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Serious gaming as climate service co-production: developing S2S forecasts for the Norwegian agricultural sector

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Abstract. Subseasonal to seasonal (S2S) forecasts offer valuable opportunities for the agricultural sector by bridging the gap between short-term weather forecasts and long-term climate projections. However, their adoption faces significant challenges, including high uncertainty, coarse spatial and temporal resolution, and difficulties in communicating probabilistic information effectively. Establishing a meaningful dialogue between forecast producers and users is crucial to ensure these forecasts address user needs. This study explores the use of a serious game methodology to facilitate such dialogue and guide the development of S2S forecast services tailored to the Norwegian agricultural sector. Through game sessions involving farmers and agricultural advisors, we identified strategies users employ to interpret S2S forecasts and uncovered diverse use approaches for these products. Our findings highlight key recommendations for service development, including ensuring seamless integration of forecasts across different lead times, providing narrative explanations of probabilistic data, supporting user familiarization with the tools, and exploring the use of recent years' conditions as reference points instead of historical averages. The serious game approach proved effective in fostering meaningful dialogue and mutual learning among agricultural users, forecasters, and service developers, ultimately supporting forecast services' co-production.

1 Introduction

1.1 Opportunities and challenges of S2S forecasts for the agricultural sector

Advancements in weather models have pushed the timeframe of short- and medium-range weather forecasts further into the future. At the same time, new developments in climate models allow for more localized and precise long-term climate projections. Subseasonal to seasonal (S2S) forecasts hold the time frame in between, aiming to bridge the gap between the two-week weather scale and the two-year climate scale (Robertson et al., 2015; White et al., 2017). S2S forecasts can be helpful tools in various sectors of society when planning for more efficient resource management, by providing likely weather scenarios from weeks to several months in advance (Bruno Soares and Dessai, 2015; White et al., 2017). The agricultural sector, in particular, can take advantage of S2S forecasts in making various operational decisions (Ceglar and Toreti, 2021).

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Examples of those are fertilizing and harvesting timing, water management for irrigation, crop-planting choices, product marketing, and estimation of crop yields (Meinke and Stone, 2005; Clements et al., 2013; Vitart, 2014).

Developing effective services for agricultural sector stakeholders, however, requires understanding their decision-making contexts and needs. In turn, for agricultural stakeholders to consider, apply and evaluate novel services such as S2S forecasts, they need to expose themselves to and become familiar with such information. This is particularly important because information on this timescale involves much greater uncertainty than short-range weather forecasts, and therefore must be presented, interpreted, understood and used in a different way, one that is unfamiliar to many.

The consistency of forecast services with decision makers' needs strongly influences their effective use. As Hu et al. suggest (Hu et al., 2006), reasons for forecasts (not) meeting user needs extend beyond the characteristics of the forecasts, such as accuracy and appearance. Other factors to be considered are farmers' attitudes toward the forecasts, social norms, barriers perceived as limiting their use, reliability of the sources, design, functionality and user-friendliness. Moreover, the use of a forecast product can be motivated by a variety of reasons. According to Ray and Webb (2016), users may access a forecast product at a certain moment because they want to consult it (use type 1), consider it as a factor influencing their decisions (use type 2), incorporating in a decision-making operational model (use type 3), or even use it as a starting point to discuss the risks related to a decision (use type 4). The availability of forecast information can also be relevant from a mental health perspective, since weather uncertainty is one of the key risk factors for farmers' mental health (Daghagh Yazd et al., 2019; Romssa, 2023).

Together with forecast providers' scarce knowledge of farmers' decision processes, communication challenges also prevent their transformation into actionable products. Communicating probabilistic information and uncertainty that characterize S2S forecasts to lay audiences is notoriously difficult (Stephens et al., 2019; Fundel et al., 2019). Cognitive biases such as motivated reasoning, the tendency to interpret new information in a way that supports preexisting beliefs, cause unintended interpretation of the forecast content (Ripberger et al., 2022).

The existence of multiple ways of evaluating the usability and usefulness of S2S forecast information services challenges the assessment of their benefits. Different frameworks have been used in the literature for this purpose, such as measuring the difference in the economic payoff of making a decision with the use of specific (probabilistic) forecast information and of making the same decision without (Hamlet et al., 2002; Oubrhou, 2023), or eliciting the maximum monetary amount that individuals would be willing to pay for the service (Lazo et al., 2009; Makaudze, 2005). Most available studies focus on the quantification of economic values, thus disregarding the variety of non-economic forecast benefits and the more subjective, contextual factors that challenge or enhance their actual use (Bruno Soares et al., 2018).

To acknowledge the existence of multiple uses of S2S forecasts and assess the requirements for successful uptake of information services, we explore a serious game methodology to inform the development of forecast services for the Norwegian agricultural sector.

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1.2 Serious gaming as a co-production tool

Involving users in the development process of a forecast service can help overcome the aforementioned challenges and contribute to the information being perceived as relevant, familiar and trusted. A co-production framework (Bremer and Meisch, 2017), involving iterative dialogue with stakeholders, allows the producers to take into account users' decision-making context, creating information that is more transparent, legitimate, and relevant for the users (Meadow et al., 2015). However, establishing an effective dialogue between individuals with different backgrounds and expertise, such as S2S developers and farmers, can be demanding.

Previous studies in climate science have demonstrated that serious games—games designed with a purpose beyond mere entertainment—can serve as powerful tools for conveying complex climate information and fostering constructive dialogue among stakeholders with diverse areas of expertise (Flood et al., 2018). In gaming simulations, participants play with a dynamic but simplified model of reality, representing a real system and its processes (Klabbers, 2009). This allows them to collaboratively explore and understand how the system works or might work under certain conditions. Game-based exercises can thus simulate actors' decision-making processes, demonstrate their consequences in the system and, in the case of our study, allow end-users to become familiar with novel types of forecast information (Kriz et al., 2022). In this work, we build on these good practices and explore a participatory game-based approach to create a platform for effective engagement and communication between S2S forecast providers and agricultural users in Norway.

Various examples of serious games focusing on or including S2S forecasts exist in the literature. Their purposes include collecting data about the preferences or thinking processes of the players by observing their choices, behaviour and discussions (Gunda et al., 2017; Stephens et al., 2019; Neumann et al., 2018; Crochemore et al., 2021; Ramos et al., 2013; Arnal et al., 2016), transmitting complex scientific information to a non-expert audience (Terrado et al., 2019; Parker et al., 2016), and promoting social learning (Koelle, 2014; Sautier et al., 2017), i.e. the change in participants' understanding due to the sharing of knowledge and points of view, that could lead to a change in behaviour in reality (Den Haan and Van der Voort, 2018). Their target audience and related formats also vary significantly, from relatively simple online single-player games designed to reach a large number of participants among the general public (Stephens et al., 2019), to complex board games that simulate the reality of a specific group of stakeholders (Sautier et al., 2017). These studies show that a different level of abstraction is needed in modelling the real system, depending on the scope of the game (Kriz, 2022).

In this work, we present Melkeværet, a hybrid board-digital game simulating the decision-making context of Norwegian farmers in fodder production, while depending on observed and forecasted weather conditions. The game was developed by the Norwegian Meteorological Institute (MET Norway) in collaboration with advisors from the Norwegian agriculture advisory organization Norsk Landbruksrådgiving (NLR), in the framework of the Climate Futures centre for research-based innovation. Despite an inevitable level of simplification, Melkeværet simulates real constraints and outcomes of management choices at subseasonal to seasonal timescales.

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The co-development and implementation of Melkeværet allowed us to explore the role of S2S forecast information in farmers' decision-making processes and identify key factors affecting the relevance and use of S2S forecasts for the Norwegian agricultural sector. These insights are crucial for guiding the development of future S2S services tailored to that sector. Since the process of developing a general seasonal forecast service was ongoing at MET Norway in parallel to this work, the game sessions were also an opportunity to test this new service with a relevant group of potential users. Similarly, a 21-day forecast had been launched by MET Norway in January 2024, thus allowing us to collect feedback on the newly released service since the first session. Additionally, the study allowed us to test and discuss in a transdisciplinary setting the use of participatory serious games as tools to foster dialogue between meteorologists and stakeholders as part of a service co-production approach. In the following section, we outline the design process of Melkeværet and describe the setting of six game sessions carried out between June 2024 and November 2025. We then present the findings of the work in relation to the processes employed by the participants to make use of the S2S forecasts, the challenges emerged in communicating information clearly and the group dynamics observed during the game sessions. In the Discussion session, we reflect on S2S forecast use types for the Norwegian agricultural contexts, the implications of the different uses for the development of tailored S2S forecast services, and the opportunities and limitations of using serious games in co-production processes of climate services.

2 Methodology

In this section, we first describe the steps we followed during the development of Melkeværet, with reference to both its analogue part (board game) and digital interface component. Then, we describe the structure and the participants of the game sessions.

2.1 Design process of Melkeværet

The development process of the game followed six steps, summarised in Fig. 1.

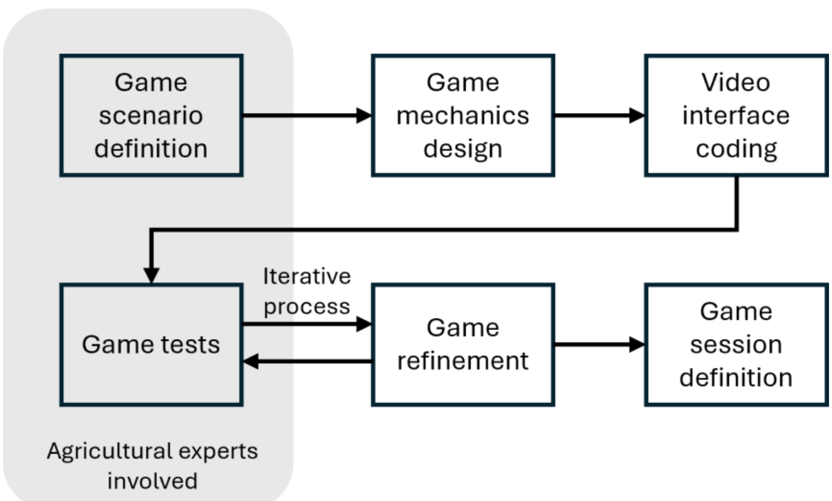

Figure 1: Graph of the Melkeværet designing process.

2.1.1 Scenario definition

The choice of the scenario was inspired by previous work on the link between weather conditions and productivity in the Norwegian fodder production sector carried in another study under the Climate Futures Centre (Oubrhou, 2023). Weather conditions throughout different seasons highly impact the Norwegian fodder production sector. For example, both very dry seasons, such as the 2018 summer (still engraved in Norwegian farmers' memories, Hempel & Kolstad 2026), and very wet seasons can negatively impact the production by affecting grass harvestings. Watering the fields, building drainage systems, and anticipating or postponing activities such as fertilizing and harvesting are strategies that farmers can employ to prepare for or adapt to difficult conditions (Hempel & Kolstad 2026).

2.1.2 Game mechanics

The game was structured around a token (pawn), representing the current time, moving week by week on a board depicting the calendar of an agricultural production season (Fig. 2). While weather conditions progressively influence players' agricultural production, those can, week after week, take actions to respond to them. Farmers' adaptation strategies, their impact on the production, and the resource constraints in terms of time and money were transformed into game mechanics, i.e. players' actions, consequences on players' performance and resource tracker.

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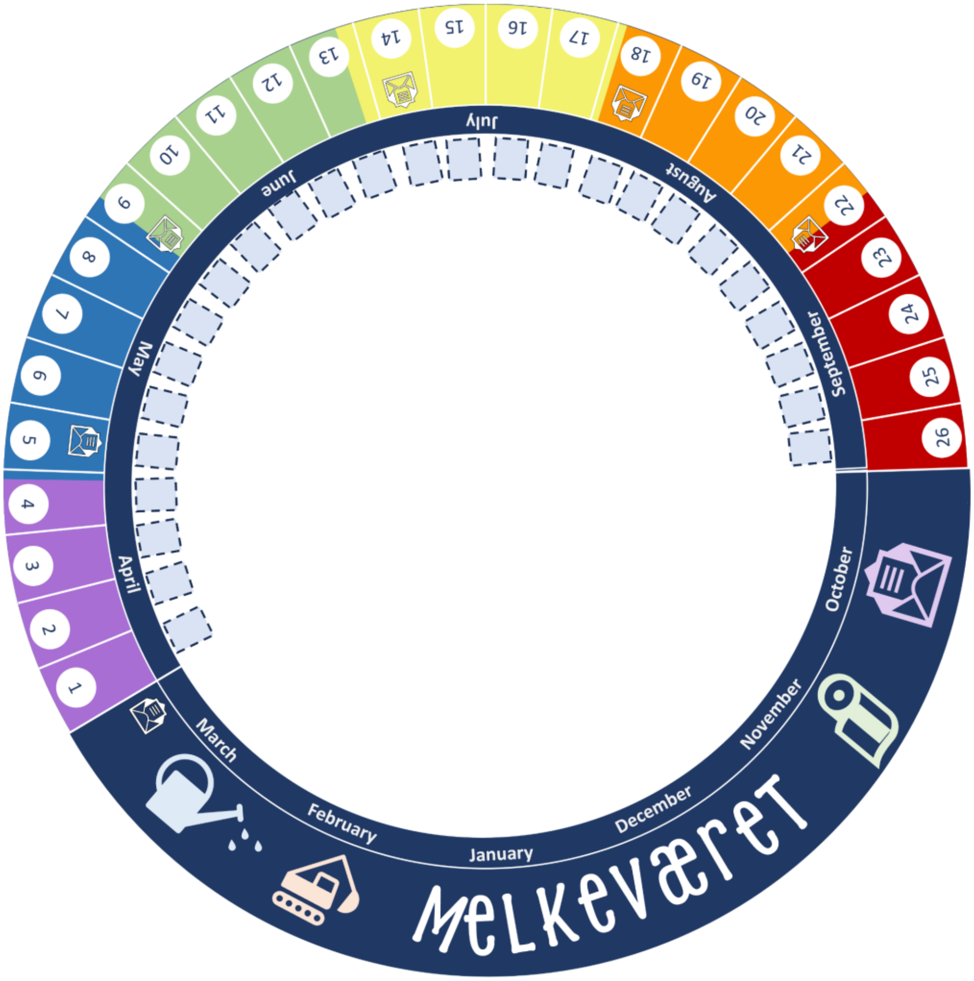

Figure 2: Board of Melkeværet game. A pawn is first placed in correspondence with March and then moved forward one week each round, until the end of the simulated season. Each week, the players can view forecast information and make decisions on their farms.

Forecast information was introduced as a set of cards available for consultation during the simulation. The cards were designed to mirror MET Norway's public forecast services:

- The 10-day forecast, freely available through the institute's Yr app/website;
- The 21-day forecast, freely available since 2024 through the YR app/website;
- The seasonal forecast, represented by probabilistic information at a regional level for the coming 3 months. In demonstration mode during the game sessions included in this paper, and freely available since September 2025 on met.no, the Institute's website.

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2.1.3 Digital interface coding

To complement the board game's physical artifacts, a digital interface was coded with the Unity game engine (https://unity.com), consisting of a grass growth model (Fig. 3). The model is based on a free elaboration of part of the system dynamic model of a farm developed by Oubrouh (2023) and of the forage model developed by NIBIO (NIBIO, nd). It takes into account precipitation and temperature conditions at weekly steps and calculates the grass production in terms of biomass and energy content. When a player harvests their field, it transforms the grass data into the amount of milk produced. It is important to note that the results of the model are not intended to be scientifically rigorous. However, pilot testing results confirmed that the model outcomes are sufficiently realistic for application in the game context.

Figure 3. Screenshot of the video interface during a trial game. For each player, the decisions made during the game are recorded, the grass biomass and quality on their field are monitored through the two graphs at the bottom, and the milk produced is represented in the bottom right corner with bottles of the same colours.

2.1.4 Game test and refinement

The game mechanics and the game scenario were also tested. Two pilot game sessions were organized involving researchers at MET Norway and NLR advisors. The role of the latter was crucial in ensuring that the game structure realistically represents farmers' everyday reality, challenges, and decision-making context. Each pilot game session led to the refinement of some aspects of Melkeværet, such as the possible actions or the resources needed to perform them, in an iterative process.

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2.1.5 Game session definition

Finally, the structure of a typical game session was defined. Two questionnaires were prepared for defined moments of the gameplay, to collect data from players on their decision-making processes and perception of the forecast products. Since the questions have been fine-tuned along the game sessions and because of the relatively low number of total participants, the questionnaires were not used for collecting quantitative data but rather provided input to the collective discussion during the debriefing phase of the game.

2.2 Game sessions' overview

2.2.1 Roles and phases

Melkeværet was designed to be played by (up to) eight participants or participant teams. Each game session was led by a facilitator, who was in charge of presenting the game and guiding the participants through the different phases, acted as a game master, and finally led the collective debriefing. In all phases, the facilitator ensured that all participants felt free to actively contribute and did not face negative experiences, clarifying the rules when some encountered difficulties, encouraging everyone to express their views, and being attentive to any conflicts that might arise. Another crucial role was the one of the observers, who were responsible for taking notes of participants' discourses and discussions in all session phases.
Six game sessions were carried out between June 2024 and November 2025, involving a total of 60 participants (see Fig. 4 for details on the categories of participants). Additionally, three forecasters, one forecast developer, one UX-designer, and two social scientists, all employed at MET Norway, participated in the game sessions as facilitators and observers, actively engaging with the participants during the game play and, especially, during the debriefing. Notes from observers and facilitators constitute the basis for this paper findings' description and discussion.

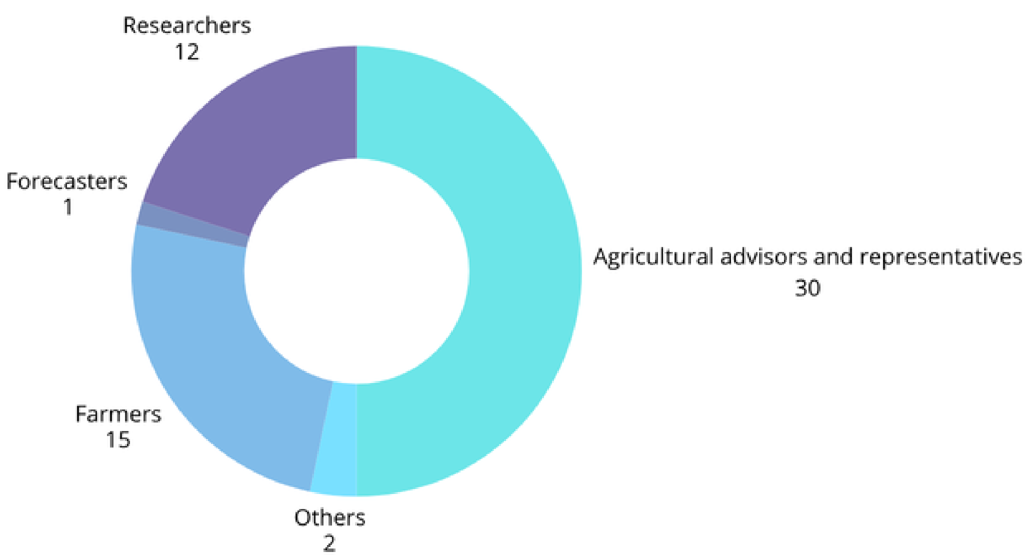

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Figure 4. Pie chart of the participants' categories in Melkeværet game sessions. Please note that in almost all cases, agricultural advisors and representatives are also farmers themselves.

The game sessions were structured into 3 phases (Fig. 5). On average, the introduction and game explanation lasted around 30 minutes, while the gameplay lasted about 90 minutes. The time allocated for the debriefing was more flexible according to the availability of the participants, from a minimum of 30 minutes up to two hours. The three phases were separated by symbolic shifts that helped ensure a smooth transition between the players' real world and the fictional world of the game: each player drawing a card with the description of their game character marked the shift from their real role to their game role, while counting each one's result in terms of remaining resources marked the end of the game simulation.

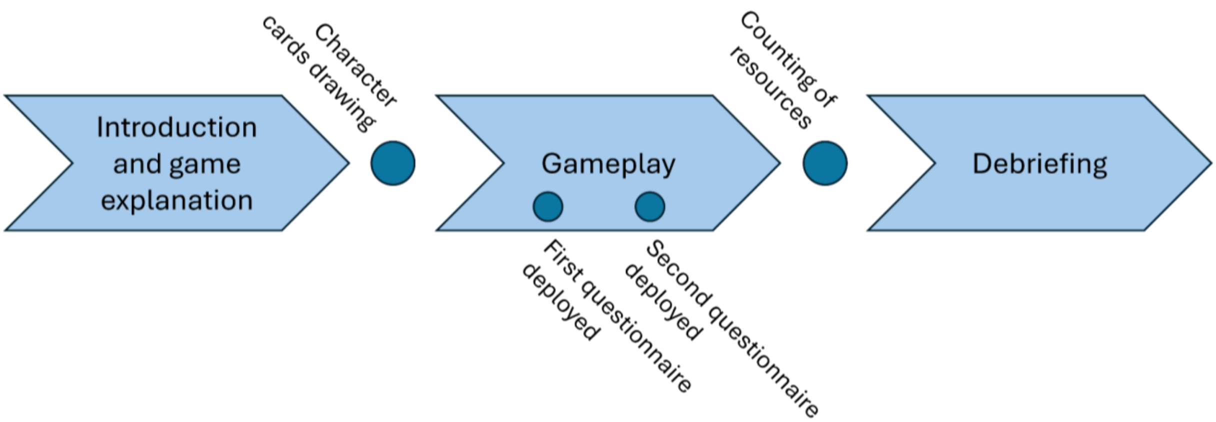

Figure 5. Structure of a Melkeværet game session. The dots represent moments that mark the transition between the game world and the players' real world or bridge them.

2.2.2 Gameplay content

Melkeværet gameplay starts with the players presenting themselves to the group according to the information contained in their character cards. All characters are farmers in western Norway, in the business of cow milk production. All the farms are the same size and are located in the same area, so they are subjected to the same weather conditions. However, the character cards determine slightly different initial resource conditions for the players, possibly giving them some advantages, such as already owning watering equipment or having a drainage system already in place on part of the field (Fig. 6).

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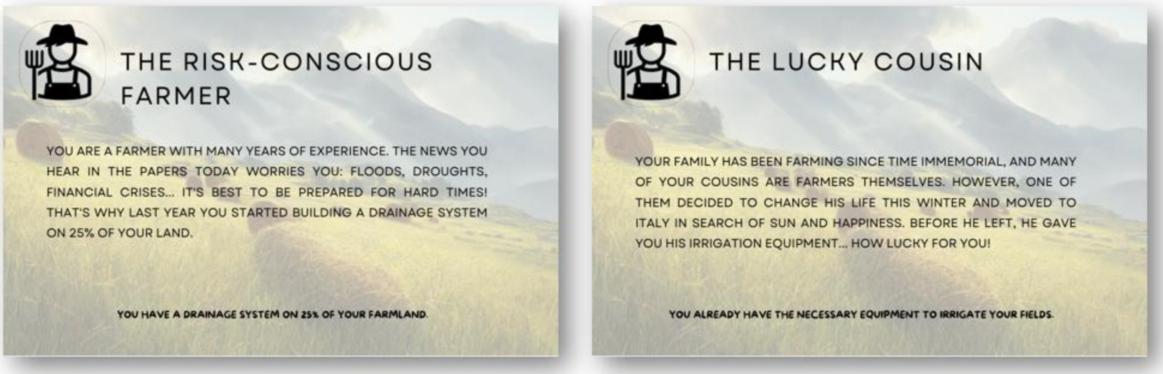

Figure 6. Two examples of players' character cards (Translation from Norwegian to English by the authors).

A pawn on the calendar board in the centre of the table indicates that it is March and the new productive season is about to start. A first seasonal forecast (Fig. 7a) is shared with the players, who have to make their first management decisions on the farm, based on their interpretation of the expected weather conditions, their experience, and their attitude towards risk. Examples of those decisions are building a drainage system to reduce the vulnerability of the pastures to heavy rain events and buying watering equipment to increase resilience in case of drought. Performing those actions requires using part of their own economic resources, which in turn increase proportionally to the amount of milk produced.

Round after round, then, the pawn is moved forward one week on the calendar board by the facilitator, and the players have to decide when the time to fertilize, harvest, or water the pastures has come. To make those decisions, they have access to a new seasonal forecast every month, and both a new 10-day forecast and a new 21-day forecast every week (Fig. 7b and 7c). The mean temperature and amount of precipitation observed are also shared each week (Fig. 7d). All players' decisions are transformed into input for the grass growing model by the facilitator through the video interface, which in turn shows the real-time results of their decisions in terms of quantity and quality of grass growth on their pastures on the screen.

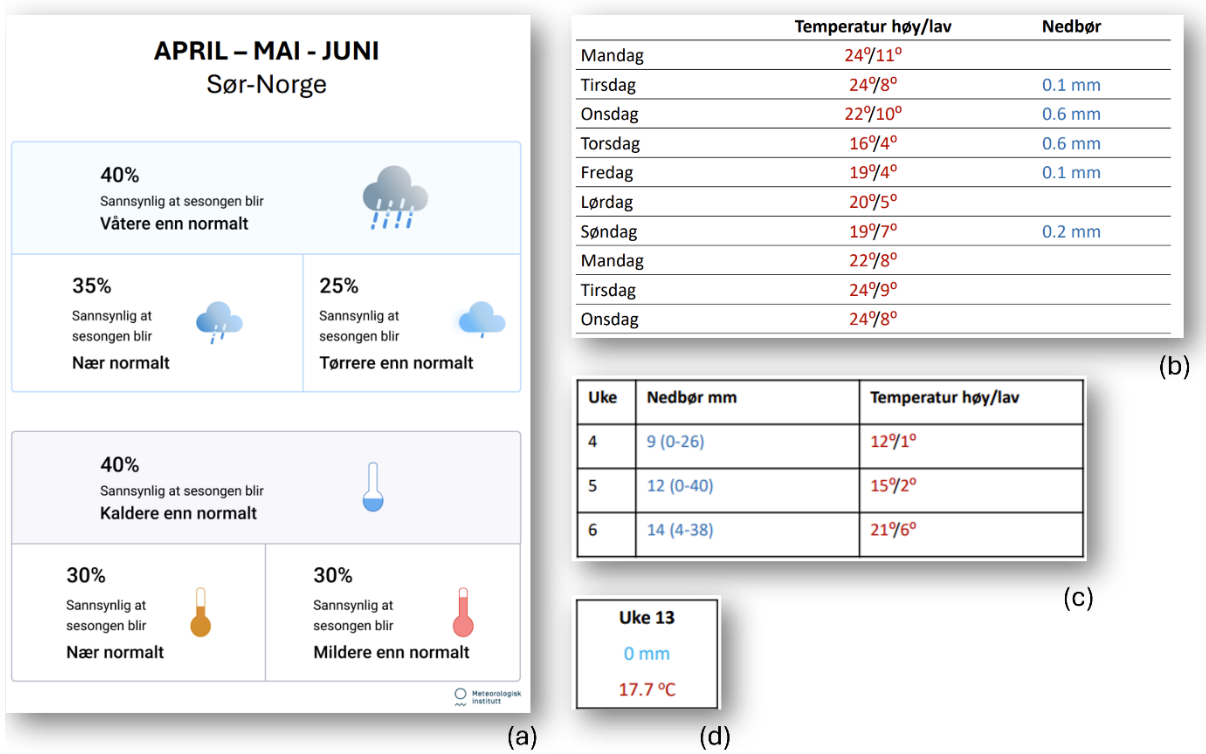

Figure 7. Examples of cards showing a seasonal forecast (a), a 10-day forecast (b), a 21-day forecast (c), and the weekly observations (d). The design and content of the forecast cards are based on MET Norway's actual forecast services.

At the end of the simulated season, the video interface displays the amount of milk each player has been able to produce based on the quantity and quality of harvested grass. The amount of milk is converted into economic resources, and the player with the higher number of resources at the end of the game wins.

2.2.3 Questionnaires

The deployment of two short questionnaires during the gameplay aimed at fostering the participants' reflection on their personal choices and preparing them for the collective discussion of the game implications in the real world during the debriefing. The first questionnaire was deployed at the beginning of the season, after the first seasonal forecast was shared with the player. It focused on the participants' perception of the forecast clarity and importance for decision-making, as well as players' confidence in their operational plan for the upcoming season. The second questionnaire was deployed at the end of the simulated season. It focused on how much the players had to change their initial plan and why, the importance that different types of forecasts had had in their decision-making processes, and their willingness to start using seasonal forecasts in their actual farming activities.

The responses to these questionnaires are not intended to have statistical value, as their main purpose was to be leveraged by the session facilitator as a starting point for the debriefing discussion. Moreover, the questions were slightly adjusted during the course of the work based on lessons learned during the game sessions. The final version of the two questionnaires is presented in Appendix A.

2.2.4 Debriefing

At the end of each game session, a debriefing was held, which is a crucial phase of a serious game experience, often described as the most important part of a game simulation (Crookall, 2023). During this phase, the facilitator led the participants through a collective reflection and sharing of their experiences. As described by Adolph and colleagues (2023), the debriefing is a "structured discussion space where anything that happened during the game will be analysed collectively and juxtapositioned with everyday life". In the case of Melkeværet, the debriefing was the space where linking the decision-making challenges experienced by the participants in the game to their everyday experiences. Leveraging their answers to the questionnaires they had filled in twice during the gameplay, the facilitator brought attention to the forecast products they had used. This allowed the facilitator to explore aspects such as participants' ability to interpret them, the existing challenges in making use of them, and their perceived accuracy and trustworthiness.

Moreover, we specifically structured the Melkeværet debriefing phase as a space for mutual learning between farmers, agricultural advisors, forecasters, and researchers. This means that the session was not only an opportunity for farmers to share their experiences and learn from each other, but also that they could gain more insights into MET Norway's weather services. The presence of expert forecasters and researchers during the game sessions, either as players or observers, and their involvement in the debriefing phase was crucial. Their availability to explain how the weather services are developed and how to make the best use of them, and to answer participants' questions, was vital for reaching this learning objective.

3. Results

3.1 Making sense of S2S forecast information for agricultural decisions

The observations during both the gameplay and the debriefings, together with the answers to the in-game questionnaires, allowed us to collect several insights into farmers' decision-making strategies and their use of S2S forecast services. Overall, we observed how weather observations, memories, experiences, and peer networks all play a crucial role in how forecast information informed their decision-making processes. First, observing the recent weather history and the phenological characteristics of the cultivation appeared essential to make informed decisions, working as a control mechanism for forecast information based on the actual grass development. For example, players were always eager to turn the card on the board to reveal the weekly observations of precipitation and mean temperature, as soon as the time pawn was moved to the following week. Additionally, some farmers suggested that the absence of an evolving visual representation of the grass is an unrealistic characteristic of the game. Going physically on the field and observing characteristics such as the stage of development of the grass, its colour, or the humidity of the ground is crucial for farmers to decide when to fertilize, harvest, or irrigate.

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Second, farmers used their experience and their memory of past seasons both to make decisions and to interpret the forecast information in a comparative way. At the beginning of the game, the facilitator always declared that the scenario referred to Western Norway, but that the specific location would have been revealed only at the end. Nevertheless, some players, especially those located in Western Norway, used their personal experience of past conditions to plan for activities on the field and to interpret the provided forecast information. We observed that most farmer participants had a clear idea of past weather conditions in their area and an excellent memory of the past years' anomalies, as well as of the implications on farming activities. An example of this is using the forecasted wind direction to adjust the expected precipitation amount at their farm location. It is fair to conclude that their continuous daily experience and reflections have made them experts in their field, and of their fields, enabling them to leverage local accumulated knowledge of meteorological phenomena to interpret and add value to the forecast information.

Third, we observed the recurrent behaviour among the participants of comparing the newly issued seasonal forecast with the previous ones provided within the season, to get an overview of the changes (in the words of one of the farmers, "to see if the forecasters changed their minds") and to interpret them as additional information. This behaviour was motivated by the fact that the seasonal forecast refers to the coming three months, so that two consecutive forecasts have a two-month overlap in their reference period.

Fourth and finally, the role of peer networks as a collective and emergent source of climate knowledge was leveraged throughout the game sessions. In general, we observed a general non-competitive attitude among players, who were willing to collaborate, share information and discuss it collectively. Moreover, the decision to harvest, water, or fertilize by one player was likely to influence others to do the same. As some participants reported, the influence of neighbouring farmers' decisions on each one's own decisions is also strong in real-life contexts. This influence process can happen through observation of what is going on in the neighbouring fields, or through the circulation of information over relationship networks characterized by a general trust sentiment toward fellow farmers.

3.2 Challenges in visualising S2S information

The Melkeværet game sessions also highlighted how visualisation and structuring of S2S forecast information affect the perceived relevance of S2S forecasts. First of all, the way the probabilistic information is visualised affects how it is understood and applied. Particularly, we observed that the uncertainty of the seasonal forecast was not always clear for the participants, who sometimes tried to interpret it as a deterministic forecast, such as commenting that "they [the forecasters] are saying that there will be heavy rain" or "they are saying that it won't rain".

A related factor is the (un)availability of references to interpret the probabilistic anomaly information. It was stated by several participants that having access to clear information on climatological normal conditions is crucial for interpreting both the seasonal forecast and the 21-day forecast. For the first one, climate normal values are necessary to transform the probabilistic information in the forecast into an overview of the coming precipitation and temperature conditions; for the latter, they would help detect when the forecasted conditions are far or close to the average conditions for that period of the year, which is an

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indicator of a strong or weak signal in the meteorological model. However, both technical aspects and the intrinsic low spatial and temporal resolution of S2S forecasts challenge the provision of a way for users to easily compare the forecast information with normal conditions in line with their personal experience.

Finally, it is worth mentioning that the process of operational implementation of MET Norway's public seasonal forecast service evolved in parallel to the Melkeværet work. The first game sessions were therefore partly used to discuss with participants several different design formats. These tests contributed to informing the choice of the figures that are now used in MET Norway's seasonal forecast service (see Fig. 8). Insights on how to improve visualisation and structuring of the seasonal forecast information included, for example, a preference for descriptive pieces of information accompanying the numerical data, since a forecaster's informed comment can convey more contextual information to interpret the data compared to the numbers alone. Others commented that specific domain variables, such as the expected length of the vegetative season, would make the service more relevant to agricultural stakeholders. Similarly, to improve usefulness for farmers, the 21-day forecast could include more specific parameters, such as the growing degree days.

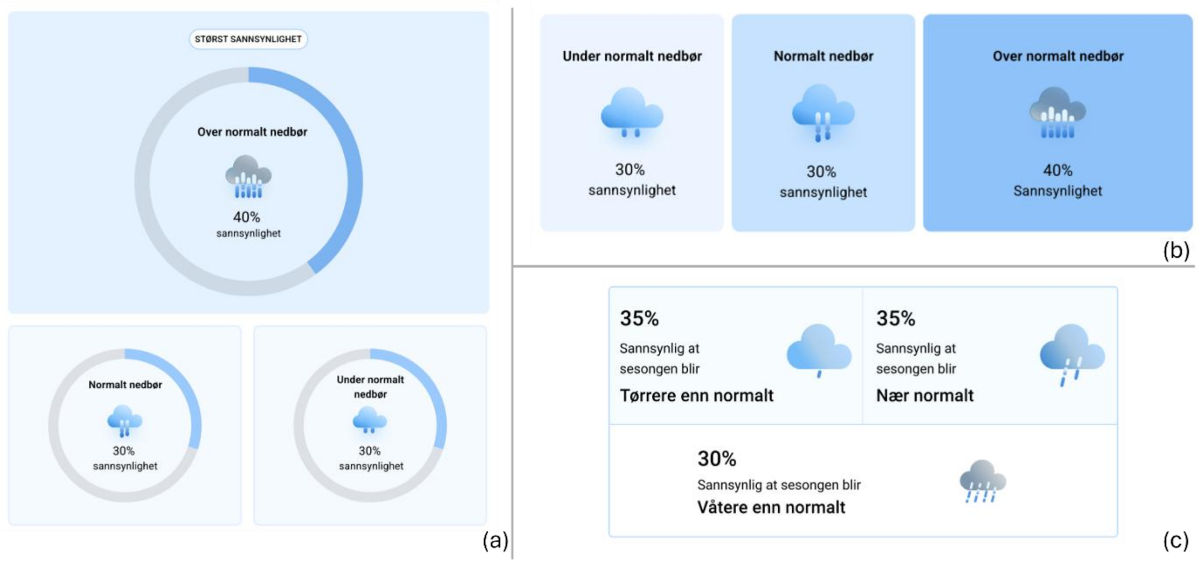

Figure 8. Seasonal forecast design options used as tests with the participants during Melkeværet game sessions (a and b) and the currently adopted design for the official seasonal forecast by the Norwegian Meteorological Institute (c), accessible at https://www.met.no/vaer-og-klima/sesongvarsel.

3.3 Adopting S2S forecasts as a gradual process of service integration

We noticed a general change in the feedback provided by the participants about the 21-day forecast over time. The first game sessions were held briefly after the service was launched, while participants in the later sessions had had more than a year to use it in their everyday lives. While the feedback was generally negative in the first sessions, it was much more positive in the last ones. Even if the low number of participants doesn't allow us to draw quantitative conclusions, we can suppose that a familiarisation process led to this change. Participants in the first sessions seldomly used the 21-day forecast during gameplay

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and reported a general lack of trust in the forecasted conditions for the third week of the forecast (days 15 to 21) during collective discussions. They argued that they had experienced in their daily life a tendency for the third week to reflect the local normal conditions most of the time, and this made the information less useful. On the contrary, participants in the last sessions used the 21-day forecast more often while playing and also reported using it often in their real-life activities. For example, several participants explained that they usually use it to identify temporal windows of specific weather conditions in the coming weeks, such as dry conditions favourable for harvesting, to plan how to prioritize resources and activities. We argue that having had time for testing the service has allowed them to familiarise themselves with it, learn how to retrieve useful information for their specific context, and how to integrate its use with the use of the already familiar 10-day forecast.

The integration of different forecast lead-times is a topic that was discussed in relation to the seasonal forecast, too. While farmers declared that it is difficult to make concrete decisions based on such uncertain information, they also argued that the seasonal forecast can provide them with a useful general idea of the coming months' conditions, especially when used at the beginning of the productive season. One participant commented that "farmers cannot avoid making decisions, so every source of information is welcome, even if very uncertain", indicating a willingness to gather as much information as possible. Moreover, we observed during the gameplay that longer-term forecasts can trigger the use of more detailed weather information. Although there is uncertainty about long-term future weather, indications of long-term challenging conditions for essential tasks can raise users' level of attention and trigger an increased use of short-term forecast services. Similarly, the indication in the 21-day forecast that a window of favourable conditions is approaching makes the users repeatedly check the 10-day forecast to plan more in detail. However, farmers didn't explicitly recognize this triggering role in the seasonal forecast themselves during collective discussions, suggesting that the recent launch of the service (only two game sessions were held after the launch, and only one seasonal forecast had been issued at that time) hadn't allowed them enough time to explore the use and benefit of the service.

3.4 Group dynamics and effective dialogue

During all the sessions, participants showed high levels of engagement. We observed in every session a gradual change in the group dynamics, with participants being more reserved in their behaviour at the beginning of the session and gradually opening up as it progressed. Importantly, the objective of drawing character cards being a symbolic turning point to help participants enter the game world was well received and helped create a playful, non-judgmental atmosphere. Moreover, we observed a progressive lowering of interpersonal barriers between farmers and meteorologists, leading to engaged discussions and exchanges both during gameplay and the debriefing phase.

4. Discussion

4.1 A revised framework for S2S forecast uses

Our findings from observing participants' decisions during Melkeværet gameplay, analysing the answers to the questionnaires, and discussing both collectively highlighted that agricultural stakeholders do not use S2S forecasts in isolation. On the contrary, they couple them with information from personal weather and agricultural observations on the field, experience, and memories of past meteorological conditions, climatological normals, and other lead-time forecasts, and are influenced by peer networks. This means that the use of S2S forecasts is more complex and varied than simply informing operational decisions. This calls into question how we evaluate the usefulness of a forecast and what parameters we take into account when developing a forecast service intended to meet users' needs.

Confirming Ray and Webb's findings (2016) on different forecast uses, we observed that farmers may want to consult S2S forecasts (use type 1) or consider them as a factor influencing decisions (use type 2), without necessarily incorporating them in a decision-making operational model (use type 3) (see Table 1). Even if the level of uncertainty of a seasonal forecast is perceived as too high and its spatial and temporal resolutions too coarse to steer decisions with major production or economic implications, farmers may want to consult it to get an overview of the most probable coming precipitation and temperature conditions, providing supplementary "situational awareness" (White et al., 2022). This is especially true in specific moments of the year, such as at the beginning of the productive season or when estimating whether favourable conditions for growth will carry on longer. Similarly, they may want to consider the 21-day forecast to prioritize operations and planning for resources in advance, for example by pre-alerting temporary staff or external providers of services in the fields that require specific weather conditions.

Moreover, we observed a potentially crucial role of S2S forecasts also in the fourth use type described by Ray and Webb (2016), namely supporting dialogue about risk. As the participants pointed out during Melkeværet game sessions, the decisions made by farmers are likely to be influenced by their neighbours' decisions and by the discussions that take place within their peer networks. As it happened during the game, risk management challenges and opportunities can be shared within those networks, and S2S forecasts can facilitate that dialogue by supporting discussions on expected conditions, impacts on farming activities, and mitigation strategies. S2S forecasts can also be used in this way by NLR agricultural advisors in their group activities with farmers, as background information when collectively discussing how to prepare for the coming conditions.

In addition, we propose to add a fifth use type of S2S forecast information, related to its integration with other information sources, especially short- and medium-range forecasts. Our findings show not only that the value of S2S forecasts for the users is increased when used in combination with shorter-term forecasts, but also that their use can trigger the perceived need for more short-range information. This happens, for example, when a seasonal forecast describes high probabilities for a wetter than usual period, triggering farmers to check short- and medium-range and typically less uncertain information to mitigate potential damages caused by heavy rain; or when several favourable dry days are expected during the harvesting period

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according to a 21-day forecast, so farmers are urged to regularly check the 10-day forecast to decide when to start harvesting operations.

Moreover, we even speculate that the use of a forecast product can improve users' trust in a different one. In this case, the 21-day forecast can improve users' trust in the 10-day forecast, thanks to a longer exposure to forecasted information for the same period. The 10 days for which the conditions are forecasted have already been shown in the 21-day forecast for a while, although with different uncertainty levels. Therefore, the users could have had time to familiarize themselves with the expected conditions, whether they have remained stable over time or have changed based on new results from weather models. However, we have not encountered any direct feedback regarding this hypothesis in the sessions so far, so more specific analysis should be conducted to confirm it.

Table 1. Assessment of the use types of the S2S forecasts of the Norwegian Meteorological Institute as observed in the Norwegian agricultural context. The classification is based on the four use types described by Ray and Webb (2016), with the addition of a fifth use type that emerged in our work.

Forecast use type	Evidence from the Norwegian agricultural context
1. Consult	The 21-day forecast is often consulted, while the seasonal forecast was launched during the period in which this work was carried out, so we don't have evidence of it being regularly consulted by users.
2. Consider	The 21-day and the seasonal forecast are considered when making operational decisions as information on what to expect in the coming weeks or months, providing situational awareness, especially in some specific seasonal moments.
3. Incorporate into an operational model	We didn't find evidence of S2S forecasts directly utilized in operational agricultural decisions targeting a period (coming weeks or months) not also covered by shorter-time lead forecasts.
4. Dialogue about risk	Since risk management challenges and opportunities are commonly shared within farmers' networks, S2S forecasts can support the discussion about expected conditions, impacts, and mitigation strategies.
5. Integrate with other information sources	S2S forecasts' value for the users is increased when used in combination with shorter-term forecasts, and their use can trigger the use of short-range information.

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4.2 Lessons learned on S2S forecasts' development

The discussion of the findings described in Sect. 3 on users' strategies to make sense of the forecast information, on the challenges related to its visualisation and on the process of adopting a new service allows us to define some general implications to take into account when developing S2S forecast services. A summary of the main implications is provided in Table 2.

First, the integrated use of different lead-time forecasts is crucial to consider when developing forecast services. We argue that it should be easy for users to access the different forecast types at the same time and compare them, and that there shouldn't be discrepancies in the information contained. For example, when developing the 21-day forecast service at MET Norway, it was chosen to maintain a consistent spatial resolution with the 10-day forecast that has long been available, to ensure that users could seamlessly integrate it into their established decision-making processes (van Bijsterveldt et al., 2026). A similar seamless integration of the seasonal forecast is still quite challenging because of its very different resolution and uncertainty characteristics. However, some progress could be made in the future in this direction, such as by providing climatological normals at point locations, instead of as coarse national maps as in the current service. Methods to improve the spatial and temporal resolution could also be explored, such as providing the forecast information for the first month -for which the level of uncertainty is generally lower- as separated from the second and third ones.

Moreover, comparing different issues of the same forecast provide additional information to the users on the changes in time of the model outcomes. For example, at some point, two farmers compared two subsequent seasonal forecasts (with a two-month overlap) and then argued that, based on the difference between them, they were confident that the following month would be wetter. This need is currently not met by MET Norway's seasonal forecast service, which only shows the most recent forecast and thus doesn't allow for such comparison.

As described in Sect. 3.2, the communication of the S2S information can be improved by providing descriptive pieces of information to help the users contextualise the probabilistic data, and by selecting variables and parameters that are more relevant to the users' application context.

The value of S2S forecasts for the users also changes with familiarisation through repeated exposure (Ponzano et al., 2025). We observed a change in farmers' trust toward the 21-day forecast from the first to the last game sessions. This could, of course, be due to coincidence since only relatively few farmers participated in the game sessions. However, we also noticed that the farmers involved in the last sessions could explain how they have integrated information from the 21-day forecast into their everyday decision-making processes, strengthening our hypothesis that there was an actual change in behaviour compared to the first sessions. This finding related to familiarisation processes is supported by Hu et al. (2006) in their analysis of factors likely to affect forecast-use behaviour. By applying the theory of planned behaviour originated in social psychology (Ajzen, 1985) to the use of forecast information among U.S. farmers, they argue that three factors exist: personal attitude and subjective utility, influence of social norms, and perceived control. Perceived control refers to the perceived ability to understand and use the forecasts correctly. This is influenced by users' exposure to the forecast and by its repeated use in real contexts, which

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allows them to develop expertise on how to interpret and how it can meet their specific decision-making needs. This implies that some time is required before being able to effectively assess the value of forecast services, and that all activities and resources aimed at supporting the familiarisation process of the users are beneficial.

Along this line, we even argue that the Melkeværet game sessions themselves play a role in the participants' process of familiarisation with forecast information. Although the use of S2S forecasts in real-life decision-making is not replaceable, their additional use in a simulated context contributes to the users' exposure and familiarisation process. This is especially relevant when the practical use of the service is coupled with the possibility of getting insights and technical information from meteorologists and forecast developers, as it happens during the debriefing phase of a game session.

Finally, the usability of S2S forecasts is dependent on the availability of clear reference points which integrate historical climatological data and on the possibility for the users to leverage personal experience with and memories of past meteorological conditions. On one hand, seasonal forecasts are usually presented as anomalies or deviations from expected climatological conditions (Bojovic et al., 2022). On the other, while some exploratory analyses show that the majority of users do not have a clear memory of average conditions in an area (Sivle et al., 2025; Sivle and Jeuring, 2022), our observations indicate that users in the agricultural sector have an excellent memory of recent or specific years and that they leverage it for their decision-making tasks at hand. This led us to speculate that expressing seasonal forecast information with reference to the conditions of recent or significant years could be more effective than referring to historical averages. Moreover, as argued by some farmers during the game sessions, climate change makes the exclusive and absolute use of historical average conditions even more questionable (Holte, 2023; Robinson, 2019).

Table 2. Overview of how findings from Melkeværet game sessions translate into lessons learned for the development of S2S forecast services.

Observations and findings	Implications for S2S forecast service development
1. Users compare and integrate forecast information with different lead times	Allow seamless integration between different lead-time forecasts
	Facilitate visual comparison between different lead-time forecasts
2. Users prefer narrative descriptions to simple numerical data	Provide a narrative description and contextualisation of the probabilistic data
3. Users prefer context-specific variables	Select sector-specific variables
4. It takes time and active use for users to learn how to take advantage of a new forecast service	Allow time and allocate resources to facilitate the users' familiarisation process

5.	Users in the agricultural context have excellent memory of recent or specific past years' conditions	Provide references to recent or significant years' conditions for probabilistic information instead of (or in addition to) historical average conditions

4.3 Strengths and limitations of serious gaming to support forecast services' co-production

The Melkeværet game has proved to be an effective tool to foster dialogue among users from the agricultural sector, forecasters, and developers of forecast services. The game created an informal atmosphere that is essential for lowering communication barriers among participants with different sectoral backgrounds (Flood et al., 2018; Vigna et al., 2024). According to our observations, four elements have in particular contributed to creating meaningful dialogue and mutual learning during the game sessions: 1) the presence of narrative elements, 2) the collaboration with NLR, 3) the choice of a hybrid game, and 4) the structure of the game sessions in terms of time management and participants' contribution.

First, as Salvini et al. (2016) pointed out, an engaging narrative can establish a safe environment and a strong intrinsic motivation in the players. Even if the narrative is more predominant in role-playing games and didn't have a large space in this simulation game, we tried to incorporate some narrative elements in Melkeværet, such as the description of the role characters. At the beginning of the gameplay, players are encouraged to present themselves to the group as their new characters. This moment symbolically marks the entrance into a new reality, similar to the one they know, but still to be discovered and free from the burden of real choices.

At the same time, having developed Melkeværet in close collaboration with NLR advisors ensured that the game setting accurately represents agricultural stakeholders' reality, although simplified to a certain extent, so that it resonates with players' everyday life (Suarez et al., 2012). Melkeværet realistically simulates the choices that farmers have to make, the challenges they face, the outcomes of their decisions, and the role of weather conditions in shaping their activities. This allowed for a smooth transition between the gameplay and the discussion about their real experience with S2S forecast services during the debriefing. As in the development process of Melkeværet, the role of NLR advisors was also important in helping us organise the game sessions and reach potential participants. In the context of Norwegian agriculture, NLR carries out extension work acting as an intermediary between research and technical knowledge, and daily farmers' activities (Hempel and Kolstad, 2026). We argue that such trusted boundary organisations can facilitate communication and play a prominent role in the co-production process of forecast services.

Third, we acknowledge the opportunities provided by a hybrid game. The digital interface gives the players robust feedback about their actions based on realistic responses of grass growth to meteorological conditions and management choices. This creates the willingness to make the best choices possible and also a certain level of curiosity about the system responses, strengthening players' engagement. On the other hand, the tangible elements of the board game, such as the physical cards with the forecast information, provide concreteness to the experience and to the discussion. This helps reduce barriers of abstractive and technical language, shape a common language, and avoid possible misunderstandings (Eisenack, 2012).

Finally, the way the game session is organised shapes how the participants interact with each other. Allowing for enough time for the game and for the debriefing, for example, is crucial in creating a positive exchange atmosphere (Flood et al., 2018). Moreover, we observed that the participation of forecasters and forecast service developers during the gameplay, not only as observers but also by taking part in discussions and providing clarifications when requested by players, was beneficial in breaking the ice and making farmers comfortable in sharing feedback and asking technical questions in the debriefing phase. Exchange of information and mutual learning was indeed a central aim of the Melkeværet game: MET Norway's forecasters, developers, and researchers could learn about farmers' use and needs of S2S forecasts, and farmers could get more insights about the institute's forecast services to better use them to support their decision-making.

Literature on co-production of climate services demonstrated that taking into account users' needs, values, and decision contexts, by involving them in iterative dialogue, ensures that services are relevant and usable (Meadow et al., 2015). The findings of this work suggest that serious gaming can effectively contribute to and complement other co-production processes, by creating an opportunity to bring providers and users in the same room and by providing service developers with a tool to communicate and engage effectively with stakeholders. Moreover, the game co-development process itself can be a way of building trust between organisations, such as MET Norway and NLR in this case, and fostering transdisciplinary collaboration (Lankford and Craven, 2020; Vigna et al., 2026).

However, a limitation of game-based approaches is linked to scaling-up challenges. Both developing a serious game that effectively simulates participants' decision-making and playing it require significant resources in terms of time and effort from the different actors involved in the process. Involving a larger number of participants is extremely challenging. We have tried to overcome this limitation by making Melkeværet playable also without the presence of forecasters and developers in the room, for example by groups of farmers during workshops led by NLR advisors. All the material and a handbook that guides the facilitator step by step in presenting the game, explaining the rules, mastering the gameplay, and conducting the debriefing are available upon request. An online form to share feedback and reflections with MET Norway is also provided. Indeed, this does not replace a game session with forecasters in terms of dialogue and mutual learning. However, it can still facilitate the familiarisation process with S2S forecast services, provide us with some feedback related to our services, and help agricultural stakeholders discuss challenges due to weather impact on their activities.

5. Conclusion

We used a serious game approach to explore the role of S2S forecast information in users' decision-making processes in the Norwegian agricultural sector, aiming to identify key factors affecting their relevance and uptake. By reflecting on the game sessions' outcomes, we collected key lessons for the development of meaningful forecast services and for the use of serious gaming simulations to involve the users in a co-production process.

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We found out that S2S forecasts, in addition to being used as information to be consulted, considered for decision-making and leveraged to discuss upcoming risks, are often used in combination with shorter-term forecasts. This requires ensuring seamless integration between the different lead-time forecasts and facilitating their visual comparison when designing the services. Moreover, providing narrative descriptions of the probabilistic data, selecting variables specifically relevant for the decision-making context and facilitating users' familiarisation process clearly enhance the successful uptake of the services. Our observations led us to also question the use of historical average conditions as a meaningful reference for probabilistic forecast information for the users, and to suggest exploring the use of recent or significant conditions instead.

The serious game approach proved to be effective in creating meaningful dialogue and mutual learning among users from the agricultural sector, forecasters, and developers of S2S services. The narrative elements of Melkeværet, its hybrid nature of physical and digital game and a careful setting of the game sessions in terms of time management and participants expertise were beneficial. The collaboration with NLR as an intermediary organisation between research and daily farmers' context not only was crucial for this project but could also be further leveraged to overcome scaling-up challenges inherent in serious game approaches.

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Appendix A

Final version of the questionnaires deployed during Melkeværet gameplay (translation from Norwegian to English by the authors).

QUESTIONNAIRE - PART 1

1. How easy was the seasonal forecast to understand?

	1	2	3	4	5	6	7	
Very difficult	○	○	○	○	○	○	○	Very easy

2. How useful was the seasonal forecast in helping you make one or more decisions in preparation for the season?

	1	2	3	4	5	6	7	
Not useful at all	○	○	○	○	○	○	○	Very useful

3. How useful do you expect it to be for the rest of the season?

	1	2	3	4	5	6	7	
Not useful at all	○	○	○	○	○	○	○	Very useful

4. Have you already planned the timing of the actions (fertilising, harvesting) you will carry out this season?

○ Yes

○ No

5. How likely is it that you will have to change your original plan during the season?

	1	2	3	4	5	6	7	
Very unlikely	○	○	○	○	○	○	○	Very likely

QUESTIONNAIRE - PART 2

1. Did you change the plan you had before the start of April during the season?

○ Yes, I completely changed my initial plan.

○ Yes, I adjusted it slightly by moving one or two actions a week forward or backward.

○ No, I performed all the actions exactly in the week I had planned to.

○ I didn’t have any plans before the start of April.

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2. Do you think you could have planned your season better from the start?
   - ◯ Yes.
   - ◯ No, because I didn't have enough information.
   - ◯ No, because it is never possible to make a perfect plan before the start of the season.

3. How useful was the 10-day forecast in helping you make one or more decisions during the season?

	1	2	3	4	5	6	7	
Not useful at all	◯	◯	◯	◯	◯	◯	◯	Very useful

4. How useful was the 21-day forecast in helping you make one or more decisions during the season?

	1	2	3	4	5	6	7	
Not useful at all	◯	◯	◯	◯	◯	◯	◯	Very useful

5. How useful was the seasonal forecast in helping you make one or more decisions during the season?

	1	2	3	4	5	6	7	
Not useful at all	◯	◯	◯	◯	◯	◯	◯	Very useful

6. Do you think you will use seasonal forecasts in your own agricultural business? Why?

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Code and data availability

The Unity files necessary for running the Melkeværet digital interface can be provided by the authors upon requests.

Author contributions

All authors contributed to the conceptualization of the work and to the writing of the manuscript. IV designed Melkeværet game with contribution of AS and JJ, coded the digital interface, conducted the game sessions, and wrote the original draft of the manuscript.

Competing interests

The authors declare that they have no conflict of interest.

Ethical statement

Any personal data collected through observation of the game sessions was anonymised and contribution to the discussions was voluntary. No ethical clearance was required by our research institute.

Disclaimer

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