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What drives local climate change adaptation? A qualitative comparative analysis

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ABSTRACT

Climate change impacts vary wildly across different geographical contexts and their effects are primarily felt on the local level, generating demand for local solutions. The local level plays a key role in the adaptation to climate change. Nevertheless, in most European countries adaptation has yet to be integrated comprehensively into local policy agendas. To further our understanding of this slow pace of local adaptation progress, we study 21 Swiss Alpine municipalities exposed to a variety of natural hazards and issues exacerbated by local climate change impacts. Building on established research on local natural hazard management and climate change adaptation, we expect four factors to play decisive roles, either on their own or in combination with each other: Past extreme events, risk exposure, perceived climate risk and existing adaptation policies at superordinate levels. We test these expectations using qualitative comparative analysis (QCA). We find that significant past extreme events and high perceived climate risk come close to being necessary conditions for local adaptation measures. High perceived climate risk on its own is also a sufficient condition for local adaptation measures to be taken while its absence is sufficient for no local adaptation measures to be taken. Thus, the importance of climate risk perception exceeds our expectation as it has clearly been revealed to be the most important factor. Future research should focus on disentangling different levels of public risk perception further and investigate the role different levels of perception or acceptance among different actor groups play in climate policy decisions.

1. Introduction

The variety of local impacts of climate change combined with our improving understanding of the limits of monotonous, large-scale, top-down adaptation approaches has led to a broad recognition that the local level has a significant role to play in adaptation to climate change (Aguiar et al., 2018; Amundsen et al., 2018; Fazey et al., 2018; Fuhr et al., 2018; Walker et al., 2015). In most democratic countries, the local level has at least partial jurisdiction over many governmental functions relevant to adaptation. Some prominent examples include the protection of infrastructure, emergency planning, and land use regulations (Vogel and Henstra, 2015). Moreover, the impacts of climate change are mostly felt at the local level (Hunt and Watkiss, 2011), generating demand for local solutions. There is also a popular argument that local stakeholders need to be included in decision-making processes because they are in the best position to solve problems related to the degradation of local resources (Ostrom, 2000) and garner local support for cooperative solutions (Ostrom, 2010). Additionally, local stakeholders are able to tailor their approaches to local community needs and specific local vulnerabilities (Corfee-Morlot et al., 2011; Smit and Wandel, 2006). Thus, both the scientific community and European Commission recognize the importance of the local level for adaptation to climate change (Fünfgeld, 2015; Nordgren et al., 2016; Robert and Schleyer-Lindenmann, 2021; Twecan et al., 2022). This is also reflected in the European Adaptation Strategy, which calls on EU member states and municipalities to jointly design and implement adaptation policies (European Commission, 2021).

However, despite the strategic importance of the local level and the many successful implementations of adaptation measures across the globe, adaptation has yet to be integrated comprehensively into local policy agendas in many countries (Dupuis and Knoepfel, 2013; Fünfgeld, 2015). Attempts to decipher the reasons for this slow progress have commonly focused on identifying barriers to local adaptation (Biesbroek et al., 2015). Specifically, local authorities often have difficulties in

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dealing with long-term problems (Biesbroek et al., 2010). Local adaptation is also embedded in larger multi-level arrangements and thus highly dependent on upper and lower levels of climate decisions as well as actions taken by other parallel constituencies (Omukuti, 2020; Yu, 2016). Additionally, the design of adaptation policies is complicated by the temporal and spatial mismatch between the source of the problem and its effects (Driessen et al., 2012; Ingold et al., 2019). Moreover, even though public awareness of manmade climate change and its impacts is rising, many still perceive climate change as a distant issue and do not acknowledge any urgent need for adaptation measures (Perrow, 2010). This is compounded by the fact that the costs of adaptation measures are immediate, while pay-outs are often subtle and will take place years in the future, leading many local authorities to instead prioritize more immediate issues (Vogel and Henstra, 2015).

However, the limited focus on barriers to adaptation is conceptually problematic and struggles to explain adaptation decision-making (Biesbroek et al., 2015). Researching the adaptation implementation deficit by exclusively studying barriers to adaptation assumes that political decision-making processes should be producing adaptive policies – if only the aforementioned barriers did not exist (Biesbroek et al., 2015). Further, compiling influential factors and categorizing them as barriers does not actually improve our understanding of the decision-making processes that led to the adaptation implementation deficit. Consequentially, "ten years of barrier thinking and analysis have yielded very limited advice about how to intervene in practice to secure better outcomes" (Biesbroek et al., 2015). Thus, our goal in this paper is to move beyond the study of barriers by identifying what causes municipalities to engage in adaptation. Specifically, we aim to answer the following research question:

What combination(s) of factors lead municipalities to adopt climate change adaptation measures?

To answer this question, we compare how different Alpine municipalities in Switzerland approach adaptation to climate change. We analyse municipalities exposed to various natural hazards—such as floods, avalanches, rock fall and landslides—which threaten to grow more intense and frequent due to the impacts of climate change. Next, through a qualitative comparative analysis (QCA), we identify the factors that are key to explaining whether municipalities engage in climate change adaptation or not.

2. Local climate change adaptation

The majority of climate change adaptation efforts must take place at the local scale (Fünfgeld, 2015; Nordgren et al., 2016). Nevertheless, huge potential to further integrate mitigation and adaptation initiatives at the local scale remains (Fünfgeld, 2015; Hurlimann et al., 2021). As many studies have shown, local climate change adaptation can take a variety of forms and is highly dependent on geographical, topographical, and socio-cultural context (Bauer and Steurer, 2015; Betsill and Bulkeley, 2006; Hegger et al., 2014; Sarker et al., 2020). Specifically, some authors have stressed the dominant role of water-related actions (e.g., concrete measures such as dams or spatial planning measures) and studies when it comes to climate change adaptation. One major reason for this focus is that floods or droughts were addressed by local authorities in many countries even before climate change impacts entered the political agenda (Bauer and Steurer, 2015; Křištofová et al., 2022). However, local climate change adaptation studies also prominently focus on other issues such as food production, land use, or forestry (Ahmed et al., 2021; Ingold and Fischer, 2014; Keenan, 2015).

From a policy perspective, local climate change adaptation might be more homogenous across and within countries, different geographical areas, political styles, and institutions (Baker et al., 2012; Nordgren et al., 2016): it includes goals and measures to reduce a community's vulnerability or exposure to any type of climate change effect (Baker et al., 2012; Khailani and Perera, 2013; Robert and Schleyer-Lindenmann, 2021). Therefore, local climate change adaptation in this regard is a strategic declaration to adapt to climate change and its consequences within the local constituency, which is typically a municipality or city (Křištofová et al., 2022).

3. Conditions for the adoption of climate change adaptation measures by municipalities

As outlined above, we are interested in local climate change adaptation from a policy perspective. We examine potential drivers that may explain the stronger or weaker adaptation policies and strategies adopted by municipalities. Here, we review the literature and outline the expectations about such potential factors.

One important effect of climate change, mainly in mountain regions (National Center for Climate Services NCCS2018), is the increased frequency and intensity of extreme events such as floods, droughts, or heavy rainfalls (IPCC, 2022). Extreme events can be an important driver for policies to be designed, introduced, or changed (Birkland, 1998; Kingdon, 1984). They can have dramatic agenda-setting effects, generating increased attention for a public problem. Thus, they may increase public support for potential solutions and have accordingly been identified as important stimuli for adaptation measures (Berrang-Ford et al., 2011). From this literature, we deduce our first expectation as follows:

Expectation 1: The recent occurrence of an extreme event contributes to the adoption of climate change adaptation measures by municipalities.

Meanwhile, recent literature increasingly emphasizes that the (political) context, as well as the properties of an event, significantly affect the extent to which an event triggers and shapes policies (Birkland and Warnement, 2014). Further, direct experience with extreme events also increases individual support for mitigation measures (Tanner and Árvai, 2018). However, these effects are often temporary, as in the absence of new events, other policy issues resurface and supplant the event-related issues (Atreya et al., 2015). Combining these two insights (specific properties of the events and temporal aspects), long-term and steady exposure (in contrast to the recent occurrence of events) to threats may also be an important driver for local climate change adaptation measures. Thus, repeated exposure increases attention to a problem even if some time has passed since the last extreme event (Giordono et al., 2020).

Expectation 2: Persistent risk exposure contributes to the adoption of climate change adaptation measures by municipalities.

Additionally, recent research indicates that risk perception may play an equally or even more important role than risk exposure or the experience of extreme events (Glaus et al., 2020; Herzog and Ingold, 2019). For example, Petrolia et al. (2013) showed that household level decision-making on flood insurance purchases depends on individual risk aversion and perception. Atreya et al. (2015), who likewise studied flood insurance purchases, concluded that while exposure does play an important role, so does risk perception. Meanwhile, Twecan et al. (2022) found that risk perception is directly related to climate change adaptation measures. Their study of smallholder farmers in Uganda showed that risk perception is not only dependent on experience with extreme events and other climate risks but also socio-cultural factors, such as the level of education. They concluded that understanding farmers' climate risk perceptions is critical to designing and implementing effective farm-level context-specific climate change adaptation policies by concerned government authorities.

Expectation 3: Increased climate change risk perception by the population contributes to the adoption of climate change adaptation measures by municipalities.

As climate change adaptation is a multi-level challenge (Bauer and Steurer, 2014), another important driver for local adaptation action may be the adaptation policies and measures taken at superordinate administrative levels. The local level is commonly expected to take on the design and implementation of concrete adaptation measures (Keskitalo, 2010). Nevertheless, local adaptation is embedded in multi-level arrangements with regional and national actors who gather and disseminate relevant knowledge, provide funding, or define legal guidelines (Galarraga et al., 2011). Moreover, local adaptation is heavily influenced by regional and national actors and institutions. Governance structures at the national or regional level can be important barriers or success factors for the implementation of adaptation measures at the local level (Amundsen et al., 2010; Juhola, 2016). The decentralized nature of multi-level governance systems allows policy initiatives to arise at different levels and best practices to diffuse across scales (Di Gregorio et al., 2019; Underdal, 2010). Frequent interactions are an important prerequisite for policy diffusion (Braun and Gilardi, 2006; Kammerer and Namhata, 2018). Thus, vertical policy diffusion may be especially likely, as federal governance structures typically foster frequent interactions between subordinate and superordinate levels. Shipan and Volden (2006) showed that demonstrating the viability of local policy initiatives facilitates their adoption at the state level. Braunschweiger and Pütz (2021) discovered similar mechanisms in the diffusion of national or state-level policies to the municipal level: policy innovators at the local level commonly cite the existence of comparable policies at superordinate levels as an important success factor as they provide technical guidance, good-practice examples, and political legitimization to local initiatives. Thus, whether adaptation policy exists at a superordinate level can also be assumed to be an important driver for local climate change adaptation action.

Expectation 4: The existence of a climate change adaptation policy at the superordinate level contributes to the adoption of climate change adaptation measures by municipalities.

Three of our four expectations pertain to risk – immediate risk exposure, persistent risk exposure and risk perception. Recent research suggests that that the decisive question may be, how risk perception and objective risk exposure relate to each other (Glaus et al., 2020; Herzog and Ingold, 2019). As such, we are particularly interested in the relative impact as well as possible interaction effects between these three conditions. Is it immediate risk exposure or persistent risk exposure that matters most? Or is a combination of both necessary for adaptation measures to be taken? Or is risk perception key and risk exposure mostly matters insofar as it influences risk perception? Additionally, Braunschweiger and Pütz (2021) suggest that existing climate policies at superordinate levels provide important guidance and political legitimization to adaptation efforts at lower levels. As such, it is possible that the existence of such strategies in combination with the presence of other factors related to risk and risk perception is necessary for municipalities to adopt climate change adaptation measures.

Thus, we do not aim to test our four expectations independently (Perez et al., 2015). We are convinced that it is the combination of factors, that leads to the adoption of climate change adaptation measures at the municipal level. The adequate model for investigating whether combinations of conditions affect an outcome, is QCA (Timberlake and Ragin, 1989).

QCA conceptualizes causal factors as combinations of conditions. Multiple different combinations of factors, or pathways, may lead to the same outcome, and the occurrence of the outcome and non-outcome may require separate pathways. These three concepts of conjunctural causation, equifinality, and causal asymmetry together are often described as causal complexity, which is one of the main elements of QCA (Mello, 2022; Rihoux & Ragin, 2012; Schneider and Wagemann, 2012).

4. Cases and methods

4.1. Case selection and data collection

Through our review of the existing literature, we formulated four expectations regarding the drivers of the adoption of local climate change adaptation measures. Three of these expectations concern immediate and persistent risk posed by extreme events and the impacts of climate change on the frequency and intensity of natural hazards as well as the perception of said risk. As such, we are particularly interested in municipalities exposed to different types of extreme events and natural hazards, such as flooding, mudflows, avalanches, and rockslides. As Alpine regions are particularly vulnerable to such risks (BAFU, 2012; Brönnimann et al., 2014; Köllner et al., 2017), we have confined our case selection to Swiss Alpine municipalities exposed to different varieties of natural hazards.

We first selected interesting municipalities based on desktop research on local adaptation projects in the Alpine regions of Switzerland as well as a preliminary analysis of cantonal natural hazard risk maps. We further refined this selection through five expert interviews with natural hazard management executives at federal and cantonal levels as well as experts on Swiss natural hazard management from among the scientific community to ensure that our cases included sufficient variance in terms of our explanatory variable. Next, we collected in-depth data on risk exposure regarding each case through a detailed analysis of the natural hazard risk maps, hazard zone maps, and the natural hazard database StorMe. We consulted any existing cantonal adaptation policies as well as survey data collected by the Swiss Broadcasting Corporation (SRG SSR) and Link Institute (2017) on the perceived risk posed by climate change to respondents. As this survey data does not include sufficiently large samples from the smaller Alpine cantons, we limited our case selection to the three larger cantons of Bern, Grisons, and Valais. Finally, we consulted data collected by the Federal Statistical Office (FSO) on local election outcomes in the 2019 election of the national council for one of the additional conditions to be employed in our robustness test.

Through this process, we settled on 29 municipalities, 8 of which had no interest in our interview request, leaving us with a final sample of 21 municipalities, as depicted in Table 1.

4.2. Method

We identified four drivers that we expect to influence whether municipalities engage in climate change adaptation action. We are interested in the roles these drivers play, not just on their own but in any possible combination. Consequently, we tested our expectations regarding the influence of these factors using a fuzzy-set QCA. QCA aims to identify necessary and sufficient combinations of conditions for specific outcomes to occur using in-depth observations of a medium number of cases. (Rihoux & Ragin, 2012; Timberlake and Ragin, 1989). It is a set-theoretic method that assigns each case with a set membership score

Table 1
Municipalities in the Sample.

Municipality	Canton	Abbreviation
Leuk	VS	Leu
Randa	VS	Ran
Saviese	VS	Sav
St. Niklaus	VS	Nik
Täsch	VS	Täs
Zermatt	VS	Zer
Diemtigen	BE	Die
Grindelwald	BE	Gri
Gsteig	BE	Gst
Guttannen	BE	Gut
Innertkirchen	BE	Inn
Iseltwald	BE	Ise
Kandersteg	BE	Kan
Lauterbrunnen	BE	Lau
Schattenhalb	BE	Sat
Albula	GR	Alb
Bregaglia	GR	Bre
Flims	GR	Fli
Ilanz/Glion	GR	Ila
Küblis	GR	Küb
Pontresina	GR	Pon

for each condition as well as the outcome. It then employs logical minimization following the principles of Boolean algebra to eliminate irrelevant conditions (Rankin, 2008; Schneider and Wagemann, 2012). This method suits our purposes for two reasons: first, its logic of equifinality and conjunctural causation is well-suited to our expectation that the relationship between objective and perceived risk exposure may be a deciding factor for the occurrence of local climate change adaptation; second, QCA is well suited for the analysis of a medium number of cases (Mello, 2022). QCA postulates, that outcome and non-outcome may require different pathways. Thus, we performed separate analyses to identify necessary and sufficient combinations of conditions for both the outcome and non-outcome.

Fuzzy-set QCA, as compared to crisp-set QCA, can assign set membership scores that are more nuanced than 0 and 1. Fuzzy sets have the advantage of losing less information in the calibration of all conditions that are not naturally dichotomous, as it allows for more sophisticated nuances to be analysed (Mello, 2022).

QCA employs several measures of fit to assess the reliability of its results. The most important of these measures are tests of consistency, coverage, relevance of necessity (RoN), and proportional reduction in inconsistency (PRI) (Mello, 2022). Specifically, the consistency of necessary conditions measures the degree to which “the outcome can be considered a subset of the condition” (Schneider and Wagemann, 2012 p.143) while the consistency of sufficient conditions measures “the degree to which the empirical information deviates from a perfect subset relation” (Schneider and Wagemann, 2012 p.129). Coverage measures the proportion of cases where we observe the outcome that can be explained by the presence of a condition or combination of conditions (Rihoux and Ragin, 2004) and thus, how important said condition is. RoN measures whether a necessary condition or combination of conditions is trivial in so far as the condition is present in almost all cases (Schneider and Wagemann, 2012). Finally, when analysing fuzzy-set data, certain conditions or combinations of conditions may be a subset of both the outcome and non-outcome and may thus be identified as sufficient conditions for both. The PRI helps identify such logical contradictions (Schneider and Wagemann, 2012). Low PRI values indicate that the condition or combination of conditions may not actually be sufficient for the outcome, despite consistency and coverage scores suggesting otherwise.

The results of QCA can also vary significantly based on condition calibration, case samples, consistency thresholds and other decisions made by the researchers. Thus, we perform robustness tests (Cooper and Glaesser, 2015; Ide et al., 2020; Schneider and Wagemann, 2012) to check how well our results hold up when our model is subjected to different alterations (see annex).

4.3. Outcome: measures addressing local climate change adaptation

A key challenge for many comparative studies on climate change adaptation policy is the definition and operationalization of the dependent variable (Dupuis and Biesbroek, 2013). While many different definitions of climate change adaptation exist, most suggest that adaptation involves reducing vulnerability to impacts of climate change and increasing adaptive capacity (Smit and Pilifosova, 2001; Smit and Wandel, 2006; Vogel and Henstra, 2015). However, this definition is still quite broad and may incorporate many different activities. Our interest lies in whether municipalities adopt climate change adaptation measures or not, and if yes, the extent to which they do so. Thus, we conceptualize the Outcome (*OUT*) of local climate change adaptation as any local measure with the specific goal to reduce vulnerability to climate change impacts and/or to increase the municipality’s ability to moderate and cope with negative consequences of climate change. *OUT* is operationalized based on our interview results. A value of 0 indicates that the municipality has not adopted any climate change adaptation measures at all. A value of 0.33 indicates that the municipality has not explicitly dealt with climate change adaptation, but local natural hazard management is well prepared to deal with any local climate change impacts that may arise during the coming years. A value of 0.66 indicates that the municipality has dealt explicitly with local climate change impacts and climate change adaptation in some form. A value of 1 indicates that the municipality has additionally adopted or participated in concrete adaptation measures.

4.4. Conditions: their operationalization and calibrations

We operationalize the four drivers outlined in our expectations with four “conditions”, as they are called in QCA. As for the outcome, we employ four-value fuzzy-set calibrations for the four conditions.

To operationalize our first two conditions, recent occurrence of extreme events (*EVENT*) and persistent risk exposure (*DANGER*), we consider floods, landslides, rockslides, mud and snow avalanches, and mudflow.

Data for the operationalization of our first condition, the recent occurrence of extreme events (*EVENT*), were collected from the StorMe database and through our interviews. The condition was calibrated according to event magnitude, how long it has been since the events took place, the monetary damages, and whether anybody was significantly hurt or killed. A value of 0 indicates that there were no large events impacting infrastructure or settled areas during the last 10–15 years. A value of 0.33 indicates that one or multiple events took place during the last 10–15 years but did not cause any damage exceeding the low four-digit range (in Swiss Francs). A value of 0.66 indicates that one or multiple events took place during the last ten to fifteen years and caused damage in the high four-digit to low five-digit range. Finally, a value of 1 indicates that recent events caused damages exceeding the low five-digit range, caused harm to persons, or took place within the last two years or a combination thereof.

The second condition, persistent risk exposure (*DANGER*), is operationalized based on cantonal natural hazard risk maps, which serve as an important basis for land use planning and regulation. They categorize settlement areas into five denominations: high risk, medium risk, low risk, negligible risk, and no risk. To calibrate risk exposure, we calculate the share of each of these categories in the total settlement area. Unfortunately, synoptic danger maps were available only for the canton of Bern. Thus, we had to evaluate hazard maps regarding individual hazards for cases in Grisons or Valais, which we complemented by also evaluating danger zone maps. Danger zone maps offer a synoptic assessment with direct legal relevance for land use; however, they are less nuanced than risk maps. As these differences between cantons impede cross-cantonal comparisons, cases are calibrated based on cantonal means and standard deviations. Municipalities with a below average percentage of settled areas in high-risk zones are assigned a value of 0.33 or 0 based on whether they lie within one standard deviation below the average or not and vice versa for values above average.

The third condition, increased risk perception (*PERC*), is operationalized based on three different measurements: First, the SRG SSR and the Link Institute conducted a representative survey on climate change in 2017, which included the question “How would you estimate the risk posed by climate change to you personally?” Wieser (2019) calibrated this data for a QCA of Swiss cantonal adaptation policies. We adopt her calibration of the data with values closer to 1, indicating higher perceived risk. Unfortunately, this data is only available at the cantonal level. Thus, we supplemented it by also asking interviewees how they judged the level of concern among the general population of their municipalities in terms of natural hazards as well as local climate change impacts and the potential cascading effects of these impacts on natural hazards. Based on their assessment, we coded public concern about natural hazards and local climate change impacts: a value of 0 means they are not at all concerned, a value of 0.33 means they are a little concerned, a value of 0.66 means they are somewhat concerned, and a value of 1 means they are very concerned. These three variables were then added together, and the new combined variable was calibrated based on deviation from the mean.

The fourth condition concerns the existence of climate change adaptation policies at the superordinate cantonal level (*STRAT*). It is assessed based on an inventory of cantonal climate policies by the Swiss National Centre for Climate Services (NCCS). The canton of Bern has yet to formulate an adaptation strategy but has published a preparatory report on climate change adaptation that contains important policy directives on adaptation. Thus, we assign it a value of 0.67. Meanwhile, the canton of Grisons has formulated a climate strategy that presents climate mitigation and adaptation as equivalent and synergistic components. We consequently assigned it a value of 1. Finally, the canton of Valais has yet to publish any official strategy or guidelines on climate change adaptation, and we thus assigned it a value of 0.

For our robustness tests, we also include two additional control variables to emphasize potential drivers due to politics (Birkland and Warnement, 2014) and in accordance with similar QCA studies (Kammermann, 2018; Popp et al., 2021; Wieser, 2019), to also highlight politics and financial aspects of climate change and environmental policymaking.

In this context, one popular indicator of the political viability of different issues is the political composition of executive authorities. Regarding the issue of climate change adaptation, we expect left-wing environmental parties that have been politically invested in climate politics for decades to look more favourable on adaptation measures than other political parties (*LEFT*) (Neumayer, 2004; Pemberton, 1975; Stadelmann-Steffen and Dermont, 2018). While municipal executives in smaller Swiss municipalities commonly do not belong to any official political parties, following the same line of argument, we expect the supporters, sympathizers, and voters of left-wing environmental parties to be more supportive of climate change adaptation than the general populace (Neumayer, 2004). Therefore, we will include a control factor in our model based on the relative share of votes cast in favour of such parties during the last election of the national council. We draw our data on local election outcomes from the FSO and add up the collective share of the vote of left wing and environmental parties (*LEFT*): the Social Democratic Party of Switzerland (SP), the Green Party of Switzerland (GPS), the Green Liberal Party of Switzerland (GLP), the Swiss Party of Labour (PdA) and Solidarity (Sol).

Finally, we argue that local awareness of different adaptation policies as well as whether they are deemed viable depends on the financial and personnel resources of the responsible local governmental agencies. As Nordgren et al. (2016) showed the importance of resources related and attributed to local climate change adaptation. The impacts of climate change take many different forms and cross the boundaries between traditional policy sectors. As such, most adaptation policies are cross-sectoral. However, as we are specifically interested in the intersection of adaptation to climate change and natural hazard management, local natural hazard management agencies are the most relevant departments. Therefore, our second control condition is based on the resources and the degree of organization of local natural hazard management (*RES*). This condition is assessed based on our interview results.

Throughout the interviews, it became evident that personnel and financial resources were often difficult to quantify, as many important tasks were fulfilled by volunteers. Additionally, people responsible for natural hazard management at the local level often take on other responsibilities as well and were frequently unable to differentiate exactly how much time they spent on natural hazard management as opposed to other tasks. Thus, our calibration process considered several qualitative factors as gauged by the answers to the following questions: Has responsibility for natural hazard management been formally assigned to anybody? Does the municipality take a holistic approach towards natural hazard management, or are responsibilities scattered and partially unclear? Does the municipality employ anybody whose duties include some form of natural hazard management, or does it rely completely on volunteers? How well prepared is the municipality to take immediate measures in the case of an extreme event?

In addition to these qualitative assessments, we also consider the personnel and financial resources invested in the construction and maintenance of natural hazard measures as estimated by the local experts. A value of 0 indicates that the municipality in question lacks clearly defined responsibilities, invests comparatively little resources in natural hazard management, and lacks concrete plans on how to react to extreme events, while a value of 0.33 indicates that only one of these three problems persists. A value of 0.66 indicates that responsibilities are clearly defined, natural hazard management is well staffed and funded, and clear plans on how to react to extreme events are in place. Finally, a value of 1 indicates that the municipality additionally takes a particularly proactive approach to natural hazard management or invests considerably more funding in natural hazard management than comparable municipalities from our sample.

Table 2 depicts all six conditions as well as the abbreviations we employ to refer to them throughout this paper.

Next, Table 3 shows the calibrations for all conditions and the outcome for all 21 municipalities:

5. Results

We first checked for any necessary conditions for either the outcome (*OUT*) or the non-outcome. Necessary conditions are always present when the outcome is also present. Table 4 shows the consistency, coverage, and relevance of necessity for all conditions as well as the negation of each condition. Our analysis of necessity yielded no result above the 0.9 consistency threshold for the outcome and one result above said threshold for the non-outcome. The conditions past extreme events (*EVENT*) and perception (*PERC*), narrowly fall short of the 0.9 consistency threshold but show relatively high coverage and relevance of necessity. This indicates that, while not consistently necessary for the outcome to occur, past extreme events (*EVENT*) and perception (*PERC*) are close to being non-trivial necessary conditions. We also found that the absence of perception (~*PERC*) is both a highly consistent and non-trivial necessary condition for no adaptation efforts to occur. However, perception (*PERC*) as a necessary condition for the outcome does not hold up well to our robustness tests (see annex). Past extreme events (*EVENT*) as a necessary condition for the outcome and the absence of perception (~*PERC*) as a necessary condition for no adaptation efforts are both highly robust results.

Next, we aimed to identify sufficient combinations of conditions. Table 5 shows the truth table for the outcome excluding logical remainders. We aimed to minimize the number of logical contradictions. Thus, we set the consistency threshold for rows to be included in the minimization process at 0.9. This threshold surpasses the established minimum level of 0.75 (Ragin, 2006) and produces only one logical contradiction: The municipality Bregaglia shows the outcome but shares the exact same combination of conditions with the municipalities Kandersteg and Grindelwald, which do not (see Table 5). This row was thus excluded from the minimization process. We also set a PRI threshold of 0.5 to identify cases of simultaneous subset relations (Schneider and Wagemann, 2012).

Table 2
Conditions for the Qualitative Comparative Analysis on What Drives Climate Change Adaptation.

Conditions	Abbreviations	Included in primary analysis
Recent extreme events	*EVENT*	✓
Natural hazard risk exposure	*DANGER*	✓
Perception of climate change	*PERC*	✓
Cantonal adaptation strategies	*STRAT*	✓
Voting share of environmental and left-wing parties	*LEFT*	×
Resources of local natural hazard management	*RES*	×

Table 3
Case Values for All Conditions and The Outcome.

Gemeinde	Event	Danger	Perc	Strat	Left	Res	Outcome
Leuk	1	0.66	0.66	0	0.33	1	0.66
Randa	0.66	0.33	0.66	0	0.33	1	0.66
Saviese	0.33	0.33	0.33	0	1	0.66	0.33
St. Niklaus	1	0.66	1	0	0	1	0.66
Täsch	0.33	0.66	0.66	0	0	0.66	0.66
Zermatt	1	0.66	1	0	0	1	1
Diemtigen	0.33	0.00	0.33	0.66	0	0.66	1
Grindelwald	0.66	0.00	0.33	0.66	0.33	1	0.33
Gsteig	0.33	0.00	0	0.66	0	0.66	0.33
Guttannen	1	0.66	1	0.66	0.66	0.66	1
Innertkirchen	0.66	1.00	0	0.66	0.33	1	0.33
Iseltwald	0.33	0.66	0	0.66	0.33	0.66	0.33
Kandersteg	1	0.33	0.33	0.66	1	1	0.33
Lauterbrunnen	0.66	0.66	0.33	0.66	1	0.66	0.66
Schattenhalb	0.33	0.00	0	0.66	0.33	0	0
Albula	1	1.00	1	1	0.66	1	1
Bregaglia	1	0.00	0.33	1	0.66	1	0.66
Flims	0.66	0.00	0.66	1	1	1	1
Ilanz/Glion	0.33	1.00	0.66	1	0.66	0.33	0.66
Küblis	0.66	1.00	0	1	0.66	0.33	0.33
Pontresina	0.33	0.00	0.33	1	0.66	0.66	0.33

Table 4
Analysis of Necessity.

	Adaptation (*OUT*)			~Adaptation		
	Consistency	Coverage	Relevance	Consistency	Coverage	Relevance
EVENT	0.864 *	0.78	0.709	0.766	0.486	0.511
DANGER	0.622	0.792	0.849	0.536	0.48	0.692
PERC	0.812 *	0.968	0.97	0.419	0.351	0.614
STRAT	0.621	0.637	0.672	0.732	0.528	0.612
~EVENT	0.431	0.723	0.871	0.653	0.771	0.89
~DANGER	0.592	0.645	0.707	0.768	0.588	0.675
~PERC	0.456	0.527	0.672	0.962 * *	0.782	0.817
~STRAT	0.539	0.741	0.838	0.496	0.479	0.72

Note: Conditions that meet the 0.9 consistency threshold for necessity are marked with two stars (**), while conditions that meet the 0.8 consistency threshold for necessity are marked with one star (*).

Table 5
Truth Table for the Outcome of "Adaptation".

EVENT	DANGER	PERC	STRAT	OUT	N	Consistency	PRI	Cases
1	1	1	0	1	3	1	1	**Nik, Zer, Leu**
1	1	1	1	1	3	1	1	**Gut, Lau, Alb**
0	0	1	1	1	1	1	1	**Die**
0	1	1	0	1	1	1	1	**Täs**
0	1	1	1	1	1	1	1	**Ila**
1	0	1	0	1	1	1	1	**Ran**
1	0	1	1	1	1	1	1	**Fli**
0	1	0	1	0	1	0.829145729	0	Ise
0	0	0	0	0	1	0.797583082	0.33	Sav
1	0	0	1	0	3	0.766203704	0.497512438	Gri, Kan, ***Bre***
1	1	0	1	0	2	0.744360902	0	Inn, Küb
0	0	0	1	0	3	0.631147541	0.328358209	Sat, Gst, Pon

Note: Cases in bold show the outcome, while those in italics are logical contradictions. Rows marked in grey were included in the minimization process.

For the analysis of sufficiency regarding the non-outcome, we set the consistency threshold at 0.75 to minimize the number of logical contradictions. In combination with a PRI threshold of 0.5, the case of Bregaglia remains the sole logical contradiction (see Table 6). Table 6 shows the truth table for the non-outcome.

These truth tables are then used to derive less complex possible solution terms through minimization. Which type of solution should be preferred has been the subject of some debate. Baumgartner and Thiem (2017) advocate that only parsimonious solutions should be considered while Dușa (2019) argues that the intermediate solution should be preferred as it is the most able to accommodate both sufficiency and parsimony. We opt to use the parsimonious solution based on the argument that it is the most robust (Baumgartner and Thiem, 2017).

Table 7 displays the parsimonious solution terms for both the outcome and the non-outcome in the notation established by Ragin and Fiss (Fiss, 2011; Ragin and Fiss, 2008). Equifinal solution paths to the outcome and non-outcome are displayed in columns with a filled-in black circle and a crossed-out circle marking the presence and absence of a condition, respectively. Minimization produced a single, simple path to both the outcome "adaptation" (*OUT*) and the non-outcome: the condition of increased risk perception (*PERC*) on its own is sufficient for the outcome to occur while its absence is sufficient for the non-outcome

Table 6
Truth Table for the Non-outcome of "No Adaptation".

EVENT	DANGER	PERC	STRAT	OUT	N	Consistency	PRI	Cases
1	1	0	1	1	2	1	1	**Inn, Küb**
0	1	0	1	1	1	1	1	**Ise**
0	0	0	0	1	1	0.900302115	0.67	**Sav**
0	0	0	1	1	3	0.819672131	0.671641791	**Sat, Gst, Pon**
1	0	0	1	1	3	0.768518519	0.502487562	**Gri, Kan, *Bre***
0	1	1	0	0	1	0.795180723	0	Täs
1	0	1	0	0	1	0.664987406	0	Ran
0	1	1	1	0	1	0.66	0	Ila
1	1	1	0	0	3	0.578947368	0	Nik, Zer, Leu
1	0	1	1	0	1	0.553691275	0	Fli
0	0	1	1	0	1	0.497487437	0	Die
1	1	1	1	0	3	0.33	0	Gut, Lau, Alb

Note: Cases in bold show the outcome, while those in italics are logical contradictions. Rows marked in grey were included in the minimization process.

Table 7
Sufficient combinations of conditions for the outcome adaptation and its complement.

	Adaptation Path 1	~Adaptation Path 1
EVENT		
DANGER		
PERC	●	⊗
STRAT		
LEFT		
RES		
Consistency	0.968	0.782
PRI	0.951	0.616
Raw Coverage	0.812	0.962
Cases	**Ran**	**Sav**
	Täs	**Sat**
	Nik	**Gst**
	Zer	**Pon**
	Leu	**Ise**
	Fli	**Gri**
	Ila	**Kan**
	Lau	**Bre**
	Gut	**Inn**
	Alb	**Küb**
Consistency total	0.968	0.782
PRI total	0.951	0.616
Coverage total	0.812	0.962

Note: A full circle denotes the presence of a condition, a circle with a cross inside the absence of a condition. Cases in bold are uniquely covered by that respective path.

to occur. These results are highly consistent, non-trivial as indicated by the high total coverage, and not sufficient for the non-outcome as indicated by the high PRI. They are also very robust: Out of ten robustness tests for the outcome, eight produced the exact same solution while the last two produced solutions that are subsets of increased risk perception (*PERC*). As for the non-outcome, five out of ten robustness tests produced the same solution while the remaining five tests produced solutions that are either subsets of the original solution (*~PERC*) or contained at least one pathway that is a subset of the original solution.

Thus, this result is impressive in its simplicity and in line with our third expectation. However, it does not support our three other expectations regarding the roles of recent extreme events *(EVENT)*, persistent risk exposure *(DANGER),* and adaptation policies at the superordinate level *(STRAT)*. The fact that past extreme events *(EVENT)* are almost a necessary condition for the outcome lends some credence to our first expectation and is in line with recent studies that found the relation between risk perception and risk exposure to be a key factor (Glaus et al., 2020; Herzog and Ingold, 2019). Nevertheless, neither persistent risk exposure *(DANGER)* nor existing adaptation policies and superordinate levels *(STRAT)* seem to be as important as we had expected. Nor do we find any evidence that any interaction effects between our conditions play an important role.

As QCA is fundamentally a qualitative method, it is worthwhile to closely examine individual cases, especially those that do not conform to our solution terms or our expectations. We noted that recent extreme events (*EVENT*) and perception (*PERC*) are almost necessary conditions for adaptation (*OUT*). The cases where we observed the outcome despite no recent extreme events (*EVENT*) are Diemtigen, Ilanz/Glion, and Täsch. The cases where we observed the outcome despite risk perception being low are Diemtigen, Lautebrunnen, and Bregaglia. What makes these cases special?

Diemtigen and Lauterbrunnen share a common denominator: third parties initiated the primary adaptation measures in both municipalities. In Diemtigen, two engineering bureaus participating in the federally funded pilot program adaptation, geo7, and Sofies-Emac, approached the municipality to discuss a partnership. They selected Diemtigen as an interesting case for geological reasons. Similarly, Lauterbrunnen is an important testing site for a research program by the Swiss federal research institute WSL on the impacts of climate change on Alpine forest management. Their participation in these projects certainly demonstrates some interest in climate change adaptation on the municipalities' parts. Nevertheless, the measures were initiated by third parties who also contributed the lion's share of the required financial and personnel resources. This may explain why these municipalities engaged in adaptation measures despite the absence of otherwise necessary conditions.

Ilanz/Glion was formed in 2014 from the fusion of 13 smaller municipalities, and many facets of its administration are still in development. Climate change is an important item on the political agenda of its municipal council, which is reflected in the city's engagement under the "energy town" label and their awareness of the importance of climate change adaptation (*PERC*). Additionally, like Diemtigen and Lauterbrunnen, Ilanz/Glion was approached by a third party: a master's student of environmental sciences looking to develop an adaptation strategy for Ilanz/Glion for her thesis. Ilanz/Glion was able to benefit from the cooperation with said student and has thus taken adaptation measures despite the lack of extreme events (*EVENT*) in recent years.

In 2017 a major landslide took place in Bondo, a village belonging to the municipality of Bregaglia. It claimed eight human lives, caused 41 million Francs in property damage, and generated a lot of media attention. While experts are divided on whether climate change had any direct influence on the event, it is still somewhat surprising that perceived climate change risk (*PERC*) should be low in a municipality where such a major event took place within the last five years. However, our interview revealed that the main reason the people of Bregaglia do not feel particularly threatened by the impacts of climate change may in fact be the extensive preventive measures taken in the aftermath of the landslide in 2017. Additionally, while the municipality is engaged in many preventive measures that reduce its vulnerability to the impacts of climate change, most are primarily implemented and financed by the canton of Grisons. This explains why we observed adaptation measures (*OUT*) in Bregaglia despite low climate change risk perception (*PERC*).

Lastly, while the municipality of Täsch has had no significant extreme events during the last 10–15 years (*EVENT*), it does have a long history of significant flooding events every 30 years or so with the last significant event taking place in 2001. During the interview, said event was explicitly mentioned as one of the main motivations for the preventive measures that the municipality is now taking. As the event happened more than 15 years ago, Täsch was not calibrated as a case in which a significant extreme event recently took place. However, a closer examination showed that past extreme events are nevertheless an important motivating factor for current measures that reduce the municipality's vulnerability to climate change. Thus, a closer examination of these cases shows, that extenuating circumstances may explain these outliers without truly contradicting any of our primary results.

6. Discussion and conclusions

In this paper, we investigate why municipalities adopt climate change adaptation measures to reduce their vulnerability to climate risks. We focus on natural hazards that are particularly relevant and cause major damage in Alpine regions: flooding, mudflows, avalanches, and rockslides (BAFU, 2012; EEA, 2009; Köllner et al., 2017). We studied 21 potentially vulnerable Alpine Swiss municipalities. We then answer the question of what factors enable municipalities to adopt climate change adaptation measures, focusing on four conditions deduced from the literature as well as two control variables. We expected the following conditions to favour local climate change adaptation: the occurrence of extreme events in the recent past, persistent climate risk exposure in the area, increased climate risk perception by the population and the adoption of climate change adaptation policies by the next higher institutional level.

Our results show that the predominant necessary and sufficient condition is the perception of climate risks by the population. When present or absent, it was necessary and sufficient for a municipality to adopt or not adopt climate change adaptation measures, respectively. Thus, this condition dominated all potential explanatory pathways. This is a very interesting result, as QCA is explicitly applied to allow for a combination of factors and pathways to lead to an outcome. So, in such a study context, if perceptions of risks are dominantly apparent, this shows their significant impact. However, different studies have shown that the different "levels" of perception or acceptance seem key (Dermont et al., 2017): while general support for climate change policy goals in the abstract is usually high, concrete measures are often more strongly opposed (Fesenfeld and Rinscheid, 2021; Mildenberger et al., 2022). As Twecan et al. (2022) show, the key to winning support for concrete measures lies not just in how risk is perceived but also how potential solutions are perceived. Future research could thus focus not only on risks and threats but also on adaptation opportunities and co-benefits (Mayrhofer and Gupta, 2016; Sharifi et al., 2021). In this way, we can see if a more positive framing of the issue enhances the uptake of adaptation measures (Dasandi et al., 2022).

Furthermore, perceptions of risks occurred together with the presence of extreme events in the near past. This shows that an event alone is not enough to induce policy change in general and local climate change adaptation in particular. Research has found that beyond the occurrence of an event, its magnitude and other context factors (such as the overall attention or perception by the population in our case) are crucial to induce any sort of change (Birkland and Warnement, 2014; Giordono et al., 2020). So, to move past the "barriers to adaptation" focus, studies should give room to the combination of several factors in order to see what makes adaptation measures update possible.

As QCA is primarily a qualitative method, one limitation of our approach is that the coding of some edge cases was ultimately up to our personal judgement. This was particularly relevant for the coding of our outcome (*OUT*), which was coded based on whether a municipality had taken climate change adaptation without considering the actual outcomes of such measures in detail, as well as the coding of the control condition resources (*RES*) used in robustness tests, which was mostly coded based on qualitative factors assessed through our interviews. These limitations are also noticeable when examining those cases that do not fit our overall results well: some cases were considered as showing the outcome (*OUT*), but the adaptation measures in question were initiated and largely implemented by third parties independent of the municipalities' interest in adaptation.

This study focused on the local level, arguing that it is also at this level that many climate change effects deploy their impact. Our research enhances our knowledge of the lowest level in a multi-level arrangement of climate policymaking, with the knowledge that the climate actions of municipalities can decisively impact upper levels in one way or the other. Finally, our research shows that even when the conditions for local climate change adaptation are met, local authorities and actors need to be further enabled to realize local climate adaptation measures by shifting resources across levels.

CRediT authorship contribution statement

Dominik Braunschweiger: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Visualization. **Karin Ingold:** Conceptualization, Writing – original draft, Writing – review & editing, Supervision.

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.

Data availability

The data that has been used is confidential.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2023.03.013.

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