation, which requires substantial responses among various actors with divergent needs, goals and requirements. In order to extend the well-established toolkit available to the Foresight community, this research raises the question of how a Delphi can be used to inform research and innovation about responsive strategy-making to contribute to the creation of new procedures, structures, and institutional settings that promote beneficial outcomes and prevent harm.

In order to answer the research question, discrepancies between desirability and probability of future options are considered missed opportunities for sustainability transitions. Therefore, they are materialized to explore how a Delphi can inspire responsive strategy-making in the future, e.g., by helping executives to plan internal processes, structures and institutional settings in advance to help materialize the good or prevent the bad in the future.

To establish such an approach, this research utilizes insights from the Responsible Research and Innovation literature [55, 74]. Explicitly, it is proposed to put the principle of responsiveness into practice to ensure that broadly configured anticipatory, reflexive, and deliberative knowledge influences and shapes the purposes, processes, and impacts of research and innovation [54], p. 38). The principle of responsiveness helps in translating potential future challenges into actionable knowledge for response [5, 37]. Therefore, responsiveness serves as a means to integrate information from the other three RRI principles – inclusion, reflexivity, and anticipation – and to use this future knowledge to seize missed opportunities or mitigate harmful contributions to secure social desirability [4, 71].

Specifically, in this research, the Delphi method was modified to involve 21 experts from the German agri-food sector in an additional third-round. This round aimed to reflect on the collective anticipations and reflections from the previous two rounds, which assessed innovation-driven changes in the German agri-food sector, to select future options with desirability/probability discrepancies. In the third-round, the experts were tasked with identifying options for future responses to the selected future options, introducing increased responsibility for subsequent decision-making in research and innovation.

The results indicate promising implications for further planning and strategy-making. Specifically, the third round has proven instrumental in managing the complexity of anticipated future knowledge, ensuring the sustainable unfolding of innovation-driven changes. Moreover, during this round, in-depth reflections have led to the formulation of strategies that show potential to significantly contribute to favorable processes, structures, and institutional settings for realizing positive outcomes or preventing negative ones. Methodologically, this study contributes to the Foresight community by proposing an approach to bridge the gap between contested and applied knowledge in subsequent strategy-making. This is achieved through a detailed exploration of discrepancies in future options and a specification of response options. Conceptually, the study contributes to framing responsiveness, highlighting its dependencies on external factors.

The paper is structured as follows. In Sect. 2 Foresight is introduced, covering its current applications in assisting strategy-development for sustainability transitions. Here, the value of Foresight in addressing discrepancies is outlined and the importance of incorporating

increased responsiveness into Foresight processes, drawing from the RRI literature. Additionally, it is explored how the Delphi method can be modified to contemplate future response options. In Sect. 3, the modified Delphi method is presented, which comprises two key components: one for selecting innovation-driven changes in the German agri-food sector affected by discrepancies and the associated risks, and another for generating expert consultation on the reasons behind these discrepancies and potential suggestions for future responses to promote beneficial outcomes and avoid harm. Sect. 4 provides a detailed analysis of the results obtained from the third-round of the Delphi. This analysis offers insights into the identified probability and desirability discrepancies and risks, including suggestions for response and the expected prospects of achieving a more desirable future through the suggestions. Sect. 5 provides an in-depth exploration of the results, discussing their implications comprehensively. It also addresses the limitations and suggests potential avenues for future research. The final section concludes by summarizing the key contributions of this research to the literature.

Theoretical background

Foresight, strategy-making in research and innovation and discrepancies in future options

Foresight is associated with long-term planning, the systematic assessment of future developments marked by uncertainty and the engagement in structured debates about complex futures [10, 12]. Thereby, the Foresight results can stimulate discussions about predictions, thus informing more sustainable, resilient, or efficient outcomes. It also plays a role in setting future, vision-driven agendas to contribute to sustainable change with innovation [3, 12, 16, 32, 51, 53].

While, Foresight, with its capacity to inform research and innovation by consulting various stakeholders to reflect e.g., on interactions between social and technological change, may produce contentious or contradictory outcomes [33, 43, 52], Foresight-related methods such as the scenario or Delphi technique also offer the opportunity to work out contradictions or to find consensus and collective solutions by providing a platform for negotiations between stakeholders [15, 16, 39, 52].

Nevertheless, the Foresight literature also points out limitations that can impede the valuable analytical toolbox from fully contributing to sustainability transitions by inspiring research and innovation agendas. Firstly, current studies are calling for a more nuanced assessment of future options, such as by looking at combinations within future options or working out more specific instructions from different viewpoints [16, 20, 39]. However, this imperative remains only partially addressed in current practices. In contrast, there is still a need for further research to assess, for instance, how desirable predictions can become more probable [25]. Research efforts are arguably often concerned with isolated aspects within future options or consensus that simplify formulating suggestions for potential reactions [1, 18, 41, 43, 58, 59, 80].

Secondly, studies delving deeper into discrepancies e.g., between desirability and probability or contested opinions, could offer more concrete recommendations for action [17, 20, 27, 44, 58]. This could complement research by showing for instance,how proactive strategies can be developed that not only help to act more sustainably in the presence of less desirable scenariosnot only [6] but also to move from less desirable to more desirable scenarios. Without the knowledge on how research and innovation can best establish new forms of production and consumption by revealing required changes across various relevant actors, potentials to contribute to sustainability transitions might be jeopardised.

Although previous studies acknowledged the need to delve deeper into the development of actionable results, questions such as 'so what?' and 'what actions can be taken?' persist when executives grapple with the predictions [80], p. 1). Cuhls [11] as well as Cairns et al. [6] expressed concerns in the past that Foresight results might could fail to inspire decisive action in subsequent discussions. This failure can lead to the perpetuation or exacerbation of existing sustainability issues or the creation of entirely new sustainability issues and addressing these challenges requires collaboration among various actors. However, due to the complexity involved, it can be difficult to find consensus across different needs, desires, and requirements through Foresight, further complicating the definition of actionable recommendations [58]. To illustrate new avenues for research and innovation to contribute to the development of more sustainable systems, this paper employs the Delphi method for extensions, aiming to address at least some of the identified difficulties.

In this paper, it is argued that relevant information for further progress can be found in the RRI literature [55, 74]. In essence, RRI aims for research processes that are inclusive, anticipatory, reflective, and responsive [55, 74]. The responsiveness principle translates insights gleaned from inclusivity, reflexivity, and anticipation into actionable guidance for informed responses [5, 54, 65]. This enables stakeholders to derive practical insights, facilitating timely actions to prevent harm or do good with

innovations. To achieve responsible management of sustainable issues and thereby achieve long-term socio-technical improvements, RRI requires substantial changes in innovation processes, structures and institutional settings and the willingness to integrate these changes as integral elements of resulting innovations [24, 66, 72].

Combining foresight, RRI and the analysis of discrepancies

RRI encourages the anticipation of potential future concerns with the broader society to reflect on what is good or what could do harm [68]. This proactive approach aims to enhance the strategic governance of research and innovation with two primary objectives: firstly, to prevent potentially adverse consequences of innovation in the future that could jeopardise e.g., sustainability, and secondly, to maximize the beneficial impacts of innovation [4, 33, 65, 76]. In this setting, potential conflicts caused by coexisting needs, desires and future expectations are not suppressed, instead, they are elevated to achieve the best possible outcome for various individuals in different contexts [31]. Importantly, once discrepancies emerge, they necessitate a response to attain the most desirable alternative.

The responsiveness principle urges researchers and innovators to respond to new insights to establish plans to govern societal challenges most desirably [65]. According to Scherer and Voegtlin [66], p. 6), this "[…] involves establishing institutions, structures, and procedures on multiple levels in order to facilitate innovations that fulfill […] [doing no harm] and […] [doing good]." Thus, responsiveness implies translating new insights into options for future response in order to enable responsible management of research and innovation that can establish better versions of the conducted research and innovation. This, in turn, can contribute to the creation of new forms of production and consumption [56].

There have been suggestions on how to make Foresight processes more responsible. These include articles on participatory agenda setting for research and innovation (PASE) [32, 64, 69] and procedures for conceptualizing Foresight processes that adhere to RRI principles [78]. However, the emphasis remains on anticipating impacts, involving a broad spectrum of stakeholders, and fostering reflexivity in agendas. While it is argued that these processes can enhance responsiveness, more emphasis should be placed on efforts to translate complex insights into practical guidance for informed responses to inform institutions, structures and procedures [32].

Therefore, the purpose of this paper is to utilize a Delphi method to identify response options for addressing future options characterized by discrepancies between desirability and probability. The following section outlines how such an approach has been developed and piloted. The Delphi survey aimed to kickstart expert consultations, allowing for a deeper understanding of desirability/probability discrepancies and risks for sustainability, pinpointing their underlying reasons, and generating recommendations for future responses to maximize future sustainability prospects of research and innovation efforts.

Development and application of a modified Delphi method

Foresight, as an approach to systematically explore and discuss complex futures with a long-term view [9], incorporates various tools and methods. In this paper, the Delphi method will be employed, leveraging its structural advantages to guide research and innovation processes toward greater sustainability.

Delphi surveys adhere to certain design elements. Experts are invited based on pre-defined expert criteria [36] to make sure they have the knowledge and experience to make competent judgments [8]. The exchange of arguments in Delphi surveys is iterative. Meaning, that experts are enabled to evaluate their considerations in relation to the opinions of other participants in two or more rounds [36, 46]. Additionally, the Delphi is a structured tool often used to inform subsequent decision-making and planning in which participants can learn from other experts and adjust their responses if considered necessary [15]. These aspects make the Delphi method particularly well-suited for integrating insights from the RRI literature and exploring avenues into strategy-making to increase responsible management of sustainability issues in transitions.

To legitimize a particular set of future options to be considered in subsequent decision-making and strategy-making processes, Delphi surveys often use criteria such as desirability and probability to narrow down the initial set of future options and define the most relevant ones concerning the given objective [16]. Probability can inform research and innovation by indicating future areas that may gain relevance, enabling the alignment of innovation developments and the strategic allocation of resources in these identified areas. Desirability indicates whether experts wish for a future to become a reality [27]. These findings can later be used by decision-makers to reflect on current research and innovation directions, e.g., to avoid ad hoc decision-making in the presence

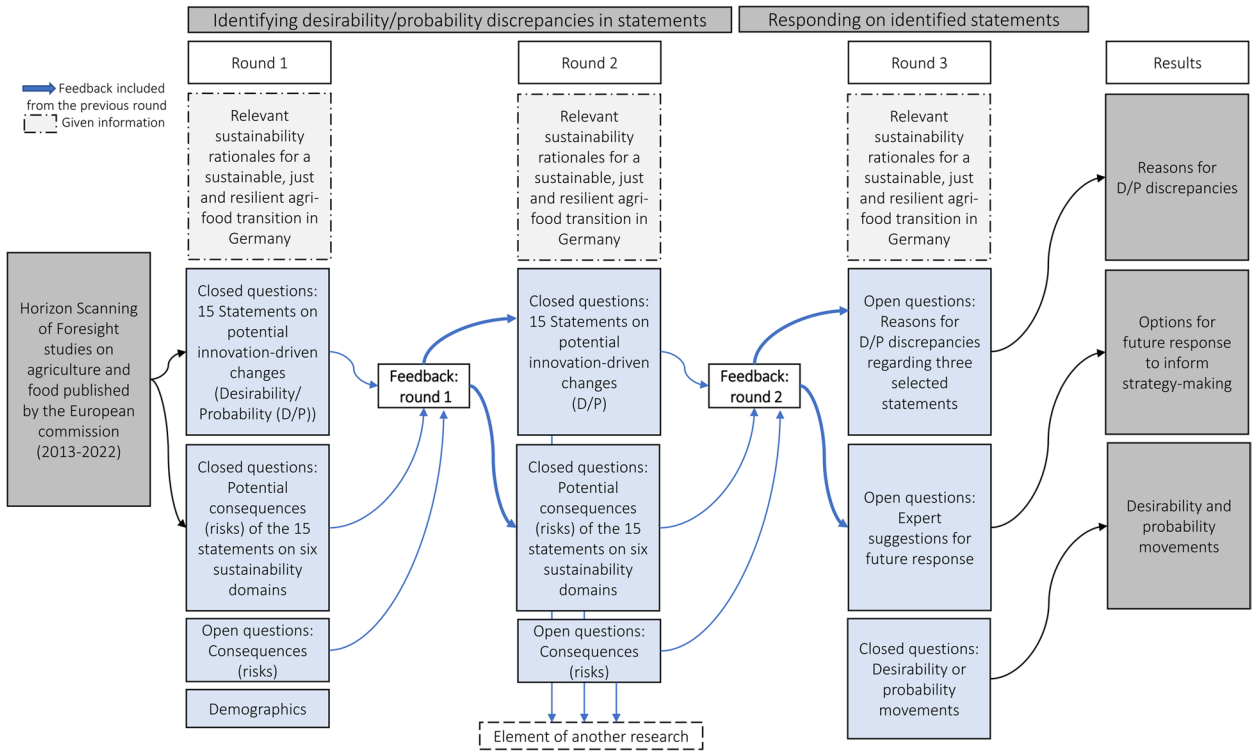

Fig. 1 Three-round Delphi design to identify options for making responsive future strategy

of unexpected events [13]. In this study, the focus is on future predictions that are either desirable but improbable, or undesirable but probable.

The present Delphi survey was in line with the mentioned design elements but made the following modifications (Fig. 1). First, German agri-food experts[1] had to be identified and selected based on pre-selected requirements, to collectively deliberate on the desirability and probability of innovation-driven future changes in the German agri-food sector in the first two rounds.[2] This happened out of an initial set of 15 statements[3] (see Appendix A). Additionally, the experts were asked to anticipate the potential consequences (e.g., risks) of the 15 statements on six predefined sustainability domains.[4]

In the second step, after the two rounds and an interim analysis of the results from the second-round, three statements were selected that were characterized by desirability/probability discrepancies. These elaborations became essential for the further deliberation, reflection and anticipation of potential recommendations to respond to the generated knowledge in the third-round. Only the experts who finished the first and the second-round were invited to the third-round to assess the three selected statements.

[1] The experts were partly members of the project Food4future and Agricultural Systems of the Future. (AdZ), out of which the present Delphi emerged, as well as selected external experts who were chosen on the basis of criteria.

[2] Scale for desirability: 1 = absolutely not desirable; 2 = not desirable; 3 = neutral; 4 = desirable; 5 = absolutely desirable. Scale for probability: 1 = 2022–2032; 2 = 2033–2043; 3 = 2044–2054; 4 = 2055–2065; 5 = never.

[3] The 15 statements were created based on a horizon-scanning process of Foresight studies with agriculture and food as their main theme, published by the European Commission over the past decade.

[4] Scale for risks: 1 = absolutely no risk; 2 = slight risk; 3 = moderate risk; 4 = risk; 5 = very high risk. The six risk aspects (or sustainability domains) were: Social equality = Potential negative impacts on access to food/services for all individuals, regardless of gender, income, age, education, and living space; Environmental and climate factors = Potential negative impacts on carbon footprint, CO_2 level, or other climate-related issues; Human well-being = Potential negative impacts on promoting and ensuring human well-being, both in terms of physical and mental nature; Social Cohesion = Potential negative impacts on the sense of belonging, solidarity and relationship between and within social groups; Technological sovereignty = Potential negative impact on national independence from external (foreign) technologies and innovation capabilities; Market infrastructure = Potential negative impact on ensuring resilient (robust) market infrastructures through fair competition and balanced market power relations between companies/organizations. The corresponding explanations for each risk aspect (or sustainability domain) were presented to the experts for better understanding.

In this paper, the focus is on the results of the third-Delphi round after the experts were asked to reflect on possible future discrepancies and risks for sustainability, in order to start elaborating on response options and how this can influence sustainability prospects of innovation-driven future changes.

Selection of statements with desirability and probability discrepancies

To be able to think about response options to innovation-driven changes in the German agri-food sector, they first had to be identified. Therefore, an initial set of 15 statements about potential innovation-driven changes in the German agri-food system were presented to German agri-food experts who fulfilled the following criteria:

- Representative position (e.g., representing larger organizational units, chair holder, executive director, etc.) or a scientific presence (e.g., published scientific papers that are considered relevant);
- Actual knowledge (e.g., informed about recent developments);
- Specific knowledge through practice or experience;
- Relation to Germany (e.g., research and work in or about Germany and can understand/speak German);
- Diverse knowledge (e.g., private and public perspective);
- Work experience measured by the number of years (e.g., at least two years of work experience)

The criteria followed suggestions from Cuhls [14] and Seeger [70] to make sure that the experts perceived the aggregated answers as relevant. Furthermore, in accordance with the RRI principle of inclusiveness, experts were required to engage with and reflect on a wide spectrum of possible perspectives to facilitate the reframing of potential issues and the exploration- of potential contestations throughout the Delphi process [55]. This was instrumental for identifying future options, including their ambiguities within desirability and probability discrepancies. The participating experts in the third-Delphi round then had to continue their deliberations based on the knowledge from the previous rounds to reflect on options that can realign the predictions with the initial goal of a just and resilient agri-food transition in the future.

Additionally, to incorporate responsible governance of sustainability issues in research and innovation, RRI encourages the description and analysis of intended and unintended impacts that innovation might have on economic, social, environmental, ethical or other sustainability dimensions [54, 55]. Thereby, RRI acknowledges that sustainability for the one does not per se imply sustainability for the other. In contrast, different expectations, desires, and needs have to be anticipated and reflected upon during assessments to foster the best possible outcomes by responding to generated knowledge [31, 47, 66]. One option to modify the Delphi method accordingly was to build the third-round not solely on the anticipated knowledge regarding desirability and probability from the previous rounds, but also on the in-depth examination and analysis of the intended and unintended impacts of innovation-driven changes on various sustainability dimensions.

Thus, the assessments in the third-round were built upon the anticipated results from the previous rounds, not only assessing 15 statements in terms of desirability and probability, but also their associated risks on six predefined sustainability dimensions, encompassing among others, potential negative impacts on the access to food/services for individuals, e.g., in terms of gender, income, age, education, and living space (social equality); potential negative impacts on the carbon footprint, the CO_2 levels, or other climate-related issues (environmental and climate factors); or potential negative impacts on the promotion and and protection of human well-being, e.g., in terms of physical and mental aspects (human well-being)[4]. These dimensions encouraged experts to reflect on distinct sustainability needs from different perspectives. The sustainability dimensions were identified in advance as essential components of a sustainable agri-food system based on the RRI literature and STEEP categories (Social, Technological, Environmental, Economic, Political). The final expert assessments after the second-round formed the basis for identifying and querying statements with desirability/probability discrepancies in the third-round to anticipate potential future response options and thereby obtain information for subsequent strategy-development, e.g., about adjustments to make positive contributions or prevent harm.

Figure 2 illustrates how the statements about potential innovation-driven changes in the German agri-food sector were assessed after the second-Delphi round. The threshold for desirability was set at 3.5, with an observable trend toward desirability. Statement 6 stands out as one of the least probable statements, with a value just above 2, but also as the only improbable one that exceeds the value of 4, indicating clear desirability. Furthermore, nearly all statements that are considered more desirable tend towards being rather probable, assuming a threshold of 3 for probability. Interestingly, however, after the second-Delphi round, the two least desirable statements are also those, which are assessed to be rather probable. Consequently, based on these results, it was decided to conduct a more detailed examination of the discrepancies in the statements 6, 13 and 15 in Delphi round three.

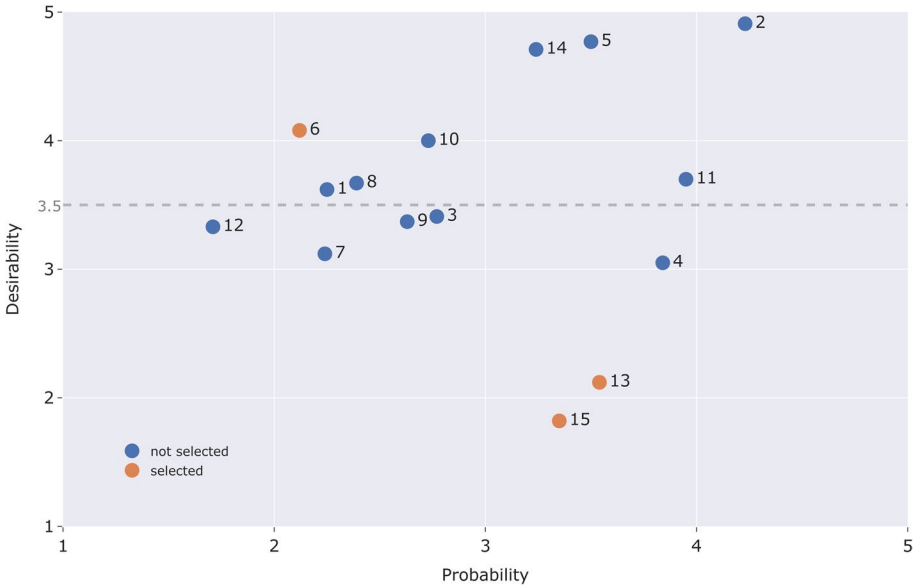

Fig. 2 Selection of innovation-driven changes in the German agri-food sector with desirability and probability discrepancies. Note: Scale for desirability: 1 = absolutely not desirable (low); 2 = not desirable; 3 = neutral; 4 = desirable; 5 = absolutely desirable (high). Scale for probability in scatterplot: 1 = never (low); 2 = 2065–2055; 3 = 2054–2044; 4 = 2043–2033; 5 = 2032–2022 (high). To display desirability and probability jointly in one scatterplot, the scales for probability had to be reversed (via SPSS)

Deriving options for making responsive future strategy

The Delphi was developed as part of the food4future project, funded by the BMBF since 2019 in conjunction with the "Agricultural Systems of the Future" program. The subproject aims to explore new food sources and cultivation methods in urban areas, contributing to the development of a sustainable and resilient agri-food system in Germany that is equitable for all.[5] The first two rounds of Delphi were executed between March and June 2022 and the third-round between July and August 2022. From a total of 560 experts from the German agri-food sector invited to participate in the Delphi, 52 experts completed the first-round and 32 the second-round. After the first and the second-round, 21 experts completed the third-round.

The third-round was designed to promote the principle of responsiveness, encouraging experts to contemplate identified discrepancies arising from collective anticipation and reflection [5, 54, 55, 74]. Its purpose was to stimulate the development of strategic plans for responsive actions in the future [65, 81]. Consequently, the third-round offered ample resources for experts to consider and propose response options based on reflections from the previous round, particularly concerning desirability, probability, and associated risks for sustainability.

In the third-round, the experts had to explain the reasons for discrepancies and find solutions to the identified and selected statements. Therefore, statements 6, 13 and 15 were again presented to the remaining experts who finished the first and the second-round. Before the experts could assess a statement, the aggregated results on desirability and probability were illustrated as histograms indicating the discrepancy. This revealed whether the statement was desirable but improbable or undesirable but probable. The desirability and probability values referred to the mean values after the second-round.

Specific questions were posed to examine the discrepancies in more detail. In the case of statement 6, experts were queried about their opinion regarding its lower probability despite a higher desirability. Conversely, for statements 13 and 15, experts were asked to explain the higher probability despite lower desirability. Thereafter, the experts were asked to explain potential reasons, which could lead a statement to be desirable but improbable or probable but undesirable. For each assessment, the experts were provided with free text fields. The second part of the questionnaire centered on anticipating potential future responses. This aimed to provide later decision-makers with insights into more beneficial structures, practices, and institutional settings that could enhance the sustainability prospects of selected innovation-driven changes or help prevent harm to sustainability caused by them or others. The second-part included the two main risks for each statement that also contributed meaningfully to the discrepancies (see Table 1). These were generated by analysing the qualitative and

[5] https://www.food4future.de/en/home

Table 1 Desirability and probability discrepancies and main risks for sustainability

No.	Desirability	Probability	Identified risks
6 (*n* = 24)	4.08	2.12	1. Intensification of soil management
			2. Increased food prices due to costly production
13 (*n* = 24)	2.12	3.54	1. Disappearance of small and medium-sized market participants
			2. Intensification of transport and logistics can create new environmental problems
15 (*n* = 17)	1.82	3.35	1. Influence and monitoring through external third parties
			2. Social risks due to a lack of data security

Results after the second-Delphi round. The number of experts who have evaluated a given statement in the second-Delphi round (n) may differ depending on the statement. Desirability and probability scores show mean scores (compare caption Fig. 2)

quantitative expert assessments from the first two rounds. The analysis involved examining the frequency with which the same risks for sustainability were formulated by different experts, their risk rating on the Likert-scale, and whether the risks were part of expert dissent.

This approach also helped focus assessments for future action on specific aspects (risks), accumulating more knowledge on targeted elements rather than limited knowledge across diverse aspects. Subsequently, experts had the opportunity to propose recommendations to mitigate risks and suggest potential response options to address discrepancies. They were then tasked with assessing whether these recommendations would render the innovation-driven future changes more probable in one case or more desirable in the other. A mutual convergence was considered an indicator that the experts have found potential options for future responses that can guide strategic plans to promote sustainability or prevent harm.

The open experts' comments about desirability/probability discrepancies and risks for sustainability were deductively coded with MAXQDA. The Delphi results to inform executives about opportunities for being responsive in the future have been divided into two themes: structures and procedures, as well as institutions. This thematic distinction was made because responsiveness involves the establishment of structures and procedures (e.g., how research is done and what technological attributes are considered) and the necessary institutional settings (e.g., political regulations or modes of consumption). Additionally, descriptive statistics were calculated in SPSS to assess the effects of the recommendations on discrepancies, such as whether they reduced discrepancies.

Background on findings from Delphi round two and the three selected statements with discrepancies

In this section, the three selected statements are placed in a more comprehensive setting considering the previous reflections regarding desirability, probability and risks for sustainability from the second-round. Specifically, it places them within the broader context of some of the other findings from round two to give an overview of how the experts envision the future agri-food system in Germany (see Fig. 2 for comparison). The results for perceived desirability (*1 = absolutely not desirable to 5 = absolutely desirability*), probability (*1 = 2022–2023 to 5 = never*), and the two main risks for sustainability (*1 = absolutely no risk to 5 = very high risk*) that emerged for the three selected statements after round two are summarized in Table 1. The table also indicates the number of experts who assessed each given statement.

The most desirable and probable prediction that emerged after the second-round is the introduction of a nutrient-rich diet in school canteens and cafeterias (statement 2). However, it is acknowledged to carry certain risks, particularly concerning social cohesion and equality, potentially benefiting only a selected few at the expense of children from households with lower income levels or different cultural backgrounds.

The prediction that the amount of land required for (per capita) food production in Germany has decreased by 70% compared to today (statement 6) represents one of the most desirable predictions of a future innovation-driven change in the German agri-food sector. Experts from Delphi round two rate it only slightly less desirable than statement 2 with the highest desirability scores of all statements. However, if statement 6 occurs under the given circumstances, experts anticipate severe sustainability risks. Specifically, these risks are foreseen for the environment and climate due to the potential intensification of land management. The expectation is that society may be reluctant to adopt alternative production and consumption methods, such as vertical production sites. Additionally, there are concerns about social cohesion, with the risk of rising prices attributed to more expensive production driven by a lack of technological knowledge and infrastructure.

Another prediction with clear sustainability dissonances is statement 4. Statement 4 also has meaningful implications for sustainability transitions, as it is assessed

below at desirability score of 3.5 and as rather probable. However, the statement was not selected because other statements are deemed more severe. While the introduction of machines in supermarkets can have positive outcomes, catering to the preferences of more mobile individuals by opening new employment opportunities (statement 4), it simultaneously raises concerns. These concerns revolve around social isolation experienced by distinct social groups, notably older individuals, and the potential detachment between consumers and food-production processes. Similar to statement 4, statement 10 also exhibits discrepancies in sustainability assessments. Statement 10 is only assessed slightly less desirable than the selected statement 6 and also less probable compared to other statements with much lower desirability scores, e.g., the selected statements 13 and 15. In terms of statement 10, experts were divided on whether local supply chains with direct links between local suppliers and consumers are desirable. Those deeming it undesirable expressed concerns about interdependencies between local and trans-regional/international supply chains. They argue that these chains should be complementary and vary depending on the geographical context. Conversely, experts who find statement 10 desirable see opportunities for several producers to market their products locally or regionally in the future, thereby diversifying the market. This approach holds potential for reducing transport and storage costs, positively impacting product freshness, and contributing to a reduction in CO_2 emissions. Statement 7 holds one of the highest risk scores among all statements. Five out of six sustainability dimensions[6] are threatened by precision nutrition, which allows fine-tuning of nutrition for individuals or groups. Although its probability is still assessed as rather low, experts view it as an ongoing evolution of present trends, including intensive research on personalized nutrition and an enhanced understanding of functional ingredients. Experts often associate precision nutrition with highly processed foods and express concerns about diminished utilization of fresh and minimally processed nutrition in the future. They anticipate higher costs for end-products, limiting affordability to only a privileged few. Statement 13 has even more severe risk assessments than statement 7, with considerable risks in all six sustainability dimensions.[7] Statement 15 bears risks in three out of the six sustainability dimensions[8] but shows the highest relative risk scores in two out of the three dimensions: social cohesion and social equality. However, both statements (13 and 15) simultaneously have higher probability scores compared to other rather undesirable statements. Regarding Statement 13, which predicts that 60% of daily groceries in Germany will be purchased online, experts' express concerns about potential negative effects on market infrastructure. The fear is that small and medium-sized market participants may disappear, with large companies expected to emerge as the winners in this development. Additionally, experts anticipate problems for the environment and climate, attributing these issues to the intensification of transport and logistics. Lastly, the experts consider it undesirable if people in Germany use digital technologies by default to make their nutritional decisions and to provide doctors, employers or insurance companies with the data (statement 15). They express concerns about potential risks to social equality through influence and monitoring by external third-parties. Additionally, there are worries about risks to social cohesion, particularly through the lack of data security, which could potentially lead to discrimination against certain groups or individuals based on factors such as ability, dietary choices, etc.

Results

The following section provides an overall assessment of the three selected statements, considering discrepancies in terms of desirability and probabilities, as well as the identified risks for sustainability. These assessments follow the experts' collective anticipation and reflection in the first two rounds with the goal to contribute to the development of strategic plans by identifying options for future responses.

Options for developing more responsive strategies in the future

This section presents detailed insights into the reasons for discrepancies and potential risks for sustainability associated with the selected future innovation-driven changes in the German agri-food sector. The insights into the reasons for the discrepancies, risks and possible suggestions for future responses emerged from the analysis of the experts' qualitative comments. The suggestions regarding potential response options include institutional aspects (e.g., regulations, production, consumption, etc.) as well as structural and procedural aspects (e.g., research, technological attributes, etc.).

[6] Statement 7: Social equality = 3,8; environmental and climate factors = 3,0; social cohesion = 3,6; technological sovereignty = 3,0; market infrastructure = 3,3.

[7] Statement 13: Social equality = 3,3; environmental and climate factors = 3,8; human-wellbeing = 3,0; social cohesion = 3,3; technological sovereignty = 3,0; market infrastructure = 3,4.

[8] Statement 15: Social equality = 3,9; human-wellbeing = 3,7; social cohesion = 3,9. Values indicate the means. Rating is done on a 5-point Likert scale: 1 = no risk; 2 = minor risk; 3 = moderate risk; 4 = high risk; 5 = very high risk.

Table 2 Expert assessment of discrepancies and recommendations for response (St. 6)

Discrepancies in innovations contributing to a reduction of land required for (per capita) food production (in Germany)	
Reasons for lower probability	- The consumption of meat dominates diets, which makes the introduction of innovations favouring other forms of nutrition difficult
	- Societal reluctance to accept new consumption and production patterns that could avoid intensification of soil management while increasing food production
	- Technological possibilities and knowledge is not sufficient to implement less land-intensive cultivation methods (e.g., indoor farming, vertical farming, cultured meat) while ensuring efficiency and scalability
	- Regulatory settings are not favouring novel production methods in Germany
Reasons for higher desirability	- The growing population calls for solutions to reduce the land required for (per capita) food production while ensuring sufficient supply
	- New land for renaturation is needed to save the environment
	- Reduction of livestock farming
Options for "doing good" with innovations contributing to a reduction of land required for (per capita) food production (in Germany)	
Institutions, Structures & Procedures	- Engage in political/societal debates to increase market prices of animal products by showing their real prices (e.g., to include cost of negative externalities or adjust sales tax, such as a lower tax on more "sustainable" food options)
	- Engage in political/societal debates to facilitate the approval of new food sources or production processes and thereby make innovations for sustainability more economically viable
	- Incorporate activities for awareness-raising and education to emphasise the benefits of plant-based diets
	- Increase participation and transparency to engage with society (e.g., utilize positive narratives in terms of novel production methods)
	- Strengthen closer cooperation between scientific and business stakeholders (e.g., to allow knowledge transfer)
	- Establish training opportunities and attractive working environments to acquire and keep skilled workers for technological advancements
	- Involve more traditional agri-food actors (e.g., farmers)
	- Identify indicators to set sustainability standards
	- Establish education programmes (e.g., in schools highlighting plant-based (vegan) diets or revitalising self-sufficiency (e.g., through urban gardening in areas like roofs, gardens, or allotment garden colonies) to promote a dietary change among the population
	- Involve political decision-makers to create attractive markets (e.g., reduce low-cost competition from abroad)
	- Focus on extensive pasture farming (e.g., use of local resources such as fertilisers and water)
	- Consider (local) compensation areas to benefit biodiversity
	- Specialize in vertical farming (e.g., hydroponic forms) to reduce the use of resources
	- Account for ecological value to increase land use through ecological farming (e.g., mixed cultures instead of monocultures or the diversification of land use)
	- Increase efficiency in production (e.g., through automation, high-precision farming or optimized technologies)

The findings from the qualitative analysis are summarized in the following. Tables 2, 3 and 4 provide a more detailed overview of the expert recommendations. The reasons for desirability and probability discrepancies illustrate the experts' assessments in the third-Delphi round. Each evaluation starts with the reasons for (higher or lower) probability to compare them with the reasons for (higher or lower) desirability. Afterwards, the experts' suggestions for future responses are outlined. They aim to fulfill two objectives: a) to increase the probability of a desirable development which is currently not probable (do good), or to increase the

Table 3 Expert assessment of discrepancies and recommendations for response (St. 13)

Discrepancies in innovations contributing to the online purchase of daily groceries (in Germany)	
Reasons for higher probability	- Trend towards digitalization evident (e.g., increasing number of delivery services, subscription offers for food boxes, etc) and technical possibilities more advanced
	- Consumers are becoming increasingly convenient (e.g., lack of time favours solutions that allow consumers to spend less time grocery shopping. Additionally, the demand for a broad and simple selection of products is increasing)
	- Online grocery shopping enables individualized food offerings
	- Opportunity for major distributors, resulting in strong market tends in the corresponding direction
	- Smaller grocery stores (e.g., in rural areas) are disappearing and alternatives for grocery shopping are needed
Reasons for lower desirability	- Rik of market concentration: Larger market players are better equipped to cope with new demands (e.g., investment in equipment), squeezing out smaller market participants
	- Larger market players can absorb the actual costs for transport, packaging and logistics, thus obscuring the true environmental costs
	- More packaging waste and traffic
	- Online grocery shopping decreases the human-food connection
	- Difficult communication due to the elimination of customer contact
	- Quality of food becomes untransparent
	- Disappearance of traditional retail can negatively affect urban structures
	- Smaller towns lose social infrastructure and options for value creation (e.g., online shops do not offer local jobs)
	- Loss of regional and (small) farming structures
Options for "avoiding harm" with innovations contributing to the online purchase of daily groceries (in Germany)	
Institutions,Structures & Procedures	- Provide best-practice examples for the establishment of comprehensive digital infrastructures (e.g., business models based on online purchasing channels for smaller retailers)
	- Engage in political/societal debates for direct support for smaller retailers (e.g., to establish online purchasing platforms that include services for shared logistics and transport)
	- Engage in political/societal debates for the establishment of tax arrangements and subsidies favoring CO_2-neutral transport
	- Engage in political/societal debates for stricter regulations regarding in favor of electric vehicles or other more climate-neutral transport and delivery concepts
	- Engage in political/societal debates to broaden options for climate-neutral transport (e.g., rail transport)
	- Engage in political/societal debates on the expansion of the transport network (e.g., autonomous public transport networks with connections for freight transport)
	- Provide approaches for alternative deposit systems for transport (e.g., boxes instead of plastic bags)
	- Engage in political/societal debates for improvements and regulatory interventions in regional logistics
	- Cooperate with regional value chains (e.g., to organize central pick-up stations)
	- Seek cooperations for the establishment of shorter transport routes
	- Promote consumer participation (e.g., with positive narratives, which strengthens consumers´ interest in production)
	- Involve small and medium-sized enterprises in food supply chains to establish trade associations (e.g., similar to vegetable boxes)
	- Increase transparency about current agricultural value chains e.g., to strengthen consumers interest in production
	- Create competencies for digital business models (e.g., for direct marketing)

Table 3 (continued)

	- Commit towards improving the competencies of more traditional agri-food system actors (e.g., smaller retailers, farmers) in digital business models and fostering collaboration
	- Elaborate alternatives for last-mile deliveries (e.g., cargo bikes)
	- Use environmentally friendly packaging (e.g., focus on recycling and reusable packaging)
	- Apply climate-friendly transport options
	- Focus on regional products that can be offered and distributed locally

Table 4 Expert assessment of discrepancies and recommendations for response (St. 15)

Discrepancies in innovations contributing to the use of digital technologies to make nutritional decisions and the sharing of data with doctors, employers or insurance companies (in Germany)	
Reasons for higher probability	- The costs of poor nutrition are rising rapidly. Therefore, preventive measures and treatments are being pursued
	- The value of data for businesses is tempting
	- Insurance companies and employers provide incentives for customers to share their nutritional and health related decisions, e.g., with bonus campaigns or reduced rates
	- Interest in learning about one's own state of health
	- Labor shortages are driving digitalization (e.g., in the health sector)
	- Desire for self-optimization coupled with too little self-assessment in society
Reasons for lower desirability	- Data on dietary choices can be used to influence consumers
	- With increasing transparency, a decline in consumer autonomy can be expected
	- Social cohesion (e.g., community and solidarity) can decrease (e.g., if the control of eating habits affects social benefits or access to career opportunities)
	- Loss of freedom of choice: Possible exclusion and disadvantages if an individual does not want to participate
	- Data protection issues could lead to exclusion of specific social groups (e.g., based on physical conditions)
Options for "avoiding harm" with innovations contributing to the use of digital technologies to make nutritional decisions and the sharing of data with doctors, employers or insurance companies (in Germany)	
Institutions, Structures & Procedures	- Engage in political/societal debates to clarify boundaries for data usage
	- Engage in political/societal debates to improve privacy and data protection policies and to ensure accountability of those that violate these rights
	- Consider aggregating data to avoid drawing conclusions about individuals at later stages
	- Engage in user education
	- Strengthen transparency about data use, data sharing and potential risks
	- Strengthen support measures (e.g., for older individuals)
	- Follow strict data protection regulations (e.g., only ask for thematically relevant data)
	- Create conditions that ensure that the extent of data entries is fully understood by all individuals
	- Ensure the voluntary nature of the data entries

desirability of an undesirable development which is currently not desirable (avoid harm) and thereby b) address the incorporated risks for sustainability. Finally, it will be assessed if the suggestions for future response led the experts to believe that the proposed recommendations for responsive action will make a statement either more desirable or more probable in order to balance the discrepancies.

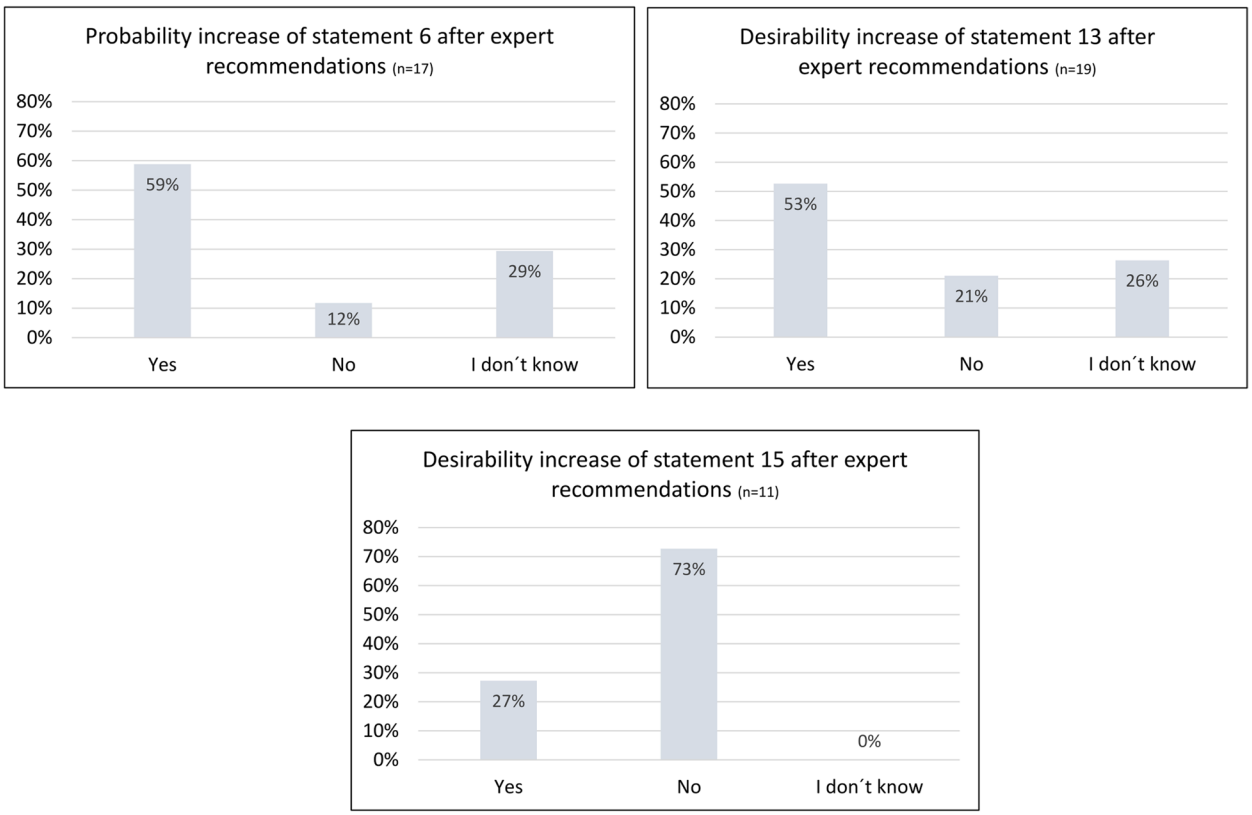

Fig. 3 Desirability/probability movements after expert recommendations for future response

Statement 6 carries the risk of a favourable future option not materializing, potentially missing an opportunity to contribute to sustainable transition by means of innovation. Experts attribute the low probability to conflicting dietary habits in the society, particularly the high meat consumption and a resistance to adopting new consumption and production patterns. The prevailing focus on animal farming in current diets, coupled with insufficient advancements in approaches like vertical farming in Germany, hinders achieving lower land use in agri-food production. Nevertheless, despite challenges, factors such as a growing population necessitate solutions to reduce required (per capita) land for food production, rendering statement 6 desirable in the eyes of the experts. Lower land use for food production also creates new aeres for renaturation, a vital component of a more sustainable German agri-food system in the future.

Experts point to potential response options in both institutional as well as structural and procedural areas. Responses targeting these areas can ultimately contribute to more favorable settings in the future that help statement 6 to materialize. The experts advocate a shift in consumption patterns towards a more plant-based and diversified diet to acquire new land for increased biodiversity (e.g., through compensation areas), especially if less farmland is allocated to animal livestock or the cultivation of animal feed. Therefore, consumer engagement should be an integral part of research and innovation processes, facilitated by participatory activities and direct collaborations for consumer education. Furthermore, technological attributes should not be centered around monocultures but favor multi-crop production. It is recommended to plan research activities according to current and future sustainability requirements, e.g., by actively planning for compensation areas or identifying sustainability indicators that can influence future standards for novel production methods in confined spaces and, thereby, contribute to the establishment of long-term sustainability measurements.

Encouraging researchers and innovators to engage in political and social debates is considered essential to have an influence on future regulations and gain competitive advantages in light of future sustainability requirements. Efforts can be directed towards determining the actual costs of animal products, e.g., to account for negative externalities in the future, or towards speeding up authorization procedures for novel food sources or production processes, which, in turn, can incentivize new research and innovation projects. Strategic networks are recommended to enhance performance, improve investment structures for niche innovations, facilitate

high-skilled labor exchanges and engage more traditional agri-food actors (e.g., farmers) as partners for change by leveraging their existing knowledge and experience while expanding it.

Statement 13 suggests an unfolding development with potentially unsustainable impacts on the future German agri-food system. Experts attribute the high probability to current trends, which have been accentuated by the Covid-19 crisis. Digitalization trends, already underway for years, have spurred technological advancements. Simultaneously, online grocery shopping has emerged as a solution to meet evolving consumer needs, providing convenience, time efficiency, and location independence without being more expensive than onsite grocery shopping. The ability to tailor offerings to individual preferences enhances the convenience of online grocery shopping but also risks weakening the human-food connection. Additionally, this development can also lead to fragmented deliveries and result in more waste, with adverse effects on environmental sustainability. Furthermore, large companies, with their established positions in retail structures and vested interest in promoting online shopping, are better positioned to navigate and capitalize on these changes, risking the squeeze-out of smaller retailers and impacting market diversity. Particularly in rural areas, smallholder structures, which are an important source of income in Germany, are increasingly threatened by the disappearance of local trading structures.

To address the adverse impacts of statement 13, experts propose measures to establish comprehensive digital infrastructures for the benefit of small and medium-sized agri-food actors in the future. Supporting these participants to form supply chain communities, such as by establishing central pick-up stations shared by regional producers, can streamline logistics and enhance efficiency. The assistance through digital platforms plays a crucial role in facilitating direct and individualized marketing between consumers and regional producers without adding extra time burdens for consumers.

To make such an infrastructure work, various efforts are required. Small and medium-sized agri-food actors need to expand their competencies in digital business models to compete more effectively. Collaboratively organized supply chains that build on these best practice examples can reshape market structures and increase the competitiveness of isolated actors. Along these lines, research and innovation are called upon to build partnerships accordingly and simultaneously, invest in new concepts for recycling and deposit management, and seek partnerships to electrify transportation. Experts emphasize the need to expand the rail network and strengthen partnerships for electrified transport and last-mile delivery in Germany.

Best practice examples can inform other market participants, thereby changing current modes of production and consumption and setting requirements for the government. Government support is crucial, both for favoring the establishment of online agri-food platforms and the extension of climate-neutral transport. Therefore, research and innovation are urged to actively advocate their digital concepts in political and social debates. Firstly, recommendations can aim at ensuring a low entry threshold for affected actors and offering support in organizing collaborative logistics and transport concepts that are available at little or no additional cost. Secondly, recommendations can aim at introducing stricter regulations in favor of electric vehicles and expanding the options for climate-neutral transport, such as rail transport or autonomous vehicles, in order to drive progress in these areas.

Statement 15 suggests an impending undesirable influence on the agri-food system in Germany. This assessment is rooted in the existing infrastructure, rapid technological advancements, widespread use of mobile devices, and a growing openness toward digital technologies for self-optimization. While external recommendations for a healthy diet can be efficient, experts' express concerns about potential restrictions or influences on individual diets. The overarching risks identified for statement 15 relate to external monitoring and social risks stemming from inadequate data security, especially regarding potential discrimination due to data misuse.

Researchers and innovators are called upon to enhance data security by encrypting data and selecting partners or server locations judiciously. Moreover, ensuring that personal information is provided voluntarily and with full disclosure of its intended use is crucial. Informed user consent is vital for voluntary data input, and transparency in data processing and transfer can be strategically employed to boost consumers´ demand for these standards in the future. These measures can serve as innovative components to differenciate future products from competitors, e.g., by exceeding current security standards while setting new standards in the future. Therefore, experts also advocate investing in user education, emphasizing the need for consumers, regardless of age, to comprehend the potential consequences of giving consent and which standards should be fulfilled.

Research and innovation should also collaborate closely with political decision-makers to devise and implement stricter accountability measures for potential violators of data protection standards. Efforts should focus on establishing clear and legally binding boundaries for data use, outlining regulations on accessible data and essential requirements, and incorporating obligations for user awareness and consent.

Desirability and probability movements after experts' suggestions for future response

This section outlines the findings regarding the desirability or probability movements after the expert´s identified options for future response. The movements were captured by asking the experts whether they believed the proposed recommendations for responsive action would make a statement either more desirable or more probable. For statements 13 and 15, it was only asked whether there would be changes in desirability since it was assumed implausible to make statements less probable. Figure 3 provides a more detailed illustration of the descriptive results regarding the desirability and probability movements.

For statement 6, which has been assessed as a desirable but improbable future option, the recommendations lead to an increase in probability. Hence, the outlined response options can help realign the prediction with the goal of achieving a sustainable contribution from research and innovation to the agri-food transformation in Germany. After asking the experts if they think that their suggested recommendations will have an impact on the probability of the statement, most of the experts answered yes (59%). This implies that the response options to statement 6 can open up new avenues for discussion. Specifically, they can contribute to securing sustainable impacts on transformation by changing how research and innovation is conducted and by establishing necessary institutional settings. In terms of statement 13, the suggested recommendations can help to increase the desirability of a probable innovation-driven future change, which has been considered undesirable in terms of its potential impacts on the future German agri-food system. If these recommendations for future responses are disregarded in subsequent discussions, there is an increased risk that the way research and innovation is conducted will negatively impact the German agri-food sector, adversely affecting sustainable change. More than half of the experts (53%) think that the recommendations for response can increase the desirability of the statements. The suggested recommendations can serve as valuable inputs for future dialogues and decision-making processes, guiding choices that may redirect the future option onto a more sustainable trajectory. For statement 15, the recommendations to respond to discrepancies by establishing alternative institutional settings, as well as structural and procedural actions, are considerably fewer compared to the other two statements. One expert points out that "[Company X] will establish this anyway […].[9]". This indicates a certain inability of research and innovation to take action. 73% of the experts believe that the identified options for future response will not lead to an increase in desirability. Hence, there is a high risk that undesirable changes will continue to manifest without sufficient response options being available to adequately mitigate undesirable effects.

Discussion

This research wanted to show how a Foresight approach with an adopted Delphi survey can inform response options for contributing to increased sustainability in the transition of the German agri-food sector. The focus was on innovation-driven future changes that fall into two categories: those that are undesirable but probable (posing potential harm to sustainability) and those that are desirable but improbable (representing missed opportunities for sustainability). Additionally, the study sought to investigate how Foresight can offer actionable insights for subsequent strategy-development and planning. This involved making response options more explicit within a broader contextual setting to deviate from unsustainable trajectories and contribute to the creation of more sustainable future systems by means of research and innovation.

It was demonstrated that engaging experts in discussions on jointly anticipated and reflected future options can enhance responsiveness in decision-making and planning processes, positively impacting future sustainability prospects. The third-Delphi round encouraged experts to make potential responses more explicit, including the establishment of alternative management structures, processes, and institutional settings to contribute to the creation of desired outcomes while avoiding undesired ones. This addresses previous concerns about Foresight assessments falling short in producing actionable outcomes to inform decision-making and planning [6, 11, 80], especially when dealing with contested knowledge [58]. This is illustrated by the suggestions aimed at increasing the probability of Germany reducing its per capita land required for food production. Despite discrepancies, the participating experts managed to go beyond the identification of areas where action is needed [27, 44] and provided concrete starting points for early strategy-development to change dietary habits in the long-term and thereby make the development more probable in the future. Moreover, suggestions helped to outline options for organizational or social innovations for consumer education or increased self-sufficiency, complementing technological advancements such as vertical or pasture farming. Additionally, the proposed responses offer clear entry points into political debates to change institutional settings that embed research and innovation in the future. Such as by

[9] Quote has been translated from German into English.

helping to determine the actual costs of animal products or by accelerating authorization procedures for novel food sources or production processes so that new niche innovations can emerge. This shows that it is possible to reduce the complexity often associated with multi-layered and controversial future options. This improvement enhances the ability of research and innovation to achieve more sustainable developments by providing in-depth information about the necessary changes required from various actors to create new forms of production and consumption.

Moreover, the presented Delphi method aimed to circumvent the risk of a superficial assessment by incorporating various aspects of future options, including underlying assumptions. This approach went beyond a narrow focus on what is most probable and desirable [1, 41], instead, it critically evaluated future options that are improbable but desirable or probable but undesirable. As demonstrated in previous studies such as from Kauffeld et al. [38], this approach can yield valuable insights for addressing future challenges. However, by introducing a third-Delphi round into the research design the research delved deeper into the discrepancies. This served to identify critical factors contributing significantly to the discrepancies. In terms of the reduction of land required for per capita food production in Germany, experts were able to attribute the lower probability of the statement to consumer behavior and the lack of technological progress in Germany. Specifically, the reduction of land required for per capita food production is less probable when the consumption continues to be based on end products from livestock farming. Conversely, it becomes more probable when consumption changes to a more plant-based diet. Concerning the aspect of people purchasing daily groceries online in Germany, experts highlighted the absence of business models and best practice examples to assist small- and medium-sized agri-food actors in the transition to digital and environmentally friendly infrastructures. This was identified as a crucial factor contributing to the lower desirability of this future option. Additionally, regarding individuals using digital technologies to make nutritional decisions and provide data to third-parties in Germany, the results suggest a lack of regulatory standards to ensure the desirability of this future option. By elucidating the critical determinants for discrepancies, they can be better addressed and mitigated. The third-Delphi round played a pivotal role in highlighting crucial determinants that require intensified focus. The observations may highlight the importance of forging closer science-business-partnerships to enhance competencies for developing digital and environmentally friendly infrastructures for logistics and transport, serving as a crucial lever for a sustainable transition and increasing the desirability of a less favourable but probable future option.

Additionally, by adding a specific focus on ensuring the sustainable unfolding of developments, potential risks for sustainability have been considered irrespective of whether a statement was deemed desirable or not. For instance, despite the desirability of reducing the land required for per capita food production in Germany, the findings show that ensuring a sustainable unfolding of this development requires broader considerations. For instance, solely focusing on technological advancements for increased efficiency is insufficient for a sustainable unfolding; instead, it necessitates complementary innovations, including innovations for organizational change to enhance transparency and engagement. The outcomes may argue for more dynamic collaboration with traditional agri-food actors, whose valuable knowledge may be overlooked, and engagement with political decision-makers to ensure universal access to end products. This shows that addressing isolated aspects to enhance the probability of desirable future options can potentially lead to unsustainable outcomes, jeopardising sustainability despite its inherent potential. This underscores the need for a multi-faceted approach, emphasizing not only isolated innovations but a nexus of interconnected innovations to navigate innovation within system transitions in a sustainable manner.

By developing and elaborating on results from the third-Delphi round, this research also intended to better conceptualize the RRI principle of responsiveness in a well-established method employed by the Foresight community. Additionally, the study aimed to contribute to the growing body of research calling for a better operationalization of the responsiveness principle to inform research and innovation [32, 64, 73, 81].

The third-round utilized the collective identification and anticipation of discrepancies to reflect on them and generate future knowledge for crafting more responsive strategies for increased desirability in developments. Thereby, the extended Delphi process presents a conceptual framework for understanding responsiveness in its dependence that goes beyond the willingness or availability of options to implement substantial changes in research and innovation processes [24, 72]. While certain Delphi results suggested that responses targeting certain research activities or technological components could positively impact desirability and probability, they also indicated that responses do not enhance the sustainability prospects per se. For instance, measures to enhance data protection, such as choosing partners or server locations wisely, do not secure social sustainability or increase the desirability of individuals in Germany using digital technologies for nutritional decisions and

data transfer to third-parties. However, the results point to unfavourable settings influenced by overall innovation behavior and institutional regulations affecting the agri-food sector, resulting in less substantial effects of research and innovation responses on reshaping the system's functioning. This underscores previous research calling for a disruption of the digital economy in Germany at multiple levels to evade sustainability lock-ins [35], but adds practical implications for science, technology and innovation as well as policy-making. If the digitization of consumption via technical devices connected with data transfer is to unfold more sustainably, various actors have to share responsibilities to address harmful side-effects for social sustainability. Regulations and institutions, in particular, need to support research and innovation so that their responses to sustainability challenges can have a meaningful impact on transforming current modes of production and consumption. Conversely, research and innovation are tasked with allocating resources to identify potential disadvantageous conditions for sustainability improvements and, thereby, hold responsible parties accountable.

Despite the valuable contributions, this research has limitations. Statement 6 did not achieve consensus on probability after the second-round. This implies that experts participating in the third-round may have viewed statement 6 as more probable from the outset, potentially affecting the observed probability movement. In such cases, the movement would be based not solely on the suggested response options but also on the composition of the expert panel. Therefore, the results are not generalizable to other expert compositions. Additionally, some observations could be influenced by desirability biases [2, 21]. Therefore, it could be the case that the recommendations for future response did not make statement 6 more probable, but only more desirable, which led the experts to also rate the statement as more probable. Finally, this study does not provide a comprehensive assessment of the agri-food system in Germany, as only three innovation-driven changes were selected. However, the results support the argument for a broader assessment in Foresight research, potentially applying a similar approach to a wider range of developments. Moreover, future research can leverage the Delphi process presented in this study to conduct similar research designs and build on the findings to develop scenarios and assess their potential impacts on outcomes. This approach would offer additional insights to expand subsequent scenario work, allowing us to not only explore contradictions but also potential future responses. Similarly, the study could benefit from incorporating insights from other, more action-orientated frameworks such as technology assessment and comparing the results with these to gain additional understandings [7, 34]. In addition, other Foresight-related methods need to be highlighted that might better suited to working out contradictions and finding solutions in an experimental way, such as the scenario technique [15]. Therefore, they should be utilized in the future. This could result in fruitful relationships for outlining additional opportunities for preventative innovation approaches.

Conclusion

Building on the RRI framework, this research aimed to contribute to sustainability transitions in the German agri-food sector by explicitly identifying potential future response options for research and innovation to address diverging innovation-driven future changes that have been collectively anticipated and reflected upon beforehand. This has contributed to existing agri-food transitions research by focusing on the German context [29, 30, 61–63]. Additionally, the Delphi procedure constituting a third-Delphi round has added a specific focus to get the most out of future options that yield missed chances for sustainability or to mitigate harmful effects. The results demonstrate that the Delphi method can be adapted to enable increased responsiveness in the future, which ultimately increases the sustainability prospects overall. To address sustainability issues in research and innovation processes more responsibly, it is crucial to recognize system complexities while elaborating on potential response options more explicitly. This helps in adopting a multifaceted approach to sustainability transitions, for instance, emphasizing the combination of technological advancements and organizational innovations to ensure sustainable trajectories. Additionally, communication procedures should reflect these complexities. Effective communication cannot be one-sided. Instead, knowledge about desires, needs, requirements, and expectations need to be captured and integrated into research and innovation processes but also distributed and expanded. In addition to methodological contributions, this research provides a conceptual approach to understanding the responsiveness of research and innovation. It highlights the dependence on external settings and advocates for strategies that distribute responsibilities to achieve substantial impacts in sustainability transitions.

Supplementary Information

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Supplementary Material 1.

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Availability of data and materials
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

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

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