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Research article

Strategies for combating climate extremes in a semi-arid region in Austria

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ABSTRACT

Semi-arid regions are particularly vulnerable to compound climate extremes. To transform a region towards climate resilience, strategies, actors and their narratives are key. Long-term analyses of strategies are rare even though required to trace their evolution, uncover changes in dynamic environments, and guide regional development. We use a qualitative research design to (i) identify regional strategies against droughts and heavy precipitation and reveal their implementation status; (ii) explore the narratives of involved actors for and against regional strategies; and (iii) extract factors that are perceived to enable or impede the development or realization of regional strategies. The theoretical concepts of strategy, actors and narratives have guided our qualitative research in the semi-arid Seewinkel region in Austria. We have conducted and analyzed semi-structured interviews with regional actors from the water management, agriculture and nature conservation sectors in the semi-arid Seewinkel region. Qualitative data analysis revealed nine factors related to strategy, actors and context that enable or impede the development and realization of strategies against climate extremes. For a strategy against climate extremes to succeed in the long-term, we find that key players, broad societal support and actors' emotional responses are equally important than long-term effectiveness, adequate financial resources, and appropriate legal frameworks. Future research could explore the interactions among the identified factors, assess their relevance at critical phases of strategy processes, and compare empirical data across various semi-arid regions to identify universally applicable enabling factors.

1. Introduction

Semi-arid regions are characterized by precipitation levels below the potential evapotranspiration (Hulme, 1996) and are particularly vulnerable to the periodic and sequential occurrence of climate extremes (IPCC, 2022). Climate extremes, including droughts and heavy precipitation, are likely to increase in frequency and severity in the next decades, with uncertainties remaining at local to regional levels (Fischer et al., 2013; Hari et al., 2020; IPCC, 2021). They may compromise water and food security (Leng and Hall, 2019; Misra, 2014; Schewe et al., 2019), destabilize ecosystems (Fang et al., 2023; Godfree et al., 2019; Vicente-Serrano et al., 2020), and adversely affect quality of life and a region's economic prosperity (Erfurt et al., 2019). Impacts may propagate between the interdependent natural and human systems and their sub-systems (Lawrence et al., 2020), and they may even 'tip' fragile systems or regions. In the semi-arid Austrian Seewinkel region, persistent droughts have adversely affected agricultural production as well as the largest endorheic lake in Central Europe (Lake Neusiedl) and its neighboring saline lakes. Drought impacts included yield reductions, decreasing groundwater levels and subsequent losses of unique habitats (Horváth et al., 2019; Krachler et al., 2012). At the same time, the Seewinkel region has experienced heavy precipitation and severe floods, with impacts on agriculture, housing, tourism and transport infrastructure (Mechtler et al., 2021). The combined impacts of recurrent droughts and heavy precipitation in a region challenge actors to adapt or transform the interconnected systems towards climate resilience in due time.

Strategy is one of the key means actors use to bring about change in a region (Van Assche et al., 2020), also in the context of climate extremes. It is defined as "a pattern in a stream of decisions" with intended and emergent elements that address a long-term goal of public interest (Mintzberg, 1978, p. 934; Neugebauer et al., 2016; Seebauer et al., 2025). The addressed goals of public interest may compete, change over time (Van Assche et al., 2020) and interact with private resources and individual interests. A strategy dealing with droughts or heavy precipitation at regional level requires the consideration of objectives for the water management, agriculture and nature conservation sectors. These

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objectives may be related (as frequently addressed in the water-energy-food-ecosystems nexus; Carmona-Moreno et al., 2019; Hoff, 2011), and expressed by actors operating in these sectors using narratives. Narratives uncover the involved actors' perspectives on the exposure and vulnerability of the region to climate extremes, their support of long-term goals of public interests as well as their reasons for corroborating or opposing a specific strategy (Seebauer et al., 2025; Shanahan et al., 2011).

However, strategy development and realization for alleviating potentially adverse impacts of climate extremes remain underexplored, while their scope of application increases with climate change (Seebauer et al., 2025; Seijger and Hellegers, 2023). Hence, long-term analysis of cross-sectoral actors' narratives and strategy development processes in the context of climate change are needed to identify success factors and derive promising adaptation or transformation approaches. While nexus research has substantially advanced cross-sectoral knowledge on the water-land-ecosystem interactions and relationships (Kropf et al., 2021; Pahl-Wostl, 2017), long-term analyses are still rare. Yet, long-term analyses are particularly useful for examining climate extremes and related uncertainties, examining long lead times of strategy realization, uncovering changes in narratives and involved actors, and enabling learning from the past. Regional investigations are of particular relevance, given that adaptation and transformation take place at individual, collective or regional levels (Park et al., 2012). While the comparably small regions currently transitioning towards dry climate conditions have received limited attention in the past (IPCC, 2022), scientific investigations or guidance could make a difference for adaptation and transformation processes in such regions – in particular if they consider the interactions between natural and human systems and their sub-systems, between different sectors and policy domains, and between drivers at different spatial and temporal scales (Stringer et al., 2017).

Our research aims at tracing the evolution of actors' narratives and analyzing the process of strategy development to extract factors that are perceived to enable or impede the realization of strategies dealing with climate extremes at regional level. We build on theoretical concepts that guide empirical data collection as well as the analysis of qualitative interviews, conducted with regional actors from the water management, agriculture and nature conservation sectors. Our work focuses on the semi-arid Seewinkel region in Austria. The region is delimited by an individual groundwater body which necessitates regional solutions for both, little and excessive precipitation. We adopt a long-term perspective of more than three decades to satisfy the requirements for investigating strategic goals and climate change. In particular, we address the following research questions: (i) What strategies dealing with droughts or heavy precipitation have been devised or imported for the semi-arid Seewinkel region in Austria? (ii) What narratives held by involved actors from the water management, agriculture and nature conservation sectors have supported or weakened the planning or revision of these strategies? (iii) Which factors enable or impede the realization of strategies addressing droughts or heavy precipitation in the semi-arid region?

Existing studies for semi-arid regions focus on regions with long experience in dry climate conditions across the world, such as the Sahel (e.g., Okafor et al., 2021), the Middle East and North Africa (Gebrael et al., 2024), and the southwestern North America (Williams et al., 2020). The investigations mostly center on observed and projected impacts of climate change on natural and human systems as well as potentials for adaption and transformation, including technical, agronomic and financial approaches (Jacobsen et al., 2012; Milgroom and Giller, 2013). Other studies explore individuals' climate change perceptions and adaptation intentions (Banerjee, 2015; Dhanya et al., 2021; Dhanya and Ramachandran, 2016; Mitter et al., 2024; Ndiritu, 2021) or assess policy options and their competing objectives for semi-arid regions (Karner et al., 2021; Mitter and Schmid, 2021). For the Austrian Seewinkel region, previous work quantified impact-response relationships under past and future climate and socio-economic conditions using hydrological, system dynamics and integrated modelling (Blaschke and Gschöpf, 2011; Karner et al., 2021; Mechtler et al., 2021; Mitter and Schmid, 2021; Valencia Cotera et al., 2023), evaluated ecosystem and landscape services by combining empirical data with spatial information (Hermann et al., 2014; Horvath et al., 2022), and developed a shared mental model focusing on the water-energy-food-ecosystems nexus (Kropf et al., 2021).

The reviewed literature suggests a knowledge gap in long-term, cross-sectoral analyses of strategy development and realization processes striving for the mitigation of likely harmful impacts of climate extremes at both, regional and global levels. In particular, investigations on recurrent and compound extremes (i.e., the potential occurrence of multiple climate extremes) are notably scarce for semi-arid regions where droughts are a primary concern and heavy precipitation is typically disregarded despite its potential significance in the future (IPCC, 2022; Wu et al., 2023; Zscheischler et al., 2018). In addition, effective procedural and practical solutions in dealing with climate extremes that are actively supported by actors from different sectors are lacking, especially for regions currently shifting towards dry climate conditions (IPCC, 2022).

Our work complements previous efforts and aims to enrich the existing body of literature through two main contributions. First, we perform an in-depth, long-term analysis of strategy development and realization for a semi-arid region experiencing both, droughts and heavy precipitation. At the same time, we consider the interactions and relationships between the water management, agriculture and nature conservation sectors. To do so, we bridge the theoretical concepts of strategy, actors and narratives and combine the conceptual advancement with a qualitative, empirical analysis. This enables us to gain deep insights into the challenges posed by the alternating patterns of droughts and heavy precipitation and their contrasting regional impacts. By examining the pursued basic and intermediate strategies, we acquire a profound understanding of how key actors drive strategy development and implementation using narratives.

Second, we explore factors that are perceived to support or hamper the development and realization of strategies for dealing with climate extremes in the semi-arid Seewinkel region. We focus on procedural, actor-related and contextual aspects to improve management responses to climate extremes and to identify potential levers for adaptive or transformative change towards climate resilience. While we have purposefully selected our study region (with the respective reasons described in the materials and methods section below), this implies that the research results are of limited generalizability and transferability to other socio-environmental contexts. However, the results could be pertinent for the largely understudied semi-arid regions that experience periodic droughts and heavy precipitation. Even in different cultural and institutional contexts, the enabling and impeding factors we study may inform processes aimed at advancing the legal and institutional environment, encouraging the continuous and long-term engagement of diverse actors, and establishing cross-sectoral authorities focused on climate resilience.

In the following section 2, we briefly introduce the characteristics of the Seewinkel region and describe strategy, actor and narrative as the main theoretical concepts that inform data collection and analysis. In section 3, we present the development of three strategies for dealing with climate extremes in the Seewinkel region. In addition, we explicate strategy-related, actor-related and context-related factors and how they are perceived to enable or impede the development or realization of strategies. In section 4, we discuss how strategic goals and means to achieve them have changed over time, and to what extent our enabling and impeding factors are relevant for other regions. We sketch limitations of our approach in section 4 and draw conclusions for semi-arid regions in section 5.

2. Material and methods

2.1. The semi-arid Seewinkel region

The Seewinkel region is about 45,100 ha in size and located in the North Eastern Plains and Hills in the federal state of Burgenland at the Austrian-Hungarian border (Fig. 1). It is delimited by a single groundwater body and classified as semi-arid because precipitation is typically lower than the potential evapotranspiration (Eitzinger et al., 2009). On annual average, precipitation is below 600 mm, and the temperature is about 10 °C (Blaschke and Gschöpf, 2011). The region has been hit by several climate extremes, including four (multi-annual) droughts (1991, 2001–2004, 2013, 2017–2022) and four flood events (1941, 1965, 1995, 2014) during the last 80 years. Large parts of the region used to be marshland before they were cultivated around the turn of the last century (Mechtler et al., 2021). At present, the dominant agricultural land use is arable land, followed by vineyards and permanent grassland (Mitter and Schmid, 2021). Partly, agricultural activities take place in nature conservation areas, which belong to the national park "Neusiedler See – Seewinkel". The Seewinkel region has attracted public attention in the last years because the water level of the touristic Lake Neusiedl was historically low (Wolfram et al., 2021). This resulted from recurring droughts because, apart from a minor inflow, the lake is fed only by rainwater. In addition, the lake does not communicate with the groundwater body because of a water impermeable layer at the bottom (Wolfram et al., 2014). The groundwater is mainly used for agricultural irrigation purposes (Reisner, 2014), while the unique saline lakes require a low distance to the groundwater level for capillary uptake of salt (Krachler et al., 2012). Drinking water is sourced from a deep groundwater body and not in direct competition with agricultural irrigation water.

For our analysis, we focus on the Seewinkel region for three main reasons. First, the Seewinkel region is located in a country that is perceived as "water rich" by its democratic leaders (Lindinger et al., 2021), but has experienced recurring climate extremes over the last decades, including severe droughts and heavy precipitation (Buras et al., 2020; Hari et al., 2020; Haslinger et al., 2019). In addition, regional warming is above the global average, which has already resulted in a shift of the climate zone (Rubel et al., 2017). Another shift is projected to occur in a worst-case emission scenario (Rubel et al., 2017), which stresses the vulnerability of the region. Second, the national and regional governments are considered effective in following the "rule of law" (Minkov and Kaasa, 2022), but the development of cross-sectoral and regional strategies for coping with climate extremes is considered a major challenge for adaptation and transformation towards climate resilience (Balas et al., 2021). The national government has adopted and regularly revised its adaptation strategy (Balas et al., 2024; Kronberger-Kießwetter et al., 2012, 2015), and the regional government has integrated context-specific adaptation measures into sectoral strategies or programs. However, strategy development is essential but in its infancy with respect to discontinuities, non-linear dynamics and surprises, cross-scale and cross-sectoral interactions, synergies and trade-offs between adaptation and mitigation, and exploiting the regional adaptation and transformation potential towards climate resilience (Balas et al., 2021). Third, water and land resources are used, conserved or drawn on by different sectors including agriculture, nature conservation, tourism, housing, hunting and fishery. However, coordination between these sectors is limited (Wolfram et al., 2021), while the prevention of resource use conflicts through strategies is increasing in importance with more frequent or more intense climate extremes projected for the future (Mitter and Schmid, 2021). Hence, aligning strategies and related rules for resource use to the regional characteristics and cultural conditions seems particularly promising (Ostrom, 1990).

2.2. Theoretical concepts

Strategy, actor and narrative are the main theoretical concepts that have guided empirical data collection with semi-structured interviews as well as qualitative content analysis of the interview data and complementary policy documents. Strategy – as defined in the introduction – is key for initiating change towards a socially desirable long-term goal, with suitable means or instruments. As such, public interests are in the focus and include water and food security, nature conservation, rural vitality and landscape products in our research context. Strategy can evolve as a purposeful plan, a pattern in a series of actions, a position in a specific environment or as a perspective on a decision embedded in a worldview (Mintzberg, 1987). This implies that strategies can be intended or emergent before they are possibly realized (Mintzberg, 1987; Seebauer et al., 2025). In this contribution, we consider intended strategies for addressing climate extremes that have been discussed, announced or planned by at least one regional actor but have not yet been implemented. Emergent strategies are not consciously planned but consistently reproduced or conveyed. Realized (i.e., implemented) strategies are set out in a legally-binding document or are confirmed, for instance, by technical constructions. Already realized strategies can be revised, for instance, by updating regulatory limits to new scientific findings or by rebuilding technical constructions. Unrealized strategies are intended strategies that are discarded or implemented strategies that

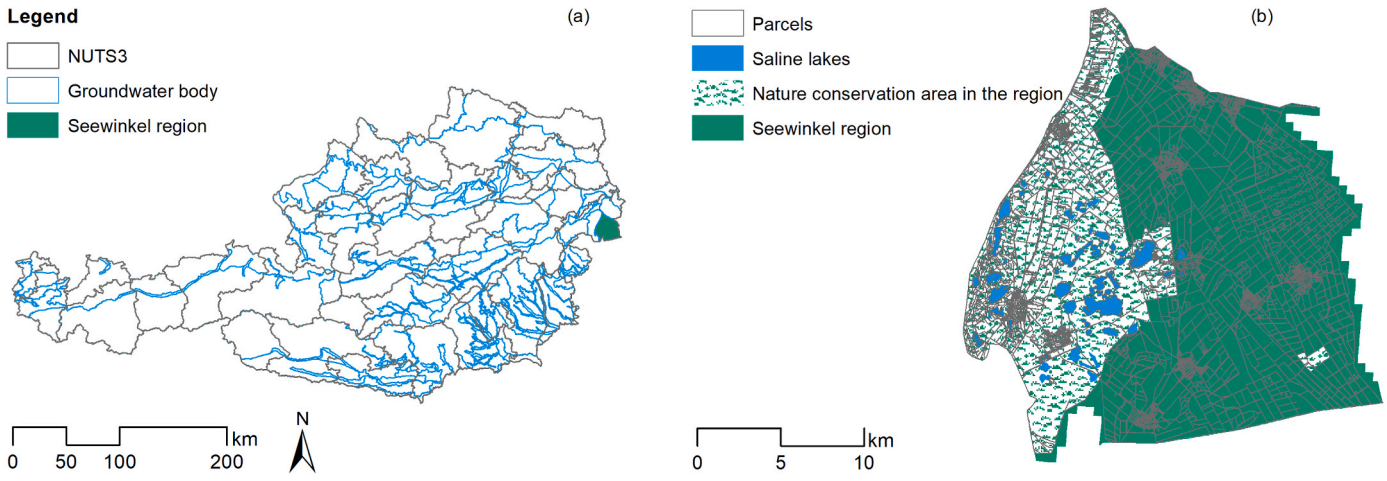

Fig. 1. Location of the Seewinkel region in Austria (a) and overview of the Seewinkel region (b). Note: The national park Neusiedler See – Seewinkel is part of the nature conservation area. Source: Own illustration based on Amt der Burgenländischen Landesregierung (2021), Nationalpark Neusiedler See-Seewinkel (2021), and Statistik Austria (2019).

are not executed or used. In addition, the concept of intermediate strategy is used for strategies that recognize the need for long-term strategies but focus on short time frames and subgoals (Van Assche et al., 2020). As such, an intermediate strategy may form the basis or contribute to the success of a long-term strategy and its goals. It should be noted that only realized intermediate strategies fulfill their purpose.

We apply a broad definition of actors, similar to Van Assche et al. (2021). This definition includes individuals, groups of individuals as well as public and private organizations that operate in the study region and are directly or indirectly involved in strategy development or realization – regardless of their interests, targets, legal status or power. Narratives are actors' stories that describe, explain or illustrate how the region of interest works, how natural and human systems interact, and what means are adequate to achieve goals considered important (Constantino and Weber, 2021). They may be linked to the ideology or identity of individual actors; they may be complementary or contradictory; they may be expressed by or ascribed to a certain actor; and they may change over time or during a debate with other actors (Seebauer et al., 2025; Shanahan et al., 2011).

2.3. Data collection

For data collection, we have developed an interview guideline, based on the theoretical concepts and aligned to the study region. The interview guideline starts with a short introduction explaining the aim of the research. Then, it provides a brief overview of prior developments in the region to establish a consistent context for the interview partners. The interview questions are organized in two main parts. The first part deals with strategies and narratives, and the second part addresses key actors.

With respect to strategies, our interview questions related to their evolution, encompassing phases of planning, design, realization, evaluation, and revision (if applicable). We also asked for the stated objectives of each respective strategy, the underlying reasons, and any potential change. In addition, we explored specific circumstances or events that were perceived to influence strategy development or realization. Then, we inquired how each strategy is connected to climate change mitigation and adaptation, dedicating a particular question to the impact of climate extremes on these strategies. With respect to narratives, our questions referred to the opinion about, the evaluation of and the perceived responsibilities for particular strategies. Additionally, we asked for individual or organizational positions towards strategies and their objectives as well as for a desirable future development of strategies for the Seewinkel region. With respect to actors, we explored the key actors involved in strategy processes, and how they interact and influence strategy development and realization. In addition, we asked for the spirit of collaboration and potential conflicts. The final question in this part focused on the interview partners' activities and responsibilities in strategy development and realization.

In the semi-structured interviews, we aimed to include a variety of actors and voices. Hence, we sampled interview partners purposefully by setting a mandatory criterion for the selection in the first step, and applying the principle of maximum variation in the second step (Flick, 2014). The mandatory criterion was the interview partners' direct relation to regionally planned or implemented strategies dealing with climate extremes in the last 35 years. For maximum variation, we involved interview partners that differ with respect to the represented sector, current and former employment, and type of organization. The sectors involved are water management, agriculture and nature conservation to address their developments and interactions. The participating interview partners are active in professional life or retired to cover a long period of time. The types of organizations involved cover the public and private sectors, academia and civil society organizations to include potentially different narratives and perspectives on future development.

Initially, actors already known from a previous research project (i.e., Kropf et al., 2021) were contacted as potential interview partners. Further contacts were established through snowball sampling (Biernacki and Waldorf, 1981; Noy, 2008), specifically targeting actors who were involved in the planning and realization of water management strategies in earlier times. In accordance with the criterion of theoretical saturation (Glaser and Strauss, 2017), sampling was completed once the interviews yielded no new insights or information. In total, one researcher interviewed 15 experts, five from the water management, five from the agriculture and five from the nature conservation sector. Eight interview partners were working for public authorities, private enterprises, interest groups or NGOs at the time of the interview (three from the water management, three from the agriculture and two from the nature conservation sector). Seven interview partners were already retired at the time of the interview (two from the water management, two from the agriculture and three from the nature conservation sector) but were involved in strategy development or implementation during their career, with some of them still actively involved on a voluntary basis. The interviews were conducted between February and April 2023. The interview format was chosen based on the interview partners' preferences and included in-person interviews at the participants' workplaces or another neutral location, as well as telephone or video conference interviews, with durations ranging from 38 to 120 min. The interview environment was designed to be conducive to open dialogue and comfort. Potential overlaps between the two parts of the interview guideline were handled by flexibly arranging the questions during the interview. The interviews were digitally recorded with the consent of the interview partners and transcribed word for word for further analysis.

2.4. Data analysis

We have conducted a qualitative content analysis using the text analysis software Atlas.ti and a combined deductive-inductive coding strategy (Mayring, 2022). Deductive codes were based on the theoretical concepts outlined above and the interview guideline. They were granulated with inductive codes derived from the empirical data. Deductive codes for the strategy concept encompass, for instance, intended, emergent, realized, revised and unrealized strategies. For actors, they relate to their sectoral approach (water management, agriculture, nature conservation) and are combined with the names of relevant organizations involved in strategy development and realization, where appropriate. Narratives were inductively categorized and linked to their advocates and their use as argument for or against a strategy. In the results section, we use direct quotes (translated into English from the original German interviews) which we assign with alpha-numerical codes that refer to the study region, the order of the interviews, and the represented sector, i.e., water management (W), agriculture (A) or nature conservation (N).

The coded data was transferred into a tabular format and ordered chronologically by strategy. This database was used to reconstruct the long-term development of strategies to cope with climate extremes as well as regional actors' narratives about these strategies. Then, the strategy-specific timelines were combined into a comprehensive time line outlining strategies, actors and narratives. The comprehensive time line was used to extract enabling and impeding factors for the realization of strategies. Hence, the enabling and impeding factors are based on the perceptions of the interview partners, which were finally reflected and cross-checked against the more detailed strategy-specific timelines. This approach allowed us to thoroughly examine strategy development and realization at regional level and over a period of time comprising several multi-year election cycles. We did not intend to compile a complete history of strategies, actors or narratives. Instead, the interview partners' perspectives and perceptions of key actors and events determined the focus of the analysis. However, we verified the timing of specific events (e.g., climate extremes, passing of regulations) with publicly available data or policy documents.

3. Results

3.1. Strategies, actors and their narratives

We have extracted three basic strategies and four intermediate strategies for dealing with climate extremes in the Seewinkel region in the last decades. The three basic strategies are: (i) regional groundwater strategy, (ii) strategy for a regional canal system, and (iii) strategy for extra-regional water supply. Their development over time, pursued goals, key actors involved including their narratives, and status of implementation are summarized below. An additional timeline is provided in the Appendix (Table A.1) summarizing information from publicly available data and policy documents. The four intermediate strategies are described in the context of the basic strategies they contribute to. They comprise: (i) introducing a new actor, (ii) launching a scientific study, (iii) granting subsidies, and (iv) conceiving or carrying out an externally funded project with specific goals and a fixed duration.

3.1.1. Regional groundwater strategy

The regional water management authorities implemented the regional groundwater strategy after a serious drought in the 1990s (Table 1). Initially, the strategy aimed to stabilize the groundwater level by legalizing farmers' wells with associated water rights and by establishing legally binding groundwater use and agricultural management restrictions given the groundwater level falls below a critical or very critical level (i.e., warning phase and restrictive phase, which are described in more detail in the Appendix). A very committed agricultural politician, who followed the political ideology of eco-social market economy, took the initiative for the regional groundwater strategy. Representatives from the water management, agriculture and nature conservation policy domains agreed to the strategy and respected it as the only practicable solution: *"And that was also a viable solution from the point of view of ecology, limnology, nature conservation, a viable solution."* (Swkl_04_N).

Intermediate strategies supported strategy realization, in particular scientific studies and new actors. Empirical evidence on the groundwater regime of the region and the characteristics of the Lake Neusiedl was regularly asked for and provided, while nature conservation was not in the focus of these studies. The new actors – a regional association for the realization of technical agricultural projects and regional water cooperatives – were mainly responsible for administrating the legal approval of the water rights for farmers. The idea for handling the water rights via water cooperatives originated from another Austrian region where it proved itself in practice. The regional association for the realization of technical agricultural projects managed the administrative process and guided the water cooperatives effectively through this process, while representatives from nature conservation were not involved. The strategy was revised (i.e., relaxed) a few years after its introduction with the aim to improve its practicability for those mostly affected. In particular, the revision should align with agricultural management practices and increase farmers' flexibility.

The drought in 2003 induced another intermediate strategy. In particular, the public sector intensified efforts and payments for improving the existing well infrastructure and increasing irrigation efficiency through advanced techniques like drip irrigation for vineyards. By contrast, the public authorities were urged not to execute the groundwater use and agricultural management restrictions defined for the restrictive phase, even though the very critical groundwater level was reached. The interview partners reported that the realization failed due to insufficient political will. Interestingly, the initiator of the strategy was still in office.

The multi-annual drought between 2017 and 2022 and its impacts directed the attention of the water management, agriculture and nature conservation sectors to the regional groundwater strategy, which was out of focus in the preceding years with enough precipitation. This period was characterized by an execution of the partly tightened warning and restrictive phases, and by intense emotions among the different actors involved. The restrictions on groundwater use were considered as the sole option to deal with the historically low groundwater table and, as such, supported by the different policy domains. However, the farmers complained about different regulations within the

Table 1
Development of the regional groundwater strategy and its implementation status over time, specifying means to achieve sectoral goals and to combat climate extremes.

Year(s)	Means	Sectoral goal	Climate extreme	Status
1990s	Define groundwater use and agricultural management restrictions	W: Stabilize GW level	D	Realized
1990s	Award water rights	A: Legalize wells	D	Realized
1990s	Re-define groundwater use and agricultural management restrictions (strategy relaxed)	A: Adjust to agricultural management practices	D	Revised
1990s	*Found water cooperatives*	*A: Administer the legalization of wells*	*D*	*Realized*
1990s	*Commission scientific studies*	*W: Provide evidence on regional water regime*	*D*	*Realized*
1997	*Found a regional association for the realization of technical agricultural projects*	*A: Administer the legalization of wells*	*D*	*Realized*
2003 et seqq.	*Grant subsidies*	*A: Improve wells*	*D*	*Realized*
2003 et seqq.	*Grant subsidies*	*A: Increase irrigation efficiency*	*D*	*Realized*
2003	Execute restrictive phase	W: Stabilize GW level	D	Unrealized
2017–2021	Execute warning phase	W: Stabilize GW level	D	Realized
2017–2021	Execute restrictive phase	W: Stabilize GW level	D	Unrealized
2022	Execute restrictive phase	W: Stabilize GW level	D	Realized
2022	Re-define agricultural management restrictions (strategy tightened)	W: Stabilize GW level	D	Revised
NA	Monitor groundwater use and agricultural management restrictions	A: Ensure compliance of agricultural management	D	Unrealized
2023	Re-define groundwater use and agricultural management restrictions (strategy relaxed)	A: Adjust to agricultural management practices	D	Revised
2023	*Commission a scientific study*	*W: Stabilize GW level* *N: Maintain ecosystems*	*D*	*Realized*
2023	Realign groundwater use and agricultural management restrictions	W: Stabilize GW level N: Maintain ecosystems	D	Intended

Notes: Intermediate strategies are marked *in italics* for reasons of reproducibility. Abbreviations: W = water management, A = agriculture, N = nature conservation; GW = groundwater; D = drought.

region and were afraid of a total irrigation ban. At the same time, they were blamed for their lacking awareness of the problem and their ignorance of the legal regulations. The water authorities were accused of ill-defined groundwater levels and insufficient monitoring activities, as stated by one of the interview partners: *"There was a problem with the way these levels were set, these extraction quantities, the extraction consensus, as it is called, and secondly with the monitoring. It was not checked."* (Swkl_08_N).

The recurring and increasingly severe droughts resulted in the intention to a complete realignment of the regional groundwater strategy in 2023. Building on the multi-decade experience, the regional groundwater strategy should finally pursue the two main goals of stabilizing the groundwater level and maintaining the unique ecosystems in the region. A scientific study has been commissioned to support this process.

3.1.2. Strategy for a regional canal system

The strategy for a regional canal system dates back to around 1900, when drainage canals were built across the region in order to reduce the fluctuations of the groundwater level and meliorate the land for cultivation purposes and settlement development (Table 2). Construction work was ongoing in particular after the severe flood in 1941, when the Lake Neusiedl reached its largest size ever recorded. Drainage cooperatives evolved as new actors at that time and focused on draining the rainwater from the region. An important weir was built at the Hungarian side of the border after the severe flood in 1965 to regulate heavy precipitation. However, environmentalists increasingly raised their voice against draining water because of its potentially adverse effects on the saline lakes. At the time of the interviews, the canal system was not properly maintained, not least because of the related high costs.

Backwater constructions started after particularly dry years in the 1980s and 1990s to keep the rainwater in the region. These constructions were built in agreement with the property owners, typically farmers, but without any administrative notice, as criticized by the interview partners. Hence, the constructions were radically removed during the flooding event in 1995 and their legalization failed because of uncertain impacts. Several actors representing the interests of nature conservation and civil society pushed for scientific evidence by groundwater models to assess these impacts and guide the construction work. However, next steps towards backwater constructions were not successful because of insufficient political will or the retracted approval of an important actor, because of the unclear distribution of high investment costs or because of divergent interests within the agricultural policy domain, as reported by one interview partner: *„there were also different opinions in agriculture. One said that the water has to run off, my land is drowning, the other said, let's make sure we hold the water back, even if a meadow is drowning."* (Swkl_01_A).

Agriculture and environmental organizations opened up new discussions about backwater constructions during the drought in 2013. Funding was limited to a demonstration project that effectively realized weirs with temporary legal authorization. This demonstration project even convinced former critics and, combined with the proactive attitude of the water management authority, the weirs were finally closed in 2022. The joint application of water management, agriculture and nature conservation authorities for an externally funded project mainly related to backwater construction was approved in 2023, after several unsuccessful evaluations. The project approval resulted in an enthusiastic mood among the partners, as summarized by one of the interview partners: "*For me, it has a spirit of optimism. So now, [snaps the fingers], now we're really going for it. Now we can get our hands on money, now we can implement something."* (Swkl_10_N).

3.1.3. Strategy for extra-regional water supply

Representatives of the water management and agriculture sectors started to discuss the strategy for extra-regional water supply (i.e., dotation) in the 1980s (Table 3). The general enthusiasm for the strategy waned when the public authorities proposed to introduce a water price to cover the expectedly high investment costs. The discussions break off but reoccurred after the serious drought in 2003. At that time, extra-regional water supply for the Lake Neusiedl was in the focus to ensure an average water level, mostly for touristic and athletic purposes, as highlighted by one of the interview partners: *"At that time, the focus was on the usability for tourism, I believe. The discussion was always very much about sailing on Lake Neusiedl."* (Swkl_14_W). The potential water supply focused on the Danube in the neighboring region of Lower Austria, which necessitated negotiations between the regional governors. Actors from the water management, agriculture and nature conservation sectors raised concerns with respect to potentially adverse impacts on the water quality of the lake. However, the discussions stopped because of limited political support from the neighboring region of Lower Austria.

The drought in 2013 and the multi-annual drought between 2017 and 2022 brought the strategy for extra-regional water supply back on

Table 2
Development of the strategy for a regional canal system and its implementation status over time, specifying means to achieve sectoral goals and to combat climate extremes.

Year(s)	Means	Sectoral goal	Climate extreme	Status
1886 et seqq.	Construct drainage canals	W: Stabilize GW level A: Meliorate land	H	Realized
1940/ 50s	*Found drainage cooperatives*	*A: Meliorate land*	*H*	*Realized*
1945 et seqq.	Construct drainage canals	A: Meliorate land, food security	H	Realized
1965	Construct a weir	W: Protect from flooding	H	Realized
1984 et seqq.	Construct backwaters, phase 1, without legal authorization	W: Keep water in the region	D	Realized
1995 et seqq.	De-construct backwaters	W: Protect from flooding	H	Realized
2008	*Apply for externally funded project (LIFE0, not funded)*	*W: Construct backwaters to keep water in the region*	*D*	*Realized*
around 2010	*Commission research projects and studies*	*W: Develop groundwater model* *N: Assess impacts of drainage canals on ecosystems*	*D*	*Realized*
2010	*Apply for externally funded project (LIFE1, not funded)*	*W: Construct backwater construction to keep water in the region*	*D*	*Realized*
2013	Backwater construction, phase 2, with legal authorization	W: Keep water in the region	D	Realized
2020	*Apply for externally funded project (LIFE2)*	*W: Construct backwaters to keep water in the region*	*D*	*Intended*
2022	Close weirs	W: Keep water in the region	D	Realized
2022	*Apply for externally funded project (LIFE3)*	*W: Construct backwaters to keep water in the region*	*D*	*Realized*
2023	Construct backwaters (LIFE3), with legal authorization	W, L, N: Keep water in the region	D	Realized
2023	Construct drainage for a particular settlement	W: Protect from flooding	H	Realized
2023	*Grant set-aside premiums*	*A: Compensate farmers*	*H*	*Realized*

Notes: Intermediate strategies are marked *in italics* for reasons of reproducibility. Abbreviations: W = water management, A = agriculture, N = nature conservation; GW = groundwater; D = drought, H = heavy precipitation.

Table 3
Development of the strategy for extra-regional water supply and its implementation status over time, specifying means to achieve sectoral goals and to combat climate extremes.

Year(s)	Means	Sectoral goal	Climate extreme	Status
1980s	Supply extra-regional water to the region	W: Stabilize water availability in the region	D	Intended
2003	Supply extra-regional water to the Lake Neusidl	W: Stabilize water level in the lake	D	Intended
around 2003	*Commission scientific study or expert report*	*W: Provide evidence on water chemistry of lake, groundwater and extra-regional water sources*	*D*	*Realized*
2013, 2017 et seqq.	Supply extra-regional water to the Lake Neusiedl or the groundwater	N: Maintain regional landscape X: Support economic prosperity of the region	D	Intended
2018	*Establish a task force*	*W, A, N: Coordinate cross-sectoral interests*	*D*	*Realized*
around 2020	*Commission scientific studies*	*W, A, N: Assess cross-sectoral effects of a potential extra-regional water supply*	*D*	*Intended*
2022	*Establish an agricultural lobby group*	*A: Coordinate and represent farmers' interests for agricultural irrigation*	*D*	*Realized*

Notes: Intermediate strategies are marked *in italics* for reasons of reproducibility. Abbreviations: W = water management, A = agriculture, N = nature conservation, X = regional economy; D = drought.

the political agenda. Both, water supply to the lake and the groundwater were discussed with water from the Lower Austrian or Hungarian Danube. Maintaining the characteristic landscape was addressed as goal, with expected beneficial effects on regional tourism, as stated by an interview partner: *"Today's approach is to preserve the lake as a water surface, as a landscape element, even with a significantly lower water level than was being discussed in former times."* (Swkl_14_W). The government of the federal state of Burgenland established a new actor, a task force, to coordinate sectoral and regional interests and develop a concept for the long-term preservation of the nature reserve. Experience from other Austrian regions supported the development of a technically feasible solution. Actors representing the different sectors requested scientific studies to assess potential effects on these sectors before realization. However, high investment costs, long lead times, competitive projects, and uncertain outcomes of a potential water supply finally limited political support. Agricultural production or irrigation were not referred to as goals of the extra-regional water supply. Farmers responded with the foundation of a lobby group to improve communication within agriculture and with actors from other policy domains.

3.2. Factors perceived enabling or impeding for the development and realization of strategies

We have identified strategy-related, actor-related and context-related factors that are perceived to enable or impede the realization of strategies, depending on their evolvement. These factors and their power are discussed below by providing illustrative examples from the Seewinkel region.

3.2.1. Strategy-related factors

The three factors directly related to strategy are (i) climate extremes, (ii) planning certainty, and (iii) financing (Table 4). With respect to climate extremes, droughts and heavy precipitation and their impacts on the region have generated discussions about the three presented

Table 4
Strategy-, actor- and context-related factors perceived enabling or impeding for the development and realization of strategies.

Factor	Enabling	Impeding	Related to
Climate extreme	Drought or heavy precipitation and their impacts building momentum	Change between dry and wet climate conditions	Strategy
Planning certainty	Clear long-term goals and objectives Easy to implement	Long lead times Lack of official support No guarantee of success	Strategy
Financing	Funding secured	High maintenance costs High investment costs Unclear distribution of costs Limited or no public money	Strategy
Agreement on strategy	W-L-E actors' broad agreement on goal and means to achieve it Synergies between sectors or policy domains	Diverging interests within and across sectors or policy domains Low priority of goals Complex problem, planning and implementation No long-term vision for the region	Actor
Awareness of the problem	Citizens' disapproval of situation Social control Strong social network	Limited or lacking recognition of individual's or sector's contribution to the problem Limited knowledge about strategy or regulation No consequences of limited adherence to strategy or regulation	Actor
Emotion	Anger about prevailing sectoral interests Enthusiastic mood	Resentment Fear	Actor
Key player	Personal motivation Political will High engagement of a public sector Intermediary, facilitator	Lacking political will Withdrawal of consent Rejection of suggestion or recommendation	Actor
Evidence	Scientific agreement Urgency emphasized Previous experience or experience from climate analog regions	Controversial limits Uncertainty	Context
Legal framework	Obligation for realization	Strong orientation towards one climate extreme	Context

strategies, which have been realized earlier or later, depending on the duration and severity of the climate extremes. Droughts clearly urged the regional groundwater strategy and its intermediate strategies, which were adjusted and implemented solely in dry periods, with the restrictive phase of the regional groundwater strategy being realized only after multiple drought years with substantial impacts on the groundwater regime in 2022. By contrast, the sequential occurrence of dry and wet years impeded the realization of strategies because the problems related to a specific climate extreme were then perceived as less urgent or not valid any more. For instance, backwaters were constructed and utilized only in drought but destroyed in wet years. Similarly, the strategy for extra-regional water supply attracted attention in years with clearly visible drought impacts while interest waned as the situation eased.

The second factor of planning certainty refers to the straightforward realization of strategies with clear, long-term goals that are easy to implement with similar means across the region. By contrast, multilateral negotiations and cross-regional or cross-border cooperation of authorities were particularly time-consuming and, hence, impeded the realization of strategies. Long lead times – such as for the strategy for extra-regional water supply – also tended to reduce political support

because it remains uncertain whether the strategy and its goals are still relevant, when finally implemented.

The third factor of financing as well as the related distribution of investment and maintenance costs are to be considered for the realization of any strategy. While high costs and limited public support impeded planning and realization, projects (co-)funded by the European Commission boosted the realization of strategies – such as backwater construction within a recently funded project within the EU LIFE Programme.

3.2.2. Actor-related factors

The four actor-related factors encompass (i) agreement on strategy, (ii) awareness of the problem, (iii) emotions and (iv) key players. Broad consensus among involved actors clearly enabled the realization of a strategy, in particular if synergies between policy domains could be reached. Such an agreement has been achieved for individual strategies such as the regional groundwater strategy, but also when applying for the project within the EU LIFE Programme mentioned above. By contrast, the lack of a long-term, jointly developed vision that considers the interactions between water management, agriculture and the unique ecosystems as well as potentially diverging priorities or interests, both within and across policy domains, hampered the realization of strategies.

With respect to the second factor, we find that the awareness of and general dissatisfaction with a situation facilitated the enforcement of strategies, while limited familiarity with a sectors' contribution to the adverse situation slowed the realization down. For instance, illegal wells and delayed agricultural adaption were discredited, which prompted initiatives related to the regional groundwater strategy. By contrast, irrigation restrictions that were partly misunderstood by the affected actors and not monitored by a neutral organization clearly limited the effectiveness of the strategy.

All types of emotions, as summarized in the third factor, can enable or hamper the development and realization of a strategy. Successful project applications typically start with a positive working atmosphere. Negative emotions – such as the fear of climate extremes and related impacts, the fear of new regulations or bans (e.g., irrigation ban) and the fear of failure – intensified reservations and thus limited the realization of strategies.

Key players hold power or resources and are individuals or organizations that actively support the development or realization of a strategy for personal, social or political reasons. Intermediaries can also serve as a key player, for instance, if they provide a neutral platform for exchange. However, if the head in a hierarchical system or partners central to a strategy deny collaboration, they can impede or even hinder the realization of a strategy – such as in the case of applying for an externally funded project for constructing backwaters to keep water in the region.

3.2.3. Context-related factors

Evidence and legal situation are classified as the two context-related factors. With respect to the first factor, empirical evidence resulting from precise and regular measurements (e.g., groundwater level) or state-of-the art models that explore, describe or explain the water regime or assess future scenarios (e.g., climate or water management scenarios) enabled strategy development if it was broadly accepted and emphasized the need and urgency for action. Previous experience and experience shared by other regions with similar climate conditions also enable change. For instance, the Marchfeld region in Austria was mentioned as a potential example for successfully implementing extra-regional water supply. By contrast, uncertainties and disagreement required attention and, hence, impeded strategy development. With respect to the second factor, we find that a body of law that is oriented towards heavy precipitation but marginalizes droughts hampers the development of strategies considering both climate extremes. Contractual agreements, however, speeded up strategy realization, in particular if they were monitored and applied for a large group of actors.

4. Discussion

4.1. Discussion of research results

4.1.1. Strategies, actors and their narratives

We have conducted in-depth analyses of empirical data on strategies against climate extremes for the Seewinkel region, which refer to a period of more than three decades. The analysis has revealed three strategies with different goals and implementation statuses. The long-term perspective proved useful to explore strategy development and changes in the strategic focus, partly in response to shifts in societal priorities. Similarly, Seijger and Hellegers (2023) emphasize that the social phenomenon of "reorientation" emerges in periods of 10–50 years. In particular, we find that the goal of the regional groundwater strategy has changed from a water-centric (i.e., stabilize the groundwater level) to a water-ecosystem-integrated focus (i.e., stabilize the groundwater level and maintain ecosystems) over the last three decades. The strategy for a regional canal system changed from a water-land (i.e., stabilize the groundwater level, meliorate land) to a water-land-ecosystems focus to keep water in the region. These changes are in line with recommendations to increase policy coherence (i.e., attuning policy goals) for achieving effective policy outcomes, given cross-cutting policy problems such as climate extremes (Candel and Biesbroek, 2016; Rayner and Howlett, 2009). The strategic focus of the regional groundwater strategy has changed only recently (in 2023), following discussions for completely realigning groundwater use and agricultural management restrictions. With respect to the regional canal system, similar discussions were launched already in 2008, when preparing a cross-sectoral project proposal to be co-funded by the European Commission.

The investigated strategies have been advanced through the growing recognition that climate extremes require cross-sectoral approaches and the cooperation between policy domains. The latter is reflected by formal exchange and informal interactions between regional actors which are encouraged through intermediate strategies such as the newly established task force (strategy for extra-regional water supply) or the cross-sectoral project co-funded by the European Commission (strategy for a regional canal system). These developments indicate an increase in policy integration in the scope of the policy frame and the variety of actors and subsystems involved (Biesbroek and Candel, 2020; Candel and Biesbroek, 2016). However, actors from the water management, agriculture and nature conservation sectors expressed the need for a "shared long-term vision" for the region to effectively manage current and projected future challenges. Similarly, Pahl-Wostl (2017) advocates for developing a nexus paradigm to foster cross-sectoral processes at local to regional levels to improve water, food and energy security and, ultimately, transform the interconnected systems towards sustainability and climate resilience. In addition, Van Assche et al. (2021) point out that "long-term" is relative to the context, affected systems, involved policy domains, designed strategies, and challenges to be addressed. Hence, long-term visions may influence future distribution of resources and power, emphasizing the need for its joint development by those affected and its adjustment to regional and cultural conditions. As such, long-term visions may be linked to the concept of "collective strategy", introduced by Astley and Fombrun (1983) for the organizational management literature. Participatively developed plausible scenarios for the European and Austrian agri-food systems (Karner et al., 2024; Mitter et al., 2020) could serve as boundary conditions for such a regional initiative on developing desirable futures.

4.1.2. Enabling and impeding factors

We have identified strategy-related, actor-related and context-related factors that are perceived to enable or impede the realization of strategies (Table 4). Climate extremes are related to strategy and have opened policy windows for realizing or revising strategies and developing intentions for new strategies in the Seewinkel region. The

sequential occurrence of droughts and heavy precipitation as well as the strong orientation of the legal framework towards floods, have, however, decelerated, delayed or even inhibited the realization of strategies. These findings are in line with empirical evidence from other regions and socio-economic contexts, suggesting that policy windows are only used if the legal and institutional environment are oriented towards the extremes, if institutions have sufficient power and flexibility for managing the extremes, and if policy advocates support effective strategies (Solecki and Michaels, 1994). From the actors' point of view, the limited relevance of droughts for strategy development in a period of particularly wet years (or vice versa) may result from the contradictory nature of these climate extremes and may be interpreted in the context of "proximity" (i.e., construal level theory; Trope and Liberman, 2010) or the "finite pool of worry effect" (Hansen et al., 2004; Weber, 2006, 2010). Construal level theory posits that individuals can only engage with their immediate experience, while other situations or climate extremes have to be mentally constructed. Hence, proximity has been suggested to alter individuals' mental constructs of climate extremes and influences which information they use to reach consensus or make decisions. This is particularly true if a region or system has a value or meaning for the individual actors and if actions or strategies are considered pertinent (Brügger et al., 2015). The finite pool of worry effect suggests that growing concern about one climate extreme (e.g., floods), may decrease concern for other climate extremes (e.g., droughts), which is particularly challenging for semi-arid regions experiencing periodic and sequential occurrence of climate extremes.

The realization of strategies may be costly and hence, distribution of costs and potential benefits have been discussed also for the Seewinkel region. Per definition, strategies address a long-term goal of public interest (Mintzberg, 1978, p. 934; Neugebauer et al., 2016; Seebauer et al., 2025), which include common resources such as water and biodiversity (Laerhoven et al., 2020). Potential problems that may arise with common resources have intensively been discussed in the literature since the famous (though criticized) publication of Hardin (1968) and have also been addressed in the Seewinkel region. For instance, citizens criticized unregulated groundwater use was which contributed to the realization of the regional groundwater strategy. Groundwater use is still free of charge in the region, whereby the interview partners referred to the very controversial discussions related to a potential introduction of a resource use price for groundwater extraction. By contrast, subsidies (e.g., for improving wells and increasing irrigation efficiency) have been introduced as intermediate strategies. This reflects that public support for subsidies is typically high, whereas higher prices or consumption taxes to address problems of public interest are, in many cases, more critically reflected (Poortinga et al., 2023; Steentjes et al., 2017).

Actor-related factors have been identified as critical for enabling strategies and change towards climate resilience in the Seewinkel region and in other regions and socio-economic contexts, even if differently categorized. For instance, Herrfahrdt-Pähle et al. (2020) differentiate cognitive, agency-related and structural features as crucial for transformation towards climate resilience, whereby cognitive and agency-related features partly reflect our actor-related factors. Their agency-related "leadership" and their cognitive "awareness of need for change" refer to connecting actors and to political will and personal motivation which we address as "key player" and "agreement on strategy". Sattler (2022) differentiate between actors' roles in governance innovation processes such as "suppliers" providing financial or material resources or "intermediaries" establishing networks. The latter is represented in our factor "key player", while the first is to some extent covered in our strategy-related factor of "financing". Similar to our factor "awareness of the problem", Moser and Ekstrom (2010) highlight "problem detection and awareness raising" as the first phase in an adaptation process which is considered critical for successful planning and realization of both, short-term measures and long-term system transformations. Van Assche et al. (2022) extract "identity" referring to a cohesive narrative for the region or system as a factor potentially enabling strategy, which is related to our factor "agreement on strategy". Emotions have not been addressed in these studies but further analysis suggest strong associations between emotions and individual support for policies (Böhm et al., 2023; Smith and Leiserowitz, 2014; Wang et al., 2018).

The availability of scientific evidence and previous, successful experience in the Seewinkel region or in other (semi-)arid regions have been described as context that enables change. Scientific evidence, own and vicarious experience are related to increased perceived self-efficacy and can thus strengthen the capacity for action (Bandura, 1977). However, interview partners asked for additional scientific evidence (e.g., field experiments for sustainable irrigation) as well as for a permanent establishment of a scientific advisory board to give regular advice to the regional actors. Similar requests for "public institutions" have been raised for the support in handling cross-sectoral challenges and facilitating sustainable developments (Tudose et al., 2023).

4.1.3. *Recommendations for dealing with climate extremes in the future*

Our analysis has focused on the historical process of strategy development and implementation. However, the results may also provide valuable guidance for future efforts to address climate extremes in the semi-arid Seewinkel region and beyond, potentially informing guidelines for adapting or transforming regions to enhance climate resilience over time. Based on our results, we may suggest regional actors to.

(i) jointly develop a shared long-term vision for the region by integrating the interests and goals of those affected, including the various sectors (such as water management, agriculture, and nature conservation) and actors (such as citizens, associations, cooperatives, private enterprises, interest groups, NGOs, public authorities, and academia) and, if necessary, supervised by an intermediary;

(ii) ensure broad societal support for strategies by defining clear long-term goals and objectives that are followed stringently, by focusing on synergies between different policy domains, and by addressing both, cognitive components and emotional responses in the communication process;

(iii) set ambitious goals for policy coherence and integration by effectively coordinating the water management, agriculture and nature conservation policy domains, considering the interconnections between the natural and human systems and their sub-systems; and by aligning policy goals as well as the means to achieve these (cross-sectoral) goals to finally deal with climate extremes;

(iv) use the momentum of climate extremes for revising or realizing strategies towards the jointly developed vision and the regionally accepted goals;

(v) foster regular formal exchange and informal interactions between representatives of different sectors and policy domains, not least to strengthen the water-energy-food-ecosystems nexus, to raise awareness for common interests, and to resolve disagreements;

(vi) advocate for aligning the legal, policy, organizational and institutional environments with different climate extremes including droughts and heavy precipitation, for instance, by delegating power and responsibility to regional institutions for their flexible and efficient management of climate extremes;

(vii) discuss the potential costs and benefits related with specific strategies and decisions, ensure adequate financial resources as well as broad agreement on the distribution of the costs and benefits by following jointly developed criteria such as equity and social balancing; and

(viii) establish a scientific advisory board for continuous interaction and advice, and consider scientific evidence in decision-making, for instance, by reducing technical or environmental unknowns and clarifying contentious points.

4.2. Limitations of data collection and analysis

We have collected and analyzed empirical data on strategies to combat climate extremes in the Seewinkel region, covering a span of over thirty years. In particular, we have identified and traced the development of three strategies and extracted factors that are perceived to enable or impede this evolution. While the results may be of particular interest for semi-arid regions facing climate extremes, our approach also has some limitations.

Data collection concentrated on regional actors' perceptions from the water management, agriculture and nature conservation sectors, partly professionally active and partly already retired. Potential interview partners that we contacted expressed their interest in our research and highlighted the relevance and actuality of the topic for the region. However, some of them faced particularly high workloads during our data collection period because of the tense situation in terms of water supply and demand and the related, in-depth strategy discussions. Others expressed concerns because interviews had partly resulted in provocative or distorted media reports, or they were cautious because of potentially confidential information. To overcome these challenges, we explained the planned procedure to the interview partners and followed high standards for qualitative data collection (Flick, 2014; Helfferich, 2011). This included considering the individual preferences of interview partners with respect to the interview setting, ensuring confidentiality, creating an open and flexible atmosphere during the interviews, remaining as neutral as possible, sharing the interview transcripts and allowing for correction of factual errors. Expect for one person heavily overloaded with meetings and work, the primarily contacted interview partners contributed to our study. Instead of the declined interview invitation, another person representing the same organization was contacted and interviewed. An indicator that the interview partners felt secure are their open reports on recriminations and discrepancies in strategy development.

Data analysis focused on strategy development and realization in the Seewinkel region in the past. Similar methods have been advised and successfully tested (Sattler, 2022; Van Assche et al., 2019). However, three main limitations remain. First, we followed a backward-looking approach to reconstruct stages in strategy development and derive factors that brought about change resulting in realized, revised or unrealized strategies. The results may be used to derive practical conclusions and next steps for the region, but do not allow for predictions or any long-term planning du to inherent uncertainties in climate and socio-economic change. Other authors have combined a backward- and a forward-looking analysis to gain additional insights (Sattler, 2022). While our interview partners reflected on the near future, we did not include more specific future-related questions because of the dynamic development in the region and in order to avoid time or mental overload. Yet, the interview partners missed a shared long-term vision for the region, as discussed above. However, hypothetical questions (Gläser and Laudel, 2009) or "vignettes" (Finch, 1987) could be used in future interviews to engage individuals in hypothetical discussions about their potential actions in specific situations or to explore how their narratives might change under different conditions (Ritchie and Lewis, 2003).

Second, individuals' perceptions were focal which implies that goals or objectives may have been ascribed by the interview partners rather than originally intended by a strategy or its issuing actors. Where possible, we talked to actors involved in earlier phases of a strategy process. Alternatively, we consulted original documents if publicly available to verify our qualitative data. Nevertheless, some uncertainty remains, in particular if strategies are praised for previously unintended but (consciously or unconsciously) ascribed objectives which have been successfully reached. Likewise, we have identified effective intermediate strategies while we cannot exclude that similar but ineffective intermediate strategies have received limited attention in the interviews and may have been disregarded in the factors that impede strategy development or realization. Third, our qualitative data set is rich in detail, not least because of the characteristics of the Seewinkel region, including multiple interactions between natural and human systems as well as between economic sectors and policy domains. This also reflects that qualitative research generates knowledge that is rooted in the specific cultural and historical context, while the transfer of the findings to other contexts or regions depends on actors who perceive these findings relevant for strategy development and realization (Curtis et al., 2000; Tracy, 2010). Beyond the study region, our findings could, however, be valuable for actors who operate in semi-arid regions and are concerned about recurrent climate extremes such as droughts and heavy precipitation.

5. Conclusions

Strategies to deal with compound climate extremes gain in importance, in particular in semi-arid regions, because of increasing global and regional average temperatures and uncertainties in precipitation volumes and patterns. Their development and realization depend on the involved actors and their narratives as well as the regional context. From our empirical data material covering strategy development and (non-) realization over more than three decades, we find that strategies focusing on water management to deal with droughts and heavy precipitation have to be advanced towards regional strategies that integrate goals of the water management, agriculture and nature conservation sectors in order to successfully cope with recurring climate extremes. Such an advancement requires intermediary strategies – including the introduction of new actors (e.g., organizations with clear responsibilities) and the production of scientific evidence. We distill nine factors related to strategy, actors and context that enable or impede the realization of strategies against climate extremes. They reveal that the evaluation of strategies along broadly applied criteria such as effectiveness and efficiency is insufficient. Rather, these criteria need to be complemented by factors such as actors' appraisal of climate extremes, their awareness of regional challenges and their emotions towards a strategy. An individual actor with power or resources can help a strategy achieve a breakthrough. However, long-term achievements require broad agreement and support among interested and affected actors as well as pertinent legal conditions and sufficient time and financial resources. The identified nine factors can be used to evaluate the status or strategy process and to realize potential levers of change. New research could focus on the interactions between these factors to exert their catalyzing effect; on exploring the relevance of specific factors in critical phases of a strategy process; on complementing empirical evidence with data from additional semi-arid regions; and on studying similarities and differences between regions and socio-economic contexts to derive enabling factors that are widely applicable.

CRediT authorship contribution statement

Hermine Mitter: Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Bernadette Kropf:** Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work Hermine Mitter used https://unigpt.uni-graz.at/chat in order to improve language and readability. After using this tool, Hermine Mitter reviewed and edited the content as needed and takes full responsibility for the content of the publication.

Declaration of competing interest

The authors declare that they have no known competing financial

interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2025.125821.

Data availability

The data that has been used is confidential.

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