Climatic Change (2026) 179:101
https://doi.org/10.1007/s10584-026-04163-y

A behavioral change approach to understanding true demand for future climate information

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Received: 17 September 2025 / Accepted: 16 March 2026

Abstract
There is a persistent gap between the supply of and demand for future climate information in adaptation decision-making. Despite various proposed solutions, including climate services and co-production, this gap remains unbridged. Here, we present a systematic sectoral analysis grounded in behavioral theory, exploring where and how climate information could support decision-making. Drawing on the COM-B framework for behavior (B) change, we examine the capabilities (C), opportunities (O), and motivation (M) necessary for climate information to inform decision-making, focusing on two climate-sensitive sectors in Germany—agriculture and forestry—and on decadal predictions as an example. Through expert focus groups ($N=24$ participants), we identify key adaptation decisions for the coming decade and analyze current decision strategies and contexts. Our findings reveal that the demand for decadal predictions is negatively impacted by knowledge gaps, lack of opportunity, and limited motivation. Instead, decision-makers often rely on strategies such as past experience and heuristics like worst-case planning that do not require precise information, but may represent smart strategies for uncertain environments. The true demand for future climate information remains masked, blocked, or unexpressed when decision-makers lack the capabilities, opportunities, or motivation to recognize, act on, or articulate it; when current decision strategies suffice, there simply is no demand. By using the COM-B framework as a behavioral lens to systematically understand the demand side, our approach offers generalizable insights that may help bridge the gap between supply and demand, design effective interventions, and guide the allocation of resources in climate research and policy.

Keywords Climate adaptation · Decision-making · Uncertainty · Climate services · Climate predictions · Useful information · Co-production

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1 Introduction

In climate research, the dominant strategy for producing actionable knowledge about the future has long been to increase the complexity of climate models (Baldissera Pacchetti et al., 2024; Burroughs, 1997). While complex modeling efforts may be indispensable for the scientific understanding of a changing climate, it is questionable whether they are truly needed to support decision-making (Dessai et al. 2009). In fact, the widespread assumption that better decisions require "better information"—with higher temporal and spatial resolution, better predictive power, or more complex variables—has been strongly criticized (Findlater et al. 2021). For more than 20 years, social scientists have argued that the persistent gap between the supply of climate information and user demands, reflected in the "climate information usability gap" (Lemos et al. 2012), stems not from a lack of data, but from a lack of alignment between what scientists produce and what decision-makers need (Cash et al. 2003; McNie 2007; Porter and Dessai, 2017; Sarewitz and Pielke, 2007). This mismatch is mirrored in a structural imbalance in climate research funding: Between 1990 and 2018, the natural and technical sciences received 770% more funding than the social sciences and humanities (Overland and Sovacool 2020).

Past attempts to reconcile the supply and demand sides of future climate information have included institutional responses, such as boundary organizations (mediating between science and policy or practice to stabilize knowledge production and facilitate the use of scientific knowledge; Guston 2001), climate services (designed to tailor and translate climate information to meet the specific needs of users; Hewitt et al. 2012), co-production processes (participatory, iterative frameworks that involve scientists, stakeholders, and decision-makers in jointly producing knowledge and solutions; Lemos and Morehouse 2005), efforts to build adaptive capacity (the ability of systems, institutions, or communities to adjust to climate change, including resources, skills, and governance structures; Eakin et al. 2014; Engle 2011), and efforts to develop more "meaningful climate science" (Shepherd and Lloyd 2021), such as physical climate storylines (narrative-based scenarios that explore plausible, physically self-consistent sequences of events; Shepherd et al. 2018).

However, although more is now known about the factors that can enable the use of climate information (e.g., interaction between producers and potential users), its uptake remains limited. In interviews, for example, Bruno Soares et al. found little evidence of seasonal and decadal predictions actually being used in Europe (Bruno Soares and Dessai 2016; Bruno Soares et al. 2018). A review by Lemos et al. (2019) concluded that decision-makers do not use climate information "as frequently or optimally as would be expected to inform decisions" (see Orlove et al. 2020, p. 286). Meanwhile, investments in modeling efforts remain high (Baldissera Pacchetti et al. 2024), and even climate services and co-production initiatives often focus mainly on information quality (Findlater et al. 2021).

In this paper, we apply the COM-B framework of behavior (B) change (Michie et al. 2011) to a systematic sectoral analysis in Germany in order to analyze the necessary conditions—capabilities (C), opportunities (O), motivation (M)—under which climate information can inform adaptation decisions. We demonstrate how the COM-B framework offers a novel perspective to (i) explain the persistent gap between information produced and information used, (ii) categorize key behavioral and contextual factors that influence whether climate information becomes actionable or remains unused, and (iii) identify necessary but currently unmet conditions for the uptake of climate information. We do not aim at providing a full model of demand, but rather present evidence demonstrating how this perspective can inform the development of promising interventions and contribute to a more comprehensive theory in the future.

Following COM-B, the necessary conditions include the capabilities to understand, interpret, and apply uncertain information, and the opportunities and motivations to do so. If capabilities like knowledge (e.g., understanding adequate responses to climate change impacts) or skills (e.g., applying an uncertain forecast in decision-making) are constrained, decision-makers may fail to recognize the benefits of climate information—the demand is masked. If opportunities are constrained (e.g., through budget limitations or regulatory barriers), decision-makers are unable to act on climate information—the demand is blocked. If motivation (e.g., belief in the benefits of climate information) is constrained, decision-makers will not articulate needs—the demand remains unexpressed. In these cases, a demand for climate information may in principle exist but would only become apparent if the conditions changed. Thus, the COM-B framework does not define demand but helps to identify the necessary (though not sufficient) conditions under which it becomes visible and actionable (see Fig. 1).

Seeing demand through this perspective may help to understand why past efforts have failed to close the gap between information produced and information used. For instance, many efforts have focused exclusively on information usability, assuming demand-side

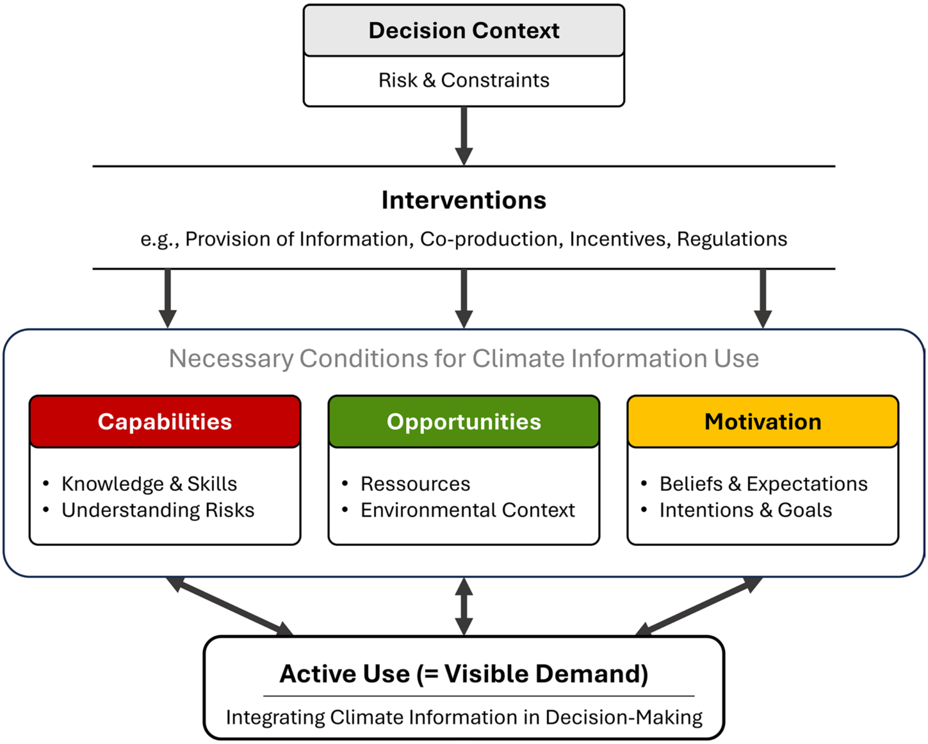

Fig. 1 Drawing on the COM-B framework, we identify capabilities, motivation, and opportunities as necessary conditions for demand to become visible and actionable. Interventions are shown as targeting these conditions rather than directly determining information use. Figure adapted from Michie et al. (2011), p. 4. Copyright (**c**) 2011 Michie et al.; licensee BioMed central Ltd

belief in its potential benefits (Kirchhoff et al. 2013) and a resulting motivation that cannot be taken for granted. Yet even when motivation is given and potential users report higher intentions to use information, such as after co-production, contextual constraints might prevent them from doing so, reflecting the well-known intention–behavior gap from psychological research (Sheeran and Webb 2016).

Ultimately, this perspective prompts a more fundamental question: When and where is better climate information truly necessary to improve decision outcomes (see, e.g., Dessai et al., 2009)? A *true demand* exists only if the information would be used AND actually improves decision-making—something that cannot be assumed. In fact, psychological research on bounded and ecological rationality has shown that simple decision strategies that do not take all of the available information into account can perform as well as or better than more complex strategies in a variety of decision-making contexts, from psychological, biological, sociological, to economical (see, e.g., Gigerenzer and Brighton, 2009 for a review). Here, COM-B's broader behavioral perspective helps to identify contexts where a lack of capabilities, motivation, or opportunities may prevent the effective use of climate information and to assess the feasibility of all necessary conditions being met. It can thus distinguish contexts where climate information use seems feasible from those where current decision-making strategies may already be good enough.

1.1 The present study

A key issue in current climate research is determining the value of medium-range climate predictions, such as decadal forecasts, for improving climate services and early warning systems (Kushnir et al. 2019; Reichstein et al. 2025). Nissan et al. (2019) have argued that the predominant focus on end-of-century projections can detract from more immediate challenges, such as managing shorter-term risks and climate variability, thereby diverting scarce financial and human resources away from these more pressing concerns. Despite a growing recognition of the importance of decadal predictions, including by the World Climate Research Programme (WCRP), a critical question remains, to our knowledge, unexplored: Under what behavioral conditions could decadal predictions meaningfully support adaptation?

In this study, we focus on two sectors in Germany that are highly sensitive to climate change—agriculture and forestry. We address three guiding questions: (i) What are the key climate-sensitive decisions for the coming decade in each sector? (ii) What information is necessary to improve how these decisions are made? (iii) How important are improved predictions relative to other factors that may impact adaptation strategies within these sectors?

While our empirical focus is national and focuses on decadal climate predictions, the general constraints on capabilities, opportunities, and motivations identified are likely to be similar for other sectors, countries, and forms of climate information. By using the COM-B framework (Michie et al. 2011) to understand the demand side, our study offers generalizable insights that may help to bridge the gap between supply and demand, to design effective interventions, and to guide the allocation of resources in climate research and policy.

2 Study design

To answer our guiding questions, we employed a qualitative approach, conducting four online expert focus groups (90–100 minutes each) with in total 24 participants systematically sampled from the German agriculture and forestry sectors. We ran two focus groups per sector: one with experts from federal research institutions and universities ("federal research and policy") and one with experts from state agencies and extension services ("state-level practice"). Participants included senior research experts with national policy relevance, state-level consultants, and department staff involved in practical implementation across diverse regions (see Supplementary Information (SI) S1 for details of sampling criteria and procedures). These experts possess deep knowledge of climate impacts, relevant adaptation decisions, and how such decisions are made in practice. They also act as translators of scientific information for decision-makers and policymakers. Final participation was $N = 7$ (federal agriculture), 8 (federal forestry), 6 (state agriculture), and 3 (state forestry), due to last-minute cancellations.

For the focus groups, we developed a semi-structured guideline that did not presuppose a demand for climate information (see S2 in the SI). Participants first discussed the current state of climate adaptation and perceived challenges, followed by sector-specific adaption decisions over a 10-year horizon. They then explored the current and potential use of climate information, the handling of uncertainty, and finally the role of climate predictions relative to other factors influencing adaptation strategies in the sector. Each focus group was preceded by a pre-group survey to anchor group discussion on key adaptation decisions and followed by a post-group survey to validate and prioritize the decisions discussed (see S2–S3 in the SI).

2.1 Data analysis

Audio recordings were transcribed using Whisper (v20240930; Radford et al., 2022) and manually corrected. We conducted a structured qualitative content analysis (Mayring 2010) of the original German data, using both deductive and inductive coding techniques. Meaning units ranged from sentence fragments to paragraphs, with overlapping codes allowed.

Deductive coding was based on the interview guideline and COM-B framework (Michie et al. 2011), covering capabilities, opportunities, motivations, decisions, decision strategies, and the status quo of climate adaptation, as well as forecast quality, climate information use, and lead times (Tables S1–S2).

Inductive coding added further categories, including decision dependencies, subtypes of missing opportunities (e.g., financial aspects or availability of materials), and subtypes of climate information use. The latter helped to link climate information more precisely to decisions. Within forecast quality, the subtypes tailoring, accuracy and reliability, and uncertainty emerged from the data (Tables S3–S4).

To ensure coding reliability, we had a second coder independently code a complete interview script (federal research and policy, forestry). In a briefing, we provided the interview script and a guideline including the research questions, the sampling procedure, the coding scheme, and an abstract describing the study. After differences in coding were resolved through discussion, the second coder coded another interview transcript (state-level practice, agriculture). Following initial coding and discussion, we assessed intercoder reliability using the coefficient kappa (Brennan and Prediger 1981) for overlapping segments per code, allowing an 80% match tolerance,[1] resulting in $\kappa = 0.75$. We used MAXQDA Analytics Pro (version 24.6.0) for all coding activities.

3 Results

We first outline the current state of climate adaptation in both sectors (Sect. 3.1) and the types of decisions that experts considered relevant for the coming decade (Sect. 3.2). We then identify the necessary conditions for the use of climate predictions, focusing on experts' and decision-makers' capabilities, opportunities, and motivations, and gaps therein (Sect. 3.3). We report the decision-making strategies currently used in practice to deal with uncertainty (Sects. 3.4 and 3.5), and the decisions that could—according to the experts—benefit from decadal predictions. Here, we consider the types of information that better predictions would need to deliver (Sect. 3.6).

3.1 Climate adaptation in German forestry and agriculture: the status quo

Experts in both sectors agreed that climate adaptation is an ongoing process that needs constant adjustment. However, perspectives on how adaptation happens and what it requires diverged notably between sectors. Forestry experts expressed a systems-oriented perspective, viewing adaptation as a response to large-scale ecological change: "It is about complete evolutionary systems being disrupted by a climatic shift." Agricultural experts, in contrast, described adaptation in more pragmatic terms, emphasizing continuity with past experience: "Agriculture is used to a certain amount of hardship and will have to adapt to it somehow and learn to cope. Just as before, perhaps to an even more extreme extent."

Experts agreed that awareness of climate change and its impacts has grown, particularly in response to the major drought events in Germany/Europe in 2018 and the following years (e.g., Rakovec et al. 2022). However, they also noted that adaptation efforts remain largely reactive, triggered by experienced impacts, rather than being anticipatory (see Table 1). Before turning to the reasons for this lack of foresighted adaptation in Sect. 3.3, we report the decisions that experts in each sector identified as important for the coming decade.

3.2 Important climate adaptation decisions

Only five experts added decisions to the list provided in the pre-group survey (see S3), and no further decisions were added during the focus groups, suggesting that the list captured the most relevant decisions.

During the focus groups, it became clear that experts considered most of the decisions identified to be essential for successful adaptation to a changing climate, emphasizing that many decisions are interdependent. In forestry, experts noted that all identified decisions have to be made. In agriculture, their relevance depended on individual farm contexts.

[1] This threshold was selected because coding was conducted below the level of full sentences, which naturally introduces variation in segment boundaries. The 80% criterion compensates for these discrepancies. Although arbitrary, it reflects our pragmatic approach in the absence of standardized procedures.

Table 1 Quotes illustrating the perceived status quo of climate adaptation in German forestry and agriculture

Positive	Negative
"And there is a lot of activity at the moment on the subject of irrigation. From the federal states, especially in Lower Saxony, in terms of water use concepts and the like. But there is also a lot of activity from the federal government at the moment when it comes to water scarcity and how it can be avoided in the future."	"I don't think we're there yet. There are many measures that can help, that could help, that perhaps need to be investigated a little further, for specific regions. But much of what is happening in practical agriculture is not yet perfectly adapted to climate change. Crop rotations that are too tight; too little or too much open soil, etc. So there's still a lot to do."
"I think the foresight here is already relatively far-reaching. It's the same for barn construction; when farmers build barns, they are very often already thinking about installing ventilation options, cooling options and so on."	"They [the farmers] tend to take the following approach: As long as the old system, the tried and tested system, still works, they stick to it. And then, when something stops working, they look for a solution."
"And I believe that we are relatively well positioned in the medium term to say, okay, we want to get back into, let's say, rejuvenation."	"And I think, as I said, the understanding [of climate change] is there, but the actions are often perhaps not really what you would call forward-looking adaptation."

Note. Quotes translated from German by the authors for illustrative purposes. An in-house translator validated the translations. Content analysis was conducted on the original German data

Experts distinguished between adaptation decisions that are ongoing and repeated, such as selecting crops, and those that are made once but have long-term implications, such as regulating water rights. These one-off decisions were described as more complex and involving multiple stakeholders.

Although responses on decision lead times varied in the pre-group survey, experts successfully organized and prioritized decisions for the next 10 years during the focus groups through moderation (Table S5). For agriculture, the federal research and policy group prioritized general diversification (also framed as risk management strategies). State-level practice experts were more concerned about practical issues, such as identifying suitable crops, ensuring the availability of effective crop protection products, and securing water for irrigation and frost protection. In forestry, there was less variation between the two groups. Both saw regeneration and reforestation (i.e., planting trees, which includes increasing genetic diversity and adapting tree species composition) and keeping water in the ground as top priorities. Given the agreement on priorities and non-exclusive nature of decisions, the planned post-group survey task of prioritizing decisions based on costs and time requirements was deemed of limited value and omitted. Prioritizing—deciding when to pursue which decisions—emerged from the discussions as a meta-level decision that may be weather- or climate-sensitive. This may be particularly relevant for decisions with long lead times or those requiring coordination among stakeholders.

Having outlined the key adaptation decisions for the next decade, we now turn to conditions that influence climate information use.

3.3 Necessary conditions for climate information use

Following the COM-B framework (Michie et al. 2011), we identified constraints in decision-makers' capabilities, opportunities, and motivation that potentially mask, block, or leave unexpressed the demand for decadal climate predictions or future climate information in general.

3.3.1 Psychological capabilities: knowledge and skills

Some experts described farmers and foresters as proactive and adaptive actors who seek out knowledge and apply it in practice. Initiatives such as “Living Labs” or EU-funded projects were highlighted as valuable testing grounds for developing and refining adaptation strategies.

At the same time, experts emphasized that adaptation is shaped by decision-makers’ ability to comprehend and respond to climate change, or a “climatic shift,” as one expert put it. This expert questioned whether the forestry sector—or indeed any sector—has fully grasped the implications of this shift or developed sufficient solutions to manage its impacts.

In forestry, difficulties arise from the interactions between climate change and processes of the ecosystem as a whole. Experts highlighted that the role of evolutionary adaptation and the interplay between abiotic and biotic stress factors have not yet been sufficiently addressed in impact research, resulting in significant knowledge gaps. Impact models struggle to accurately replicate observations of drought-induced tree mortality. One expert noted that, while adaptation plans exist, no strategies are in place for the scenario in which these plans fail.

In agriculture, even among experts, the definition of appropriate adaptation sometimes remains contested. For example, one expert noted that discussions often arise around whether to prioritize high-yield crop varieties, which may exhibit higher yield variability, or varieties offering more consistent yield stability around a mean value. Moreover, in the absence of reliable forecasts for year-to-year variability, decisions and recommendations remain uncertain and difficult: “One year is dry, the other wet. So do you grow a drought-tolerant variety or not?” Experts agreed that increasing climate variability makes it harder to adapt and that rigid systems such as standardized fertilization are no longer adequate. However, they also emphasized that shifting to more flexible strategies requires both specialized knowledge and skills that decision-makers may lack.

These insights suggest that even experts tasked with providing adaptation guidance are often challenged when it comes to interpreting available information and translating it into actionable recommendations. The challenge lies not only in understanding climate change, but also in identifying what constitutes a “good” response, particularly in complex, highly interdependent systems (Sect. 3.3.2).

A related challenge is the accessibility of forecasts. Experts perceived them as too complex or insufficiently tailored to support decisions (Sect. 3.5). This highlights a critical barrier: Even experts who must both understand predictions and communicate their implications to practitioners or policymakers face difficulties interpreting available information. From our perspective, this is particularly concerning, as these experts represent the primary potential users of such forecasts. As one commented: “I think the fundamental challenge is to build a bridge between those who design or provide forecasts and those who need to use them, in a way that is easily accessible.” Another noted: “If you asked people in agricultural practice what will happen if we don’t quickly improve decadal climate forecasts, they’d say: What, decadal forecasts?” In other words, end-users might not even be aware of forecast possibilities and thus lack the motivation to participate in co-production or develop the skills to use them. As experts emphasized, without better access and training, consultants included, the information will remain disconnected from decision-making routines.

As these findings illustrate, the ability to express a need for climate information presupposes the capabilities to understand, interpret, and apply that information. Without the cognitive and procedural skills to do so, or the foundational knowledge to determine what constitutes a better decision in the first place, potential users may not be able to recognize how climate information could help—in this case, the demand is masked.

3.3.2 Opportunities for action: financial, structural, and environmental constraints

Experts identified a large number of external factors that complicate the implementation of climate adaptation decisions in agriculture and forestry. They deemed these external constraints to be currently more relevant for local adaptation than more or better climate information. In particular, experts considered constraints like time limitations, regulatory restrictions (e.g., on crop protection), and limited availability of crops, plants, and protection products to be extremely important. Three types of constraints—financial, structural, and environmental—were discussed in more detail.

3.3.2.1 Financial constraints The substantial costs of implementing adaptation decisions (e.g., making forests climate resilient, establishing agroforestry, or developing irrigation systems) were described as a central constraint in both sectors—and as a major barrier for private forest owners. Inflexible agricultural subsidy systems, the need for upfront financing, and overly bureaucratic subsidy application processes were reported to negatively influence adaptation and innovation.

The increasing climate variability also has financial impacts. Experts emphasized that in wet years, the need for additional crop protection measures poses an economic challenge for farmers in a tense market environment. Some experts pointed to a potential conflict between farming and climate adaptation: "Farmers have to be able to make a living from their yields and their farming activities. And that sometimes contradicts climate adaptation a little, and I think that makes implementation relatively difficult or challenging." Experts identified financial uncertainties as one of the reasons why farmers and private forest owners tend to perceive adaptation measures as risky and instead stick to existing management methods.

3.3.2.2 Structural constraints from value chains, logistics, and data access For practitioners, implementing adaptation decisions such as crop diversification was seen as extremely difficult within the highly specialized agricultural sector: "For example, if I think about growing sunflowers, well, then I might first need a value chain for that. I might have to adapt my soil cultivation and harvesting techniques. So, yes, if I now want to grow more mixed crops, then I immediately have a lot of technical challenges." Similar constraints exist in forestry: "I mean, the saplings have to be planted somehow. Contracts have to be signed, often at times when you might not be able to foresee how, what, and when things will happen. It's the same in other areas of forestry. So there is a lot of pragmatism involved, which then breaks down the theory." Thus, although recommendations for climate adaptation exist, there are significant obstacles to their practical implementation for decision-makers.

In addition to these challenges, some experts described problems in accessing relevant data and information infrastructure for research. For example, one expert had no direct access to regionalized climate data. Others pointed to the fragmented, nonstandardized, or inaccessible nature of datasets that are necessary to model climate impacts, such as high-resolution yield or ecological observational data. This lack of accessible data hampers experts' ability to recommend informed adaptation options.

3.3.2.3 Environmental constraints Experts in both sectors emphasized that, in theory, there are always several options for action, allowing flexibility. In agriculture, extension services engage in extensive experimentation, and systems continuously adapt to climate change in a process of co-evolution.

Yet none of this helps to solve the conflicting objectives that arise when environmental factors interact. For example, agricultural experts explained that pest control measures targeting the reed glass-winged cicada completely counteracted soil protection efforts. Additionally, farmers who attempted to switch to summer crops as an adaptation decision were forced to return to winter crops due to repeated drought conditions. This, in turn, led to increased challenges with pesticide use and resistance problems. Although cultivating cover crops between the main crops may improve soil quality, it also increases water consumption. Water availability was highlighted as a barrier to adapting to drought and frost through irrigation and frost protection systems: Sometimes water is simply not available in the quantities needed. We interpret this as a dependency on—or call for—adaptation at a different, municipal level (water storage, transport). Ultimately, increased climate variability, also identified as a constraint in terms of capabilities, makes adaptation more challenging, experts noted.

In forestry, extreme weather events like storms have overwhelmed experts and practitioners with a huge amount of unexpected work that has "nothing to do with forest management or planned forest development. What we are doing is reacting rather than acting."

In summary, these findings highlight that when experts or decision-makers operate in environments where financial, regulatory, logistical, or environmental constraints dominate, they may not see a way to act on climate information, meaning that demand is blocked.

3.3.3 Motivation: reflective and automated drivers of adaptation

Following COM-B, we categorize reported motivational factors into reflective motivation (deliberate reasoning, long-term planning) and automatic motivation (habitual behavior, emotional responses).

3.3.3.1 Reflective Motivation Experts emphasized that climate change and its consequences were widely acknowledged across society. Many decision-makers and stakeholders were described as increasingly aware and engaged.

At the same time, experts described a general pattern in how people respond to recent experience: Whereas extreme events increase urgency, leading to political action and planning, periods of normal weather reduce the perceived need for adaptation—an insight in line with research on recency effects in decision-making from experience (Hogarth and Einhorn 1992; Hertwig et al. 2004). Fluctuations between extreme droughts and excessively wet years were reported to discourage experimentation, as efforts optimized for one condition may fail under the next: “A few varieties became established during the dry years: early-maturing wheat varieties that finished storing nutrients before the summer drought really took hold. These varieties were then cultivated on a relatively large scale last year. And in wet years, they have completely failed in terms of raw protein content. You could say it’s a combination that has really caused some people to fall on their faces twice over.” As a result, experts perceived practitioners to hesitate in committing to specific adaptation strategies. One expert also expressed a sense of pointlessness in light of global dynamics, questioning the value of local adaptation if major emitters abandon international agreements.

Experts disagreed on whether better climate information could improve motivation and help shift from reactive behavior to proactive adaptation. Some argued that motivation may increase if the information were perceived to effectively reduce risk. Others said that climate models had reliably forecast climate change all along and that we as a society have to learn it “the hard way.”

3.3.3.2 Automated Motivation Experts reported that the sheer scale of climate-related changes causes frustration and a feeling of helplessness, especially in forestry, where recent forest diebacks have dramatically altered landscapes. One expert emphasized that we, as human beings, struggle to accept these changes. In addition, forestry experts noted that management approaches are deeply shaped by experience, which is even reflected in the language used. As one put it: “There are no native or foreign tree species. They are all here when the climate is suitable, and they will all disappear when that is no longer the case.”

Agriculture experts described marked individual differences in farmers’ motivation, from those who are flexible and constantly adapting to those who prefer to continue using established methods for as long as possible.

As these findings illustrate, decision-makers may be negatively affected by experiences of failure, feel overwhelmed by climate variability, see little hope in the face of global developments, or be heavily influenced by existing traditions. These factors can limit their motivation to explore other, potentially better adaptation strategies, leaving demand unexpressed. The lack of opportunities and capabilities described in the previous subsections may also negatively influence motivation and thus demand: Without sufficient opportunities, potential users may see little value in demanding climate information, even if such information were accessible.

In the following section, we explore how decision-makers currently deal with uncertainty and navigate the identified constraints.

3.4 Decision strategies under uncertainty

The experts described a range of decision strategies that farmers and foresters apply to make decisions under uncertainty. These included (i) relying on past experience, (ii) learning from others, (iii) “navigating by sight,” that is, adapting only when the observed conditions require it, (iv) diversifying, and (v) planning for the worst-case scenario (see Fig. 2). Some of these strategies can be classed as heuristics, as they rely on simple rules rather than optimization based on probabilities and complex calculations (Gigerenzer and Gaissmaier 2011). In some environments, such heuristics can result in better outcomes than more complex strategies (e.g., Gigerenzer and Brighton, 2009).

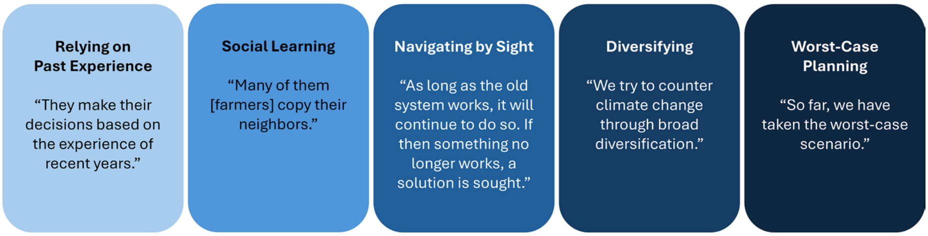

Fig. 2 Five decision-making strategies described by experts in agriculture and forestry: relying on past experience (agriculture and forestry), navigating by sight (reacting only when problems arise; agriculture), social learning (copying peers; agriculture), diversifying (spreading risks by adopting varied practices; agriculture and forestry), and worst-case planning (forestry)

3.4.1 Relying on Past Experience

Experts noted that practitioners rely heavily on recent experience when making decisions. This observation is consistent with findings from the psychology of risk, which distinguishes two teachers of risk, namely, description and experience (Hertwig and Wulff 2022), and from naturalistic decision-making research, which highlights how domain expertise and pattern recognition often replace formal prediction (Klein 2008).

3.4.2 Social Learning

Experts in agriculture described decision-making based on peers' behavior, with farmers "copying their neighbors." This aligns with social learning theory and heuristics that emphasize adaptation through observation and imitation (Bandura and Walters 1963; Hertwig et al., 2012; Offerman and Sonnemans, 1998).

3.4.3 Navigating by Sight

Agricultural experts reported that some practitioners prefer to stick to what they know as long as it works and adapt only when necessary, rather than proactively implementing long-term adaptation measures. The tendency to navigate by sight aligns with two strategies from the literature: status quo (Samuelson and Zeckhauser 1988) and deliberate inaction (Anderson 2003). Experts emphasized that navigating by sight may be a reasonable strategy as long as predictions remain too uncertain.

3.4.4 Diversifying

Some experts suggested that uncertainties should not be reduced, but rather acknowledged in planning processes. They advocated for considering the broadest possible range of scenarios rather than committing to a single future projection: "We are simply trying to address the process of climatic change, as I said before, through broad diversification." Another expert emphasized the importance of resilient agronomic practices, such as improving soil structure to retain water under both drought and heavy rainfall conditions. While not explicitly labeled as diversification, we interpret these measures as such a response, aimed at maintaining productivity across a wide range of climatic scenarios. (Naïve) diversification

(Benartzi and Thaler 2001; DeMiguel et al. 2009) represents a robust heuristic to reduce exposure to unpredictable outcomes.

3.4.5 Worst-Case Planning

Planning for the worst case was reported in both forestry groups. This strategy aligns with a minimax heuristic (Savage 1951; Wald 1949): focusing on the worst possible climate scenario and choosing actions that minimize the damage in that scenario.

In summary, the decision strategies that farmers and foresters currently apply do not depend on precise future climate information. This raises two central questions about the demand for such information: Do these decision strategies already represent the best fit in light of the constraints and uncertainty faced by decision-makers? If alternative, prediction-based strategies are conceivable, what information would they require?

3.5 Experts' current use of climate information and perceived limitations

None of the 24 experts—except for two modelers who use them in research—reported applying climate predictions on the subseasonal to decadal timescales, and they were not aware of any concrete use cases in practice. While Sect. 3.3.1 addressed gaps in users' capabilities to interpret and apply predictions, we now turn to how the experts themselves evaluated the predictions. These evaluations are critical because they influence whether predictions are seen as worth integrating, regardless of users' technical ability to do so.

Most experts acknowledged the potential value of climate predictions. However, they perceived them to be "imprecise," "unreliable," "too broad," and "uncertain" (summarized hereafter as "imprecise"), and therefore do not yet integrate them into advisory or planning routines. Instead, both experts and decision-makers rely on past observations, short-term weather data, and information derived from scenario-based long-term projections. To better understand what experts meant by "imprecise," we examined in detail how experts evaluated forecasts. Three core themes emerged.

3.5.1 Lack of Tailoring

Experts considered ensemble means—the averaged results from multiple simulations and/or forecast models—uninformative for practical decision-making. While they may help in developing broad strategies, practical decisions have to address variability and extremes. One expert and policy consultant noted: "[T]he fact that it's getting warmer overall, I don't need a decadal forecast for that. Everyone knows that already." Another expert emphasized that scenario-based information (e.g., best- vs. worst-case bounds) is better aligned with decision-makers' needs: "Because these are precisely the scopes for action where I, as a manager, need to understand the difference between a best-case and a worst-case scenario."

Experts also discussed the appropriate resolution of climate predictions. Some called for finer spatial/temporal detail (e.g., for localized extremes like frost or heavy rainfall), while others argued that coarser resolutions (e.g., state-level or multi-year trends) would suffice, provided they reliably indicate relevant risks like droughts. Impact researchers added that higher resolution is only useful if complementary data (e.g., yield data) are available at similar scales, which is currently rare.

3.5.2 Accuracy and Reliability

Experts acknowledged that predictive accuracy declines with lead time and requires aggregation. However, they stressed that usefulness depends not on precision but on robust indications of relevant variables (Sect. 3.6), with societal acceptance of scenarios and their implications often outweighing technical accuracy.

3.5.3 Interpreting and Handling Uncertainty

While experts called for scenario-based information, such as best-/worst-case outcomes, they also criticized wide prediction intervals. In accordance with Løhre et al. (2019) wide intervals were perceived as uncertain and probabilistic forecasts dismissed ("you may just as well throw a dice") unless near-deterministic (e.g., "if we could say we are 90 to 95 percent certain"). The issue here may lie less in understanding uncertainty than in acting on it: Decision-makers may lack institutional or normative thresholds for using probabilistic forecasts. Consequently, even if they understand the forecasts, they may remain unusable in practice.

Taken together, these findings suggest that current climate predictions fail to meet potential users' needs—either because they are misaligned with existing decision strategies, or because users lack the capabilities and structures needed to apply them. This interpretation aligns with the descriptive analysis of our pre-group survey: With the exception of the agricultural state-level practice group, experts rated improvements in climate predictions on subseasonal to decadal timescales as less critical than other factors (e.g., better integration, communication, or economic incentives; Fig. S1).

Next, we explore what information climate predictions would need to deliver to be considered relevant to decisions.

3.6 Future climate information perceived as relevant to decisions

In the pre-group survey, responses on necessary weather/climate indicators for decision-making or recommendations in this regard varied widely. Answers for crop diversification, for example, ranged from "precipitation and temperature over longer periods," "dry spells, heavy precipitation, water balance," "expected yield distribution or yield risks," to "there are too many individual direct and derived variables that are relevant."

Interestingly, experts found it easier to articulate information that they perceived as potentially relevant to decisions when thinking out loud about possible climatic developments in the focus groups. Across all groups, experts emphasized the importance of predictions about climate variability: within a year (intraannual), between years (year-to-year), and across multiple years (multi-year), for both temperature and precipitation (Table 2). They saw this information as potentially relevant for water management, crop selection, diversification, and prioritization. One expert explained: "Well, if I knew better whether this dry period we've had in the last 10 years will continue or whether we are now going back into a much [wetter] period, as we've seen in the last one-and-a-half to two years, that would make it clear what is on the agenda for me in the next few years." All groups especially highlighted the risks associated with seasonal droughts.

Table 2 Decadal climate information types and related adaptation decisions

Type of climate information	Potential decisions supported
Intraannual (seasonal) variability in temperature and precipitation for the coming year	Planning investments (agriculture); planning crop rotations (agriculture)
Year-to-year and/or multi-year drought risk (spring and summer)	Investing in irrigation (agriculture); crop diversification (agriculture); choosing tree species and selecting planting times (forestry); planning short rotation plantations (forestry)
Year-to-year and multi-year variability in precipitation	Securing water rights (agriculture); water storage (agriculture, water management); drainage (agriculture, forestry); retention (agriculture, forestry)
Climatic water balance (seasonal)	Crop selection and diversification (agriculture); implementing agroforestry systems (agriculture); improving soil structure (agriculture)
Consecutive hot days (summer)	Investing in cooling for livestock farming
Growing Season Length (GSL); yearly/multi-yearly temperatures and frost risks (winter)	Pest prognosis (forestry); selecting planting times (forestry)

Note. Experts referred to different types of droughts, including prolonged dry spells, low precipitation combined with high temperatures, and more general multi-year dry conditions

All groups referenced the years 2018–2020 as impactful in shaping perceptions of extreme heat and drought. The potential recurrence of such conditions is a key concern, as one expert commented: "What if a climatic water balance like that of 2018 to 2020 were to be repeated?"

Experts in the state-level practice group for the forestry sector also expressed interest in understanding larger-scale drivers, like cold fronts, that help explain local climate changes. One expert emphasized that better explanations of local phenomena could help advisors communicate more effectively with decision-makers, noting that the relevant information currently has to be pulled together from various sources.

4 Discussion

This study explored the necessary conditions for decadal climate predictions to inform adaptation decisions in Germany's climate-sensitive agriculture and forestry sectors. To this end, we conducted four systematically sampled online expert focus groups with 24 participants in total, followed by structured qualitative content analysis based on the COM-B framework for behavior change (Michie et al. 2011).

4.1 Necessary conditions for information use

Our results indicate that although measures are currently being taken to adapt to climate change, medium- to long-term adaptation efforts remain limited. Important adaptation decisions for the next 10 years identified by the experts include crop and farm diversification, developing and implementing suitable insurance schemes, developing effective crop protection strategies, securing water availability (agriculture); and forest regeneration and reforestation, rewetting, and water retention (forestry). Furthermore, the act of prioritizing—deciding when to pursue which decisions—emerged as an important meta-level decision.

We identified various constraints on decision-makers' capabilities, opportunities, and motivation that shape these decisions and the perceived value of climate predictions:

1. Capabilities were reported to be limited among both decision-makers and experts themselves. Decision-makers lack some of the knowledge and skills needed to handle impacts effectively, while experts struggle to translate climate information into actionable recommendations. Even among experts, what constitutes "good" adaptation was sometimes contested. Climate predictions are often perceived as insufficiently tailored, unreliable, or difficult to act on due to wide intervals and weak probability signals.
2. Opportunities were limited by external factors such as high adaptation costs, regulatory and logistical constraints, and environmental trade-offs that frequently prevent decision-makers from adapting to an uncertain future. Even when experts or decision-makers recognize the potential value of improved predictions, these opportunity constraints can diminish their perceived importance or prevent their adoption. Indeed, experts emphasized that such opportunity constraints currently outweigh the benefits of better information.
3. Motivation was shaped by both reflective factors, such as the urgency felt after extreme events, and automated drivers like frustration and tradition. While experience of recent events can spur action (recency effect), fluctuating conditions—such as alternating droughts and floods—tend to discourage experimentation and reinforce reactive strategies. Ingrained practices and feelings of helplessness in the face of phenomena such as forest diebacks further suppress proactive adaptation. Experts disagreed on whether better predictions could help overcome these barriers, with some arguing that society must learn "the hard way."

In line with these constraints, we found that subseasonal to decadal predictions are currently not used in practice, either by the experts interviewed here or by the decision-makers they know of or work with. Instead, decisions are made using simple strategies and heuristics—relying on past experience, navigating by sight, social learning, diversifying, and worst-case planning—that do not rely on such predictions.

4.2 What is the true demand for future climate information?

Constraints on information uptake also impact whether a demand for climate information becomes visible and actionable. First, demand may be masked by missing capabilities. For example, farmers might consider a seasonal drought forecast useful only if they know how to respond and how effective the response will be. Second, demand can be blocked by a lack of opportunities. Foresters might use a decadal drought forecast to plan planting times only if they have the opportunity to manage workflows flexibly (e.g., availability of resources like seeds or trees and workforce for planting). Third, demand may remain unexpressed due to motivational constraints. Policymakers whose motivation to support adaptation measures depends on recent weather events may fail to recognize the potential of medium-term forecasts to, e.g., inform funding decisions. Only if the necessary conditions for the use of climate information are met will a demand become visible and actionable. The question whether all these conditions can be realistically implemented in practice remains, however.

At the same time, our results show that the lack of climate predictions uptake does not necessarily indicate a lack of demand—but that it matters how demand is assessed. On the one hand, demand should not be presupposed but elicited in a neutral manner. On the other hand, it is important to open up a space for exploring potential solutions that is not constrained by how decisions are currently made. When asked directly, experts initially struggled to provide details of the climate information needed to make specific decisions. However, when discussing potential changes in climate conditions during group discussion, they expressed particular interest in better information on intraannual, year-to-year, and multi-year variability, as well as extremes in temperature and precipitation over the coming years. They then began linking this information to a range of concrete decisions, including prioritization, investment planning, crop choice and rotation, and water rights (agriculture); planting time selection and pest control (forestry); and water storage, drainage, and retention (water management). Thus, a problem-driven elicitation approach, starting from anticipated climatic developments rather than from current decision processes, may help make potential information needs visible even when the necessary conditions for its use are not (yet) in place.

Finally, taking the COM-B perspective to understand the demand side redirects attention to a fundamental question: When and where is the provision of better climate information truly necessary to improve decision outcomes (see, e.g., Dessai et al., 2009)? Even if all constraints were removed and all necessary conditions met, information may still remain unused if the strategies currently applied are perceived as sufficient. Put differently: A true demand exists only where the use of climate information would actually improve decision processes and/or outcomes.

Our results highlight the need to assess true demand by comparing the processes and outcomes of decision strategies currently in use with those based on better climate information. While experts can evaluate what constitutes a better operational decision within existing workflows, assessing decisions involving medium- or long-term adaptation is more complex due to knowledge gaps and the highly interdependent nature of decisions with various levels of uncertainty, ranging from forecast uncertainty to the more Knightian or "radical" uncertainties of markets, ecosystemic response, and technical or societal developments (Kay and King 2020; Knight 1921). Psychological research on bounded and ecological rationality has shown that these are exactly the types of conditions under which some of the strategies currently in use—such as the heuristics identified—might outperform strategies that require more, but still uncertain, information (Gigerenzer and Brighton 2009). In the same spirit, Simon (1956) proposed that in real-world situations people do not optimize but "satisfice," aiming for "good enough" solutions.

The urge to optimize rather than satisfice—in our case, to use climate predictions in addition to existing knowledge about climate change—may partly reflect a cultural belief in optimization rather than a real need. Such an "ideal–reality gap," as observed for highly uncertain "transformative life decisions" in Western, educated, industrialized, rich, and democratic societies, can increase the cognitive and psychological burden without improving outcomes (Hechtlinger et al. 2025). Reframed for the current context, the key question is thus: Where are (better) climate predictions actually needed—and where is the pursuit of better climate information an attempt to optimize where optimization is not necessary or feasible?

4.3 Implications for bridging efforts and future research directions

Overall, we propose that a sectoral analysis grounded in behavioral theory, as presented in this study, offers a starting point to systematically understand where and how climate information could inform decisions. Our approach does not replace existing efforts in this direction, such as climate services and co-production projects, but suggests the COM-B framework as a useful behavioral lens to complement them. It serves as a valuable tool to identify the necessary conditions for use of climate information and thus to better align the supply and demand sides.

However, before investing in better climate information and co-production, the first question should be: Which decisions actually require better information, and which could be made equally well without it? For existing operational workflows, methods like Applied Cognitive Task Analysis (Militello and Hutton 1998) and Decision Calendars (Ray and Webb 2016) may help users articulate and compare alternative strategies and identify potential entry points for climate information. But in the interdependent and highly uncertain context of medium- to long-term adaptation, evaluating the potential value of climate information requires assessing decision strategies under radical uncertainty, where benefits unfold only over extended time horizons. This is a methodologically challenging task that calls for robust methods that do not treat uncertainty solely as quantifiable risk. Instead, it requires integration of methods from different research traditions, such as multi-criteria decision analysis (e.g., de Brito and Evers 2016), structured expert elicitation (e.g., Magnan et al. 2025; Morgan 2014), and expert forecasting and aggregation (Atanasov et al., 2025; Tetlock and Gardner 2015)—applied to factual and, where indicated, even counterfactual decision processes and outcomes.

From this perspective, understanding true demand for climate information is also inherently a meta-decision-making problem: It requires evaluation of which decision-making processes are appropriate in a given context. Yet there is still "a need for research on the meta-decision-making question: How should decision-makers choose which decision-making process to use?" (Siders and Pierce 2021, p. 1). We see this line of research and the development of appropriate methods as a key avenue for future research, as a true demand for climate information exists only where current strategies, or alternative heuristics, are insufficient—where "good enough" is *not* enough.

5 Conclusions

Using the example of decadal climate predictions in German agriculture and forestry, we have demonstrated how the COM-B framework (Michie et al. 2011) offers a novel perspective to explain the persistent gap between information produced and information used, categorize the behavioral factors identified in the literature that influence whether climate information is adopted or ignored, and identify necessary but unmet conditions for its use.

Consistent with previous work, our results challenge the assumption that climate adaptation requires information that is "better" in terms of resolution, predictive power, complexity, or tailoring to specific decision-makers' needs. Rather, as we show, demand emerges only if decision-makers have the capabilities, opportunities, and motivation to put this information to practical use.

Moreover, we argue that for there to be a true demand for climate information, it must be clear that decision strategies incorporating that information are superior to those that do not. Otherwise, what is perceived as demand may simply reflect discussions between producers and potential users about hypothetically helpful information, leaving it unclear whether the information provided will be used and will ultimately make a difference. While this study cannot answer where there is a true demand for (decadal) climate predictions in German agriculture and forestry, it demonstrates how applying the COM-B framework can help to understand the necessary conditions for demand to become visible and actionable in the first place—and to assess the feasibility of meeting those demands in practice. It underscores the need to critically assess where climate predictions—or future climate information more generally—add value, and where they do not, in order to design effective interventions: To be truly effective, co-production and climate services, as examples of bridges between supply and demand, need to be coupled with research that looks at the necessary conditions for information use and the effectiveness of that information to improve decision-making. We believe this is a key effort for future practice and research aimed at developing scalable, evidence-based solutions that improve climate adaptation in contexts critical to society.

Supplementary information The online version contains supplementary material available at https://doi.org/10.1007/s10584-026-04163-y.

Acknowledgements We thank Amanda Fink for serving as a second coder and Susannah Goss for editing this manuscript. Additionally, we thank our anonymous reviewers who provided helpful input to improve our work.

Author contributions Fabian Rüsenberg: Conceptualization, methodology, investigation, formal analysis, project administration, visualizations, writing. Nadine Fleischhut: Conceptualization, methodology, supervision, validation, funding acquisition, writing (reviewing and editing).

Funding Open Access funding enabled and organized by Projekt DEAL. This research was funded under the FONA line of the Bundesministerium für Bildung und Forschung (BMBF), Grant 01LP2327C, “Coming Decade”, and financially supported by the Hans Ertel Centre for Weather Research (HErZ) of the German National Meteorological Service, grant 4823DWDP6B. Open Access Funding provided by Freie Universität Berlin.

Data availability All data are freely available: https://osf.io/5bj4e/.

Declarations

Ethics approval and consent to participate This study was granted by the Ethics Committee of the Max Planck Institute for Human Development (Date: 15/10/2024, No. A 2024–32). Informed consent was obtained from all individual participants included in the study.

Declaration of generative AI and AI-assisted technologies in the writing process During the preparation of this work, the authors used GPT-4o and Le Chat to improve the readability and language of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Conflict of interest The authors declare no conflict of interest.

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