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Factors shaping short- and long-term climate risk communication: Taxonomy and importance-performance analysis for Alpine multi-hazard preparedness

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Article

Keywords: climate risk communication, communication adaptation, Importance-Performance Analysis, APA-lens, Alpine region, multi-stakeholder evaluation, disaster risk reduction

Posted Date: July 7th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9777718/v1

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Additional Declarations: No competing interests reported.

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Abstract

Natural hazard risks in Alpine regions are intensifying under climate change, placing growing demands on risk and crisis communication systems under multi-hazard regimes. Despite substantial cross-disciplinary research, evidence on what factors shape effective risk communication, and whether scientific experts, policy actors, and affected communities prioritise these factors differently, remains fragmented.

This study addresses these gaps through a two-study, three-stage sequential mixed-methods design in rural Alpine regions of Central Europe. Study 1 is based on the outcomes of two practitioner workshops and risk communication literature to generate 111 influence factors, classified into 20 subcategories across six clusters via directed content analysis (Fleiss' κ = 0.643 cluster; κ = 0.504 subcategory). An online Importance-Performance Analysis survey in Study 2 evaluated each subcategory across three stakeholder groups (scientific experts, n = 20; policy actors, n = 19; community stakeholders, n = 51). Respondents also assigned each subcategory to intended purpose and temporal orientation within the APA-lens, an evaluative analytical reference.

Mean importance ratings ranged from 3.67 to 4.56 (five-point Likert scale), supporting the taxonomy. Performance ranged from 2.33 to 3.41, with positive importance-performance gaps across all subcategories, indicating a systemic implementation gap. Importance ratings did not differ across stakeholder groups. An exploratory trend indicated that policy actors rated institutional and individual-psychological factors as better implemented than experts and community stakeholders did. The most common APA-phase assignment was 'all three phases' for all twenty subcategories, and the most common temporal orientation was 'both short- and long-term' for all but one subcategory, consistent with an integrative reading of climate risk and adaptation communication.

The study offers: (a) an empirically validated taxonomy of six clusters and twenty subcategories of communication-relevant factors; (b) a stakeholder-sensitive assessment identifying a systemic implementation gap across the full taxonomy; and (c) a first exploratory signal that policy actors may perceive governance-related performance differently from experts and community stakeholders. Findings are framed against SDG 10 and SDG 13 and translate into concrete leverage points for equitable preparedness policy.

Keywords

climate risk communication; communication adaptation; Importance-Performance Analysis; APA-lens; Alpine region; multi-stakeholder evaluation; disaster risk reduction

1. Introduction

Anthropogenic climate change is altering hazard regimes globally, with mountain regions among the most strongly affected (IPCC 2022; Pepin et al. 2022). The European Alps are warming at approximately twice the global average rate (Kotlarski et al. 2023; Fuchs et al. 2025) – with temperatures in the Austrian Alps having risen by 3.1°C since pre-industrial times (Fuchs et al. 2025), daily heavy rainfall has increased by about 8 % over the past four decades (Fuchs et al. 2025) – which systematically alters hazard frequencies. These trends translate into increasing demands for Alpine populations to prepare for both short-term responses to acute events and long-term adaptation. *Risk and Crisis Communication* (RCC) serves as a key enabling function for both horizons (Haslinger et al. 2025), though warning and adaptation are organised separately. Research systematically addressing RCC *strategies* (short- and long-term) remains underrepresented (PSAC 2019; Hansson et al. 2020).

Beyond operational gaps, rural Alpine RCCS (like in Austria or Bavaria, Germany) design is a matter of multi-level governance (municipal, regional, and cross-border). These political framework conditions dictate whether strategies can successfully bridge short- and long-term perspectives (PSAC 2019; Fuchs et al. 2025). Whether public communication strategies can combine short- and long-term perspectives depends not only on the communicative content but also on the political and governance-related framework conditions in which they are embedded (Hansson et al. 2020; Graf et al. 2026a; Graf et al. 2026b). These frameworks (see below in detail) operate within an international policy architecture: the Sendai Framework positions RCC as central to disaster preparedness (UNDRR 2015), while SDG 13 (Climate Action) and SDG 10 (Reduced Inequalities) mandate equitable access to information to mitigate communication-related vulnerability (United Nations n.d; UNDRR 2015; United Nations 2015; Hansson et al. 2020).

Following Graf et al. (2026a) the present study uses *risk and crisis communication* (RCC) strategies to denote deliberately designed measures that aim to strengthen risk perception, promote preparedness, and enable protective action, embedded within the broader process of RCC. Despite this normative mandate, empirical evidence on the factors that drive the effectiveness of RCC strategies in rural Alpine settings remains fragmented across disciplines, stakeholder groups, levels, and policy domains (Khan and Mishra 2022; Fathollahzadeh et al. 2023). Hence, three identified gaps motivate the present contribution: 1) influence factors are distributed across different disciplines such as psychology, governance studies and communication science, and have not been evaluated in an integrated, cross-disciplinary manner applicable across stakeholder groups (Hansson et al. 2020; Fathollahzadeh et al. 2023). Most existing factor catalogues are either theoretically derived or expert-driven, leaving their relative priority in applied settings empirically unexamined. 2) RCC research has documented divergence between expert and lay assessments of risk (Fischhoff et al. 1978; Renn et al. 2008), and the shift from deficit-model thinking, which treats public responses as deficiencies to be corrected, towards a recognition that expert and lay perspectives each carry their own rationality (Höppner et al. 2010) – practitioners tend to attribute success in RCC to internal factors such as personal ability and effort, while explaining failure through external factors like the difficulty of the task or the nature of the audience (Boholm 2019) – has not been translated into systematic empirical comparisons of how different stakeholder groups prioritise concrete communication factors. For climate-related risk in particular, Carlton and Jacobson (2016) demonstrate substantive differences between expert and non-expert mental models of climate change, yet such comparisons have not been extended to alpine multi-hazard contexts. Whether community members and scientific experts diverge in their assessments of what makes RCC effective remains an open empirical question with direct implications for equitable strategy design. 3) Although warning and adaptation communication are institutionally and analytically separated, evidence indicates they draw on structurally similar influence factors, with temporal orientation constituting a shift in emphasis rather than a categorical difference in the underlying communication system (Höppner et al. 2010; Boholm 2019; Graf et al. 2026a). A systematic scoping review found that purely long-term adaptation-oriented communication accounts for only 1.4% of the reviewed strategies, and hybrid configurations integrating both temporal horizons remain systematically underexplored (Graf et al. 2026a). The systematic exclusion of community perspectives from strategy design significantly compounds the gap between theory and practice. Currently, many early warning systems continue to operate through top-down mechanisms, offering only limited inclusion of affected populations in their design and evaluation (Baudoin et al. 2016). However, addressing this gap requires

more than just normative best-practice guidelines, an explorative bottom-up approach to communication practice is necessary to capture how practitioners and stakeholders' own (learning) experiences shape their understanding of effectiveness (Boholm 2019). Without empirical evidence on how communities prioritise communication factors across temporal contexts, current evidence-informed approaches lack a robust empirical foundation (van Aalst et al. 2008; Scolobig et al. 2022).

This study addresses these gaps through a two-study, three-stage sequential design. Drawing on two practitioner workshops, one focused on long-term climate adaptation communication, one on short-term warning communication, and literature, a consolidated taxonomy of influence factors for climate risk and adaptation communication was developed and validated (Fuchs et al. 2025). An Importance-Performance Analysis (IPA) survey was conducted, addressing these factors across three stakeholder groups (scientific experts, policy and administrative actors, and community stakeholders) in rural Alpine regions of Austria and Bavaria, with respondents additionally assigning each factor to a communicative phase and temporal orientation of the APA-lens (Graf et al. 2026b; Graf et al. 2026a). The current methodology aims to establish an empirically validated taxonomy of factors affecting Alpine climate RCC; to perform an exploratory comparison across multiple stakeholders regarding importance and performance evaluations; and to empirically examine whether the derived classification patterns align with an integrative interpretation of the APA-lens, wherein awareness, preparedness, and action function collectively, and short- and long-term horizons are interconnected rather than separated.

Findings inform equitable disaster preparedness policy and provide an empirical basis for the design of RCC strategies in multi-hazard Alpine settings. The paper is structured as follows. Section 2 develops the theoretical framework, including stakeholder divergence (2.1), institutional barriers to temporal integration (2.2), the APA-lens (2.3), and the research questions and hypotheses (2.4). Section 3 reports method and results study-by-study, following the sequential mixed-methods logic in which Study 1 develops and validates the taxonomy of influence factors and Study 2 evaluates this taxonomy in a multi-stakeholder Importance–Performance survey. Section 4 reports the empirical findings, Section 5 discusses their implications for RCC strategy and disaster policy, and Section 6 concludes with practical recommendations and outlook.

2. Theoretical Background

The theoretical framework for this study integrates three perspectives on RCC: stakeholder divergence (2.1), temporal integration (2.2), and the Aware–Prepare–Act lens as analytical heuristic (2.3). The research questions and hypotheses derived from this framework are presented in Section 2.4.

2.1. Divergent stakeholder priorities in risk communication strategies

RCC strategies are employed within multi-actor governance processes involving scientific experts, policy and administrative actors, and community members in structurally distinct positions. Experts contribute to hazard assessments and design communication systems, policy actors translate scientific input into institutional implementation and regulatory decisions, and community members interpret risk information and respond through self-protective and adaptive behaviour (Höppner et al. 2010). Within multi-actor early warning systems, different actors contribute to a range of activities, including risk assessment, system design, communication, and response. However, their roles and responsibilities often overlap and vary depending on the context (Clegg et al. 2022). The efficacy of these strategies depends on the configuration of stakeholders, whose structural positions determine each group's communication requirements and the way each group evaluates its quality (Höppner et al. 2010; Graf et al. 2026b).

This divergence between stakeholder rationalities is documented across hazard contexts. In the context of Austrian Alpine landslides, Scolobig et al. (2017) show that stakeholders in expert, administrative, and community positions tend to align with hierarchical, individualist, and egalitarian rationalities, leading to different priorities regarding communication design and responsibility allocation. At the system level, Baudoin et al. (2016) document that traditional Early Warning Systems designs follow expert-driven, top-down approaches that structurally

underrepresent community needs. Mehta et al. (2022) demonstrate that this gap persists in flood warning design: agency-designed operational warnings emphasise technical detail, while community members respond more positively to behaviour-oriented warnings emphasising specific actions.

Despite this described divergence in stakeholder positions, studies focus on risk perception and design preferences rather than on communication factors that different groups find important or lacking. Studies addressing communication factor priorities in Alpine contexts examine single stakeholder groups without cross-group comparisons (Maidl et al. 2021), and systematic reviews identify a wide range of components but do not systematically assess them across stakeholder groups (Fathollahzadeh et al. 2023). Whether expert, policy, and community stakeholders diverge in their IPA assessments of concrete RCC strategies factors remains an open empirical question with direct implications for equitable communication strategy design.

2.2. Temporal integration in RCC

RCC for natural hazards goes beyond early warning. It contributes to disaster risk reduction and climate change adaptation (IPCC 2012; Graf et al. 2026a) and covers all phases of disaster risk management – mitigation, preparedness, response, and recovery (Khan and Mishra 2022). In risk governance, communication is conceptualised as a constant companion throughout all phases of the risk governance cycle rather than a separate stage (Renn et al. 2011). This range requires addressing two temporal scales: short-term warnings for acute weather events such as storms and heavy rainfall, and long-term communication about how climate change alters hazard frequency and intensity over decades.

Research showed that the communication of warnings related to weather and climate-related adaptation operates within separate institutional structures. Meteorological services, education authorities and civil protection units maintain distinct mandates, time horizons and resource allocations (Graf et al. 2026a), the systematic underrepresentation of long-term adaptation communication has been documented in cross-hazard syntheses (Höppner et al. 2010; Graf et al. 2026a). In the European Alps, where precipitation regimes, snow cover, and the frequency of extreme weather events are shifting systematically due to climate change (Fuchs et al. 2025; Haslinger et al. 2025), this institutional separation shapes how warning and adaptation communication are governed. Drawing on interviews with twenty institutional and practitioner actors in South Tyrol, Carnelli and Pedoth (2024) document that RCC in the prevention and preparedness phase remains underdeveloped relative to emergency response capacity. Therefore, the missing link in the combination of short-term warning and long-term adaptation has direct implications for international policy frameworks (e.g., SDG 10 and SDG 13, UNDRR 2015). As posited by Hansson et al. (2020), the aforementioned mandates constitute communication-related vulnerability in the context of disasters, because groups with limited access to risk information are disproportionately exposed in disaster contexts. The systematic underrepresentation of long-term adaptation communication is therefore problematic on both conceptual grounds and in terms of the equitable distribution of preparedness capacity across populations and time horizons. Research in alpine settings has examined RCC and preparedness in single stakeholder groups (Maidl et al. 2021; Eusse-Villa et al. 2024), however, overall systematic research on alpine adaptation-oriented communication remains limited (Höppner et al. 2010). Furthermore, there are no integrated comparisons of importance and performance across expert, policy and community stakeholders, mapped onto temporal orientation, for alpine multi-hazard contexts.

2.3. The APA-lens

Within the present study, the APA-lens (Graf et al. 2026b) provides the structural framework for assigning influence factors to communicative functions and temporal orientations. It is used solely as an organising tool to enable subsequent comparative analysis across stakeholder groups.

2.4. Research Questions

The arguments developed in Sections 2.1 to 2.3 provide a rationale for empirically examining how stakeholder groups assess the importance and performance of RCC factors across temporal orientations in alpine multi-hazard contexts. As outlined in Section 2.1, a divergence between stakeholder rationalities in the domain of RCC was documented. As outlined in Section 2.2, there is a documented temporal asymmetry between warning-oriented and adaptation-oriented communication. As outlined in Section 2.3, the APA-lens was introduced as a heuristic for structuring communicative purpose and temporal orientation. Hence, three research questions guide the empirical analysis:

> ***RQ1****: Which factors do practitioners and stakeholders identify as influencing climate risk and adaptation communication in alpine multi-hazard contexts?*
> ***RQ2****: How do experts, policy actors, and community stakeholders assess the importance and performance of identified factors, and do their assessments diverge systematically across groups?*
> ***RQ3****: How do respondents assign factors to APA phases and temporal orientations?*

The three questions are addressed sequentially: RQ1 is addressed in Study 1 (Section 3.1), which develops and validates the taxonomy of influence factors; RQ2 and RQ3 are addressed in Study 2 (Section 3.2), which evaluates this taxonomy across stakeholder groups. RQ1 is descriptive and exploratory: no directional expectation is formulated, as the question seeks to identify the relevant factor set rather than to test predicted relations. For RQ2, prior work on stakeholder rationalities (Section 2.1) supports a directional expectation: expert, policy, and community stakeholders are expected to prioritise different factors (Höppner et al. 2010; Baudoin et al. 2016; Scolobig et al. 2017; Mehta et al. 2022). The APA-lens is conceptually positioned as a holistic heuristic in which Aware, Prepare, and Act functions operate jointly and are not theorised to follow distinct temporal logics (Graf et al. 2026b). Accordingly, RQ3 does not test phase- or time-specific predictions. Instead, it examines whether respondents' assignments of influence factors reflect this holistic structure or whether stakeholder groups implicitly prioritise communicative purposes or temporal orientations. The question, therefore, assesses the alignment between the conceptual model and stakeholder perceptions rather than the existence of theoretically expected differences.
The methodological design, instruments, and analytical procedures used to address these research questions are presented in Section 3.

3. Method and Results

The study employs an exploratory sequential mixed-methods design (Creswell 2014), in which a qualitative component (Study 1) generates and validates the analytical foundations for a subsequent quantitative component (Study 2; Figure 1). Within this design, Study 1 identifies influence factors which shape climate risk and adaptation communication in Alpine multi-hazard contexts. Study 2 evaluates the identified factors from study 1 across three different stakeholder groups using an IPA (Martilla and James 1977) and analyses how respondents assign each factor to a communicative purpose of the RCC strategies and to the temporal orientation of the APA-lens. The empirical context comprises rural Alpine regions in Austria and Bavaria. Stages 1 and 2 of Study 1 develop and validate the factor taxonomy. It answers RQ1 and provides the basis for the survey instrument used in Study 2. The methodological details of the survey instrument, the sampling procedure and the analytical strategy for study 2 are reported in Section 3.2. Given the sequential dependence of Study 2 on the taxonomy produced by Study 1, methodology and results are reported study-by-study rather than separately (Section 3.1 for Study 1, Section 3.2 for Study 2). The discussion (Section 4) integrates the findings from both studies.

[Figure 1 about here]

3.1. Study 1 - Factor Identification and Validation

The procedure was conducted in two stages (Figure 1, Study 1): Stage 1 – factor identification from three complementary sources (Section 3.1.1); Stage 2 – cross-source merging, categorisation, and inter-rater reliability assessment (Section 3.1.2). The resulting taxonomy is reported in Section 3.1.3.

3.1.1. Stage 1 – Factor Identification

To identify the factors influencing RCC strategies in Alpine multi-hazard contexts, three sources were combined: two structured practitioner workshops covering complementary temporal foci (long-term adaptation and short-term warning) and a literature scan. Both workshops were designed as multi-stakeholder sessions with moderated group discussions, following established best-practice principles for stakeholder participation in environmental decision-making, including systematic stakeholder representation, clear objectives, and skilled facilitation (Reed 2008).[1 2]

Workshop 1 – Long-term adaptation communication strategies. The first workshop was held on October 18th, 2025, in Graz as part of the 6th International Avalanche Symposium and attended by eight experts from climate service departments, federal hazard mitigation, regional adaptation administration, avalanche warning services, applied climate consulting and a regional KLAR! climate adaptation network. The 1.5-hour on-site session focused on long-term communication for adaptation to Alpine snow- and avalanche-related hazards. It used a moderated plenary discussion structured along the three APA phases, in which participants contributed experience-based factors, jointly evaluated the emerging set, and prioritised critical leverage points. The session was conducted by two facilitators (moderation and observation), who documented the discussion in structured minutes. From these minutes, the two facilitators subsequently extracted and consolidated 57 distinct factor items, retaining the participants' wording and contextual references wherever possible.

Workshop 2 – Short-term warning RCC strategies. The second workshop took place March the 2nd 2026 as a closed online session (via Webex) with full audio recording and collaborative real-time documentation on a shared Miro board. Nine experts from regional warning centres, civil protection management, meteorological and hydrographic services, railway infrastructure protection, flood forecasting, cultural heritage protection, military and project leadership attended this session. It focused on short-term warning communication for natural hazards and complemented Workshop 1 in temporal orientation. The 1.5-hour session also used a moderated plenary discussion structured along the APA phases, with simultaneous documentation on a shared Miro board and full audio transcription. Participants contributed experience-based factors structured around the same dual guiding question "where I have failed / what has worked", followed by collective validation in plenary (n = 35 raw factor items, derived from the Miro-board documentation and the audio transcript).

Literature scan – short-term and long-term communication strategies. Following the procedure described by Graf et al. (Graf et al. 2026a), the literature was screened for explicit or implicit references to factors influencing RCC effectiveness (success factors, risk factors, barriers, and enablers). The scan yielded 47 distinct factor items, extracted independently of the workshop pools (online Data S4_Supplementary_LiteratureScan[3]).

3.1.2. Stage 2 – Cross-source merging, categorisation, and inter-rater reliability

In total, the sources identified n = 139 influence factors on RCC strategies (Workshop 1: 57; Workshop 2: 35; literature scan: 47; see also Figure 1). To encounter redundancy, a merging process was adopted, where three raters independently reviewed, marked potential redundancies and identified repetitive underlying concepts. A factor was merged when at least two of the three raters reached consensus. Items without a majority agreement on a proposed merger were retained as separate factors. Items consolidated through merging were combined into master factors (“M”); the complete audit trail of merging decisions, including the source IDs of items combined into each master factor, is provided online (S2_Supplementary_MergingAuditTrail[3]). This procedure produced a consolidated pool of 111 items.

Categorisation followed a directed qualitative content-analytical approach (Hsieh and Shannon 2005), in which initial coding categories were derived deductively from prior theory and subsequently refined inductively during analysis. The procedure was informed by Mayring's content-structuring qualitative content analysis (Mayring 2015), combining theory-driven category assignment with iterative refinement based on empirical material. A coding manual was developed to define each subcategory operationally, complemented by inclusion criteria, exclusion criteria**,** and decision rules for boundary cases (online Data: S1_Supplementary_CodingBook.pdf[3]).

The deductive foundation drew on Fathollahzadeh et al. (2023), who delineate five communication components (message, message-sender, message-receiver, message-environment, message-process), and on Hansson et al. (2020), who identify three drivers of communication-related vulnerability (individual, social-structural, situational); subcategory differentiation for trust-building and co-design was drawn from Scolobig et al. (2022). Complementary anchors for individual-psychological subcategories (IP.1, IP.2) and for experiential knowledge (KL.2) were drawn from the Protective Action Decision Model (Lindell and Perry, 2012), the constructs of threat perception, protective action perception, and pre-decisional experiential filtering. Synthesis yielded six primary clusters: Communication Design (CD), Sender Credibility (SCR), Individual-Psychological Factors (IP), Knowledge and Learning (KL), Socio-Cultural and Contextual Factors (SC) and Institutional and Governance Factors (IG), within which 20 subcategories were developed through deductive–inductive coding anchored in primary references (see Table 1).

Table 1 Taxonomy of influence factors on climate risk and adaptation communication in Alpine multi-hazard contexts[4]

Main Cat.	ID	Subcategory	Description	*Primary*	*Additional references*
Communication Design	CD.1	Language & Style	Linguistic dimension of the message	*(Fathollahzadeh et al. 2023)*	*(Weyrich et al. 2019; Golding 2022; Scolobig et al. 2022)*
	CD.2	Format & Visualisation	Visual-medial dimension of the message	*(Fathollahzadeh et al. 2023)*	*(Scolobig et al. 2022)*
	CD.3	Content & Action Orientation	Substantive content dimension	*(Fathollahzadeh et al. 2023)*	*(Lindell and Perry 2004, 2012; Scolobig et al. 2022)*
	CD.4	Dialogue & Channel Strategy	Interactional and dispersal dimension	*(Fathollahzadeh et al. 2023)*	*(Hansson et al. 2020; Scolobig et al. 2022)*
Sender Credibility	SCR.1	Sender Attributes (perceived)	Source attributes	*(Fathollahzadeh et al. 2023)*	*(Scolobig et al. 2022)*
	SCR.2	Sender–Receiver Trust Relationship	Relational source-audience bond	*(Hansson et al. 2020)*	*(Scolobig et al. 2022)*
	SCR.3	Communicative Disposition	Sender's relational stance	*(Scolobig et al. 2022)*	*(Fathollahzadeh et al. 2023)*
Individual-Psychological	IP.1	Risk Perception & Appraisal	Cognitive risk evaluation	*(Lindell and Perry 2012; Fathollahzadeh et al. 2023)*	*(Hansson et al. 2020)*
	IP.2	Motivation & Action Readiness	Motivational state	*(Lindell and Perry 2012; Fathollahzadeh et al. 2023)*	*(Rogers 1975; Ajzen 1991)*
	IP.3	Disengagement & Avoidance	Aversive psychological state	*(Fathollahzadeh et al. 2023)*	*(Rogers 1975; Hansson et al. 2020; Weyrich et al. 2021)*
Know	KL.1	Domain Knowledge of Risk	Substantive risk knowledge	*(Fathollahzadeh et al. 2023)*	*(Hansson et al. 2020; Scolobig et al. 2022)*

	KL.2	Experiential Knowledge	Experience-based learning	*(Lindell and Perry 2012; Hansson et al. 2020)*	*(Terpstra 2011)*
	KL.3	Communication & Transfer Competence	Communicative skill	*(Fathollahzadeh et al. 2023)*	*(Preuner et al. 2017; Scolobig et al. 2017; Scolobig et al. 2022)*
Socio-Cultural & Contextual	SC.1	Cultural & Normative Context	Cultural-normative conditions	*(Fathollahzadeh et al. 2023)*	*(Hansson et al. 2020; Scolobig et al. 2022)*
	SC.2	Demographic & Socio-economic Context	Demographic conditions	*(Hansson et al. 2020)*	*(Scolobig et al. 2022; Fathollahzadeh et al. 2023)*
	SC.3	Information Environment & Media Context	Situational information conditions	*(Hansson et al. 2020)*	*(Scolobig et al. 2022; Fathollahzadeh et al. 2023)*
Institutional & Governance	IG.1	Resources & Capacities	Operational resources	*(Hansson et al. 2020)*	*(Scolobig et al. 2022; Fathollahzadeh et al. 2023)*
	IG.2	Political & Regulatory Framework	Regulatory conditions	*(Scolobig et al. 2022)*	*(Scolobig et al. 2015; Preuner et al. 2017; Hansson et al. 2020; Scolobig et al. 2022)*
	IG.3	Inter-institutional Coordination	Cross-institutional cooperation	*(Scolobig et al. 2022)*	*(Scolobig et al. 2015; Fathollahzadeh et al. 2023)*
	IG.4	Communication Continuity & Process Quality	Long-term process management	*(Scolobig et al. 2022)*	*(Fathollahzadeh et al. 2023)*

Three independent raters coded each item using the manual and a self-rated certainty score (1 = clear, 2 = tendency, 3 = uncertain), to identify items relevant for discussion, following the principle of marking coder uncertainty in consensus-based coding (Hemmler et al. 2022). As a first step, an initial probe set of 11 items spanned all six clusters and combined six unambiguous cases (one per cluster, calibrating basic category understanding) with five documented boundary cases between adjacent constructs (e.g., generalised trust between SCR.2 and SC.1; topic fatigue between IP.3 and SC.3), following maximum-variation sampling principles (Patton 2015). The three raters independently coded a trial set, and differences were resolved in a structured consensus discussion of the coding rules, adapting the negotiated agreement principle (Campbell et al. 2013) to a three-rater configuration. Eight of the eleven probe items served as calibration cases that prompted clarifications of the coding manual and were excluded from the κ calculation; the remaining three required no manual revision and were retained. The final 103 items were then coded independently against the calibrated manual. Inter-rater reliability was assessed using Fleiss' κ (Fleiss 1971), with category labels normalised prior to computation to standardise five non-systematic spelling variants in the rater entries. Item-level agreement is reported alongside κ for transparency; values are interpreted according to Landis and Koch (1977).

3.1.3. Study 1 - Results

Study 1 addresses RQ1 by developing and validating a taxonomy of influence factors. Combining outputs from both practitioner workshops and the targeted literature scan, the cross-source merging procedure consolidated 139 source items into 111 distinct factors (see the supplementary material). The final inter-rater reliability assessment was therefore based on N = 103 items (100 post-probe items plus 3 retained probe items). In comparison, the full taxonomy pool comprises N = 111 items (the 103 reliability-assessed items plus 8 calibration items, the latter post-hoc recoded against the finalised manual and integrated into the taxonomy).

As shown in Table 2, the inter-rater reliability was computed for the three-rater coding (m = 3) at two analytical levels. At the main-category level (k = 6, N = 103), Fleiss' κ = 0.643 indicated substantial agreement (Landis and

Koch 1977), with observed agreement $\bar{P}$ = 71.2% and chance-expected agreement $\bar{P}_e$ = 0.194 (Table 2). The distribution of item-level agreement demonstrated a uniform consensus (3/3) among three raters for 60.2% of items, a majority agreement (2/3) among two raters for a further 33.0%, and an absence of majority agreement (1/3) for 6.8%. The latter cases were addressed through structured plenary discussions. At the subcategory level (k = 20, N = 102), Fleiss' κ = 0.504 indicated moderate agreement ($\bar{P}$ = 53.3%, $\bar{P}_e$ = 0.059); however, one item was excluded as a duplicate entry identified during data cleaning. Across the 103 subcategory ratings, 41.7% reached unanimous agreement, 33.0% showed majority agreement, and 24.3% did not reach a majority. The lower subcategory κ reflects the finer 20-fold categorical differentiation within already-substantially agreed main clusters, rather than coding inconsistency. Subcategories within the same cluster represent conceptually distinct mechanisms (e.g., linguistic, visual, content-related, and dialogical features within Communication Design). This informs the analytical treatment of subcategories as individual units in Study 2 (Section 3.2). The complete item-level coding record, along with rater self-certainty scores, is available in the supplementary material (see S3_Supplementary_ItemLevelCoding_InterRater[3]).

Table 2 Inter-Rater Reliability; Inter-rater reliability of the categorisation procedure (Fleiss' κ; Fleiss, 1971), computed separately for the main-category level (k = 6) and the subcategory level (k = 20). Interpretation following Landis and Koch (1977). $\bar{P}$ = observed agreement; $\bar{P}_e$ = chance-expected agreement. Formula: $\kappa = (\bar{P} - \bar{P}_e) / (1 - \bar{P}_e)$

Level	k	N (Items)	Fleiss' κ	Interpretation	$\bar{P}$	$\bar{P}_e$
Main category	6	102	0.643	Substantial (0.61–0.80)	71.2 %	0.194
Subcategory	20	102	0.504	Moderate (0.41–0.60)	53.3 %	0.059

The final taxonomy comprises 20 subcategories, organised into six thematic clusters (see Table 1 and Figure 2). The full operational definitions are presented in Table 1, with the theoretical anchoring detailed in Section 3.1.2, and the complete codebook in the supplementary material (see S1). Subcategories represent conceptually distinct mechanisms that influence RCC strategies and constitute the analytical units for the subsequent stakeholder evaluation in Study 2. Across the taxonomy, item counts at the subcategory level range from n = 1 (SCR.3 Communicative Disposition) to n = 12 (CD.4 Dialogue & Channel Strategy), reflecting the conceptual breadth and frequency with which each subcategory emerged in the consolidated source pool. The six clusters group subcategories along the communication process from message artefact (CD, 4 subcategories) and sender (SCR, 3 subcategories) through receiver-side cognition (IP, 3 subcategories) and knowledge (KL, 3 subcategories) to contextual (SC, 3 subcategories) and institutional (IG, 4 subcategories) conditions. Item counts indicate the relative representation of subcategories in the consolidated source pool. The assessment of the IPA across stakeholder groups at the subcategory level is addressed in Study 2 (Section 3.2).

[Figure 2 about here]

3.2. Study 2 - Analytical Framework

The study combines two complementary analytical frameworks. The IPA identifies where communication factors are recognised as important but rated as underperforming. The APA-lens locates these gaps along two dimensions of the communicative system: communicative purpose and temporal orientation. Used together, the two frameworks enable examination of each factor's relative priority, the magnitude of any importance–performance gap, and its position within the broader communicative architecture of RCC strategies.

3.2.1. Importance-Performance Analysis

The empirical analysis uses IPA as a diagnostic instrument to evaluate each subcategory along two dimensions: perceived importance and current performance. The APA-lens provides the conceptual reference along which respondents additionally assigned each subcategory to a communicative purpose (Aware, Prepare, Act) and a temporal orientation (short-term, long-term, both). The respondent-level assignment serves as an empirical test of whether the theoretically postulated APA dimensions resonate with stakeholder perceptions, not as a measurement of APA functions.

The IPA was introduced by Martilla and James (1977) as a technique for translating evaluative survey data into active management decisions. The method asks respondents to rate a defined set of attributes on two independent dimensions: the perceived importance and current performance. The resulting mean scores are on a two-dimensional grid divided into four diagnostic quadrants: Keep Up the Good Work (high importance, high performance), Concentrate Here (high importance, low performance), Low Priority (low importance, low performance), and Possible Overkill (low importance, high performance). Subsequent IPA refinements (cf. Ormanović et al. 2017) formalised the gap score $G = I - P$ as an explicit diagnostic signal that supplements quadrant assignment, with positive gaps indicating areas where investment is most urgently warranted. A documented limitation of the classical IPA design is the ceiling effect: when importance ratings cluster systematically at the upper end of the scale, the scale midpoint loses discriminatory power. Ormanović et al. (2017), in their systematic review of IPA modifications, identify the data-centred crosshair (Data Centred Quadrant Model, DCQM), originally proposed by Martilla and James (1977), as preferable to the classical scale-centred crosshair, as it preserves meaningful differentiation across the attribute space regardless of the response distribution. Given the systematic clustering of importance ratings for RCC factors, this study applies the data-centred approach. IPA has been extended to disaster risk management contexts by Lin et al. (2025), who demonstrate the utility of IPA in evaluating disaster adaptation frameworks for isolated island communities, identifying capacity gaps that remain invisible in unidimensional importance or performance assessments. In this study, IPA is operationalised in Study 2 (see Section 3.4) for cross-stakeholder evaluation of the factors identified in Study 1.

Sample and Procedure

The online survey was administered via Lime Survey and complied with applicable data protection regulations. Informed consent was obtained from all participants prior to survey access. Participants were recruited from rural alpine regions in Austria and Bavaria. The link to the online survey was disseminated via social media (LinkedIn, WhatsApp, Instagram) and within the authors' professional network to better reach policy actors and scientific experts. During the data collection period, 186 persons began the survey, of whom 91 (48.9%) completed the questionnaire. During screening of the survey data, one case was identified that displayed a uniform response pattern across all questions on importance, performance, APA phase and temporal orientation, with the first available response option selected for every item. As this pattern indicates a lack of meaningful item-level judgment, the case was excluded from all subsequent analyses. As a robustness check, the analyses were repeated while retaining this case, and the results showed no substantive differences (available online, Study2_Robustness_check[3]). Consequently, the final sample comprised 90 participants, of whom 47 (52.2%) identified as male, 31 (34.4%) as female, 2 (2.2%) as non-binary, and 10 persons (11.1%) preferred not to disclose their gender. The mean age of the participants was 44.91 years (SD = 11.65). Most participants had prior personal experience with natural hazards in the alpine region (n = 75; 83.3%), either with direct personal consequences (n = 20; 22.2%) or without (n = 55; 61.1%). The sample comprised three stakeholder groups, namely 20 (22.2%) scientific experts, 19 (21.1%) policy actors, and 51 (56.7%) community stakeholders.

Measures

In the survey, each factor identified in Study 1 was presented to participants on a separate page, along with the four evaluation questions described below.

Importance rating. Participants were asked to rate each factor's importance by answering the following question: "How important is this factor for effective climate RCC?" Answers were given on a five-point Likert scale, ranging from 1 = "not important at all" to 5 = "very important".

Performance rating. Participants were asked to rate each factor's current performance by answering the question: "How well is this factor currently implemented in practice?" Answers were given on a five-point Likert scale, ranging from 1 = "not implemented at all" to 5 = "implemented very well".

APA phase. Participants were asked to assign each factor to an APA phase by selecting one of the following options: "Aware", "Prepare", "Act", "All" or "None". Each option was accompanied by a brief description of the phase (e.g., for "Aware": "Raising awareness: People recognise and understand the risk")

Temporal orientation. Participants were asked to assign each factor to a temporal orientation by selecting either "Short-term", "Long-term", or "Both". Again, the options were accompanied by a brief description. "Short-term" was defined as "Warning, acute event (hours to days)" and "Long-term" as "Adaptation, preparedness, resilience (months to years)".

Statistical Analysis

Descriptive statistics (mean, standard deviation, range) were calculated for importance, performance and the importance-performance gap. The importance-performance gap was calculated by subtracting the performance rating from the importance rating. For the IPA matrix, mean importance ratings were plotted against mean performance ratings. The quadrants of the matrix were defined using data-centred crosshairs based on the grand means of importance and performance across all subcategories.

Mixed-design ANOVAs were utilised to investigate differences between stakeholder groups. Separate ANOVAs were conducted for each category and dependent variable (importance, performance, and importance-performance gap). Subdimensions were included as within-person and stakeholder groups as the between-person factor. Inspection of Q-Q plots of model residuals (see online repository) indicated moderate deviations from normality, especially for importance ratings. However, given that ANOVA is generally robust to moderate violations of normality (Glass et al. 1972), it was retained as the method for the present analyses of group differences. When the sphericity assumption was violated, the Greenhouse-Geisser correction was applied. To reduce alpha-error inflation due to multiple testing, the ANOVA p-values are additionally reported as adjusted p-values using the Benjamini-Hochberg method. Significant ANOVA effects involving the stakeholder group were followed up using estimated marginal means with Holm-adjusted pairwise comparisons. All analyses were conducted using two-sided tests with an alpha level of .05.

For the nominal variables, APA phase and temporal orientation, relative frequencies were calculated to report the modal value for each subcategory.

All analyses were conducted in RStudio (version 2026.04.0+526) with R (version R-4.6.0). The data and scripts are available in the online repository for this paper (Study2_Analysis[3]).

Results Study 2

Importance-performance analysis (IPA)

Descriptive statistics for importance ratings, performance ratings, and the importance–performance gap, both for the whole sample and by stakeholder group, are reported in Tables 3, 4, and 5, respectively. For the importance ratings, the results consistently showed mean values above the scale mid-point (3) across all subcategories and stakeholder groups. The mean ranged from 3.67 (Domain Knowledge (KL.1), Demographic & Socio-

Economic Context (SC.2)) to 4.56 (Dialogue & Channel Strategy (CD.4)) in the whole sample. This supports the selection of these subcategories as relevant factors in Study 1. The mean values for performance ratings ranged from M = 2.33 (Disengagement & Avoidance (IP.3)) to M = 3.41 (Inter-Institutional Coordination (IG.3)) in the whole sample. The mean importance-performance gaps were positive across all subcategories. Thus, mean importance ratings were consistently higher than mean performance ratings across subcategories, indicating a general perceived implementation gap.

Table 3 Importance Analysis. Descriptive statistics for importance ratings for the whole sample and by stakeholder group.

		Whole sample (n = 90)				Experts (n = 20)			Policy actors (n = 19)			Community (n = 51)		
Subcategory		**Rank**	**M**	**SD**	**Range**	**M**	**SD**	**Range**	**M**	**SD**	**Range**	**M**	**SD**	**Ra**
Communication Design														
CD.1	Language & Style	2	4.53	0.58	3 – 5	4.65	0.49	4 – 5	4.47	0.61	3 – 5	4.51	0.61	3 -
CD.2	Format & Visualisation	6	4.41	0.63	3 – 5	4.65	0.59	3 – 5	4.16	0.76	3 – 5	4.41	0.57	3 -
CD.3	Content & Action Orientation	4	4.46	0.72	2 – 5	4.25	0.64	3 – 5	4.32	0.82	2 – 5	4.59	0.70	2 -
CD.4	Dialogue & Channel Strategy	1	4.56	0.72	1 – 5	4.45	0.60	3 – 5	4.42	0.84	2 – 5	4.65	0.72	1 -
Sender Credibility														
SCR.1	Source Attributes	7	4.38	0.83	1 – 5	4.60	0.50	4 – 5	4.11	0.74	3 – 5	4.39	0.94	1 -
SCR.2	Relational Trust	9	4.20	0.77	2 – 5	4.00	0.73	3 – 5	4.11	0.81	3 – 5	4.31	0.76	2 -
SCR.3	Communication Stance	18	3.68	1.06	1 – 5	3.80	0.89	2 – 5	3.68	1.34	1 – 5	3.63	1.02	2 -
Individual-Psychological Factors														
IP.1	Risk Perception & Cognitive Appraisal	8	4.26	0.87	1 – 5	4.00	0.92	2 – 5	4.53	0.61	3 – 5	4.25	0.91	1 -
IP.2	Motivation & Volition	12	4.14	0.88	1 – 5	3.70	0.86	2 – 5	4.42	0.69	3 – 5	4.22	0.90	1 -
IP.3	Disengagement & Avoidance	16	3.96	1.12	1 – 5	3.85	0.93	2 – 5	3.95	1.08	1 – 5	4.00	1.22	1 -
Knowledge & Learning														
KL.1	Domain Knowledge	20	3.67	0.95	2 – 5	3.35	1.04	2 – 5	3.47	1.02	2 – 5	3.86	0.85	2 -
KL.2	Experiential Knowledge	14	3.99	1.18	1 – 5	3.65	1.14	2 – 5	4.21	1.03	1 – 5	4.04	1.23	1 -
KL.3	Transfer Competence	5	4.43	0.65	3 – 5	4.55	0.51	4 – 5	4.37	0.60	3 – 5	4.41	0.73	3 -
Socio-Cultural & Contextual Elements														
SC.1	Cultural & Normative Context	17	3.78	0.96	1 – 5	3.35	1.04	1 – 5	4.05	0.85	2 – 5	3.84	0.92	2 -
SC.2	Demographic & Socio-Economic Context	20	3.67	1.06	1 – 5	3.35	0.93	1 – 5	3.42	1.26	1 – 5	3.88	0.99	1 -
SC.3	Situational & Information Environment	10	4.18	0.88	1 – 5	4.10	0.91	2 – 5	4.11	0.81	3 – 5	4.24	0.91	1 -
Institutional & Governance Factors														
IG.1	Resources & Capacity	11	4.16	0.91	1 – 5	3.95	0.89	2 – 5	4.16	1.01	1 – 5	4.24	0.89	2 -
IG.2	Political & Regulatory Framework	15	3.98	1.03	1 – 5	4.00	0.79	3 – 5	4.32	0.82	3 – 5	3.84	1.16	1 -
IG.3	Inter-Institutional Coordination	3	4.51	0.81	2 – 5	4.35	0.99	2 – 5	4.84	0.37	4 – 5	4.45	0.83	2 -
IG.4	Communication Continuity	13	4.06	0.81	2 – 4	3.95	0.83	2 – 5	3.95	0.78	2 – 5	4.14	0.83	2 -

Table 4 Performance Analysis: Descriptive statistics for performance ratings for the whole sample and by stakeholder group.

		Whole sample (n = 90)				Experts (n = 20)			Policy actors (n = 19)			Community (n = 51)		
Subcategory		**Rank**	**M**	**SD**	**Range**	**M**	**SD**	**Range**	**M**	**SD**	**Range**	**M**	**SD**	**Ra**
Communication Design														
CD.1	Language & Style	4	3.19	0.69	1 – 5	3.10	0.45	2 – 4	3.47	0.70	3 – 5	3.12	0.74	1
CD.2	Format & Visualisation	12	2.94	0.74	1 – 5	2.95	0.60	2 – 4	3.32	0.82	2 – 5	2.80	0.72	1

CD.3	Content & Action Orientation	7	3.07	0.76	1 – 5	2.95	0.83	1 – 5	3.21	0.85	1 – 5	3.06	0.70	1
CD.4	Dialogue & Channel Strategy	3	3.29	0.81	1 – 5	3.45	0.83	2 – 5	3.37	0.76	2 – 5	3.20	0.83	1
Sender Credibility														
SCR.1	Source Attributes	2	3.33	0.82	1 – 5	3.60	0.60	3 – 5	3.32	0.82	2 – 5	3.24	0.89	1
SCR.2	Relational Trust	5	3.18	0.82	1 – 5	3.35	0.93	2 – 5	3.11	0.74	2 – 5	3.14	0.80	1
SCR.3	Communication Stance	17	2.71	0.90	1 – 4	2.85	0.81	1 – 4	2.58	1.07	1 – 4	2.71	0.88	1
Individual-Psychological Factors														
IP.1	Risk Perception & Cognitive Appraisal	8	3.03	0.97	1 – 5	2.95	0.89	1 – 5	3.42	0.96	1 – 5	2.92	0.98	1
IP.2	Motivation & Volition	11	2.96	0.97	1 – 5	2.55	0.83	1 – 4	3.47	0.96	2 – 5	2.92	0.96	1
IP.3	Disengagement & Avoidance	20	2.33	0.72	1 – 4	2.15	0.75	1 – 3	2.32	0.82	1 – 3	2.41	0.67	1
Knowledge & Learning														
KL.1	Domain Knowledge	15	2.90	0.79	1 – 5	3.10	0.79	2 – 5	2.89	0.88	1 – 4	2.82	0.77	1
KL.2	Experiential Knowledge	6	3.10	0.95	1 – 5	3.15	0.99	1 – 5	3.26	0.99	1 – 4	3.02	0.93	1
KL.3	Transfer Competence	15	2.90	0.78	1 – 5	3.00	0.79	2 – 5	2.95	0.71	2 – 4	2.84	0.81	1
Socio-Cultural & Contextual Elements														
SC.1	Cultural & Normative Context	18	2.52	0.84	1 – 5	2.30	0.80	1 – 3	2.74	0.93	1 – 5	2.53	0.81	1
SC.2	Demographic & Socio-Economic Context	19	2.43	0.75	1 – 4	2.30	0.73	1 – 4	2.47	0.84	1 – 4	2.47	0.73	1
SC.3	Situational & Information Environment	9	2.98	0.83	1 – 5	2.95	0.89	1 – 5	3.21	0.79	2 – 5	2.90	0.83	1
Institutional & Governance Factors														
IG.1	Resources & Capacity	11	2.96	0.83	1 – 5	3.05	0.89	1 – 5	3.00	0.94	1 – 4	2.90	0.78	1
IG.2	Political & Regulatory Framework	16	2.79	0.85	1 – 5	2.75	0.79	1 – 4	3.00	0.82	2 – 5	2.73	0.90	1
IG.3	Inter-Institutional Coordination	1	3.41	1.02	1 – 5	3.25	1.02	1 – 5	4.11	0.66	3 – 5	3.22	1.03	1
IG.4	Communication Continuity	15	2.90	0.90	1 – 5	2.70	0.80	1 – 4	3.47	0.77	2 – 5	2.76	0.91	1

Figure 3 shows the importance-performance matrix for all subcategories. Given that the data-centred approach was applied to identify the crosshair of the matrix, the quadrants represent relative importance and performance. This allowed identification of priority factors within subcategories that were uniformly rated as important. The results showed that Format & Visualisation (CD.2) and Transfer Competence (KL.3) should be prioritised (quadrant *concentrate here* with higher relative importance and lower relative performance) while efforts should be maintained for Language & Style (CD.1), Content & Action Orientation (CD.3), Dialogue & Channel Strategy (CD.4), Resources & Capacity (IG.1), Inter-Institutional Coordination (IG.3), Risk Perception & Cognitive Appraisal (IP.1), Situational & Information Environment (SC.3), Source Attributes (SCR.1) and Relational Trust (SCR.2) (quadrant *keep up the good work* with higher relative importance and higher relative performance). The other factors showed lower relative importance, thus falling into the quadrants of *lower priority* and *possible overinvestment*.

[Figure 3 about here]

The results for the importance-performance gap in the whole sample showed the largest gap for Disengagement & Avoidance (IP.3; M = 1.62), Transfer Competence (KL.3; M = 1.53) and Format & Visualisation (CD.2; M = 1.47). The smallest gap was found for Communication Stance (SCR.3, M = 0.97), Experiential Knowledge (KL.2, M = 0.89) and Domain Knowledge (KL.1, M = 0.77).

Table 5: Importance-Performance Gap: Descriptive statistics for the importance-performance gap for the whole sample and by stakeholder group.

	Whole sample (n = 90)				**Experts (n = 20)**			**Policy actors (n = 19)**			**Community (n = 51)**		
Subcategory	**Rank**	**M**	**SD**	**Range**	**M**	**SD**	**Range**	**M**	**SD**	**Range**	**M**	**SD**	**Range**
Communication Design													

CD.1	Language & Style	5	1.34	0.82	-1 – 3	1.55	0.60	0 – 2	1.00	0.82	0 – 2	1.39	0.87	-1 – 3
CD.2	Format & Visualisation	3	1.47	1.01	-1 – 3	1.70	0.92	-1 – 3	0.84	1.01	0 – 3	1.61	0.96	0 – 3
CD.3	Content & Action Orientation	4	1.39	0.88	-1 – 4	1.30	0.86	0 – 4	1.11	0.81	-1 – 2	1.53	0.90	-1 – 4
CD.4	Dialogue & Channel Strategy	6	1.27	1.03	-1 – 4	1.00	1.12	-1 – 3	1.05	0.91	-1 – 2	1.45	1.01	-1 – 4
Sender Credibility														
SCR.1	Source Attributes	16	1.04	1.00	-3 – 4	1.00	0.79	0 – 2	0.79	0.92	-1 – 3	1.16	1.10	-3 – 4
SCR.2	Relational Trust	17	1.02	1.01	-3 – 3	0.65	0.88	-1 – 2	1.00	0.94	0 – 3	1.18	1.05	-3 – 3
SCR.3	Communication Stance	18	0.97	1.24	-1 – 4	0.95	1.00	0 – 3	1.11	1.37	-1 – 4	0.92	1.29	-1 – 4
Individual-Psychological Factors														
IP.1	Risk Perception & Cognitive Appraisal	9	1.22	1.09	-1 – 4	1.05	0.89	0 – 3	1.11	1.10	0 – 4	1.33	1.16	-1 – 4
IP.2	Motivation & Volition	13	1.19	1.25	-4 – 4	1.15	1.09	-1 – 3	0.95	1.18	-1 – 3	1.29	1.35	-4 – 4
IP.3	Disengagement & Avoidance	1	1.62	1.29	-1 – 4	1.70	1.22	0 – 4	1.63	1.16	0 – 4	1.59	1.39	-1 – 4
Knowledge & Learning														
KL.1	Domain Knowledge	20	0.77	1.12	-1 – 4	0.25	1.12	-1 – 3	0.58	0.90	-1 – 3	1.04	1.13	-1 – 4
KL.2	Experiential Knowledge	19	0.89	1.04	-3 – 4	0.50	1.10	-3 – 2	0.95	1.08	-1 – 3	1.02	0.99	-1 – 4
KL.3	Transfer Competence	2	1.53	0.96	0 – 4	1.55	0.60	0 – 2	1.42	0.96	0 – 3	1.57	1.08	0 – 4
Socio-Cultural & Contextual Elements														
SC.1	Cultural & Normative Context	7	1.26	1.14	-1 – 4	1.05	1.19	-1 – 4	1.32	0.89	0 – 3	1.31	1.21	0 – 4
SC.2	Demographic & Socio-Economic Context	8	1.23	1.14	-2 – 4	1.05	1.05	-1 – 3	0.95	1.08	0 – 3	1.41	1.19	-2 – 4
SC.3	Situational & Information Environment	11	1.20	1.18	-2 – 4	1.15	1.04	-1 – 3	0.89	1.29	-2 – 3	1.33	1.19	-2 – 4
Institutional & Governance Factors														
IG.1	Resources & Capacity	11	1.20	1.31	-3 – 4	0.90	1.45	-3 – 4	1.16	1.17	-1 – 3	1.33	1.31	-2 – 4
IG.2	Political & Regulatory Framework	13	1.19	1.42	-4 – 4	1.25	1.16	0 – 4	1.32	1.06	0 – 3	1.12	1.63	-4 – 4
IG.3	Inter-Institutional Coordination	15	1.10	1.12	-2 – 4	1.10	1.29	-1 – 4	0.74	0.56	0 – 2	1.24	1.19	-2 – 4
IG.4	Communication Continuity	14	1.16	1.19	-3 – 4	1.25	1.21	-1 – 4	0.47	0.70	-1 – 1	1.37	1.25	-3 – 4

IPA group differences

Table 6 offers an overview of all ANOVA effects. To answer the research question of how stakeholder groups differ in their perception, the following results focus on the ANOVA effects related to group differences. Before adjusting for multiple comparisons, the analyses indicated group differences in performance ratings for *Institutional & Governance Factors* (IG; $F(2,87) = 4.39$, $p = .015$, $\eta^2p = .09$) and *Individual-Psychological Factors* (IP; $F(2,87) = 3.20$, $p = .045$, $\eta^2p = .07$) Additionally, a significant group x subcategory interaction effect was observed for performance of I*nstitutional & Governance Factors* (IG; $F(5.11,222.08) = 2.34$, $p = .042$, $\eta^2p = .05$). Finally, the

ANOVA on the importance-performance gap yielded a main effect of group for the category *Communication Design* (CD; $F(2,87) = 4.00$, $p = .022$, $\eta^2p = .08$). However, these effects did not remain statistically significant after correcting for multiple comparisons, with adjusted p-values of .091, .136, .153 and .130, respectively. Thus, these results are interpreted as exploratory trends rather than confirmatory evidence. Closer inspection of these trends for the category *Institutional & Governance Factors* (IG) suggested a higher performance perception in policy actors than in experts and community stakeholders for the subcategories Communication Continuity (IG.4; compared to experts: $t(87) = 2.81$, $p(adj) = .012$; compared to community: $t(87) = 3.07$, $p(adj) = .009$) and Inter-Institutional Coordination (IG.3; compared to experts: $t(87) = 2.78$, $p(adj) = .013$; compared to community: $t(87) = 3.45$, $p(adj) = .003$; see Figure 4 for a visualisation of this interaction effect). Additionally, exploratory follow-up comparisons suggested that policy actors reported higher perceived performance than experts across the category *Individual-Psychological Factors* (IP; $t(87) = 2.50$, $p(adj) = .042$) and that policy actors reported a smaller importance-performance gap than community stakeholders across the category *Communication Design* (CD; $t(87) = -2.83$, $p(adj) = .018$).

[Figure 4 about here]

Table 6: Results of the mixed-design ANOVAs conducted to identify stakeholder group differences in importance and performance ratings, as well as the importance-performance gap. Tests were conducted two-sided with an alpha level of .05. Bold p-values indicate significant effects.

		Main effect group				**Main effect subcategory**				**Interaction group X subcategory**			
Category		**F**	**η²p**	**p**	**p(adj)**	**F**	**η²p**	**p**	**p(adj)**	**F**	**η²p**	**p**	**p(adj)**
Dependent variable: importance													
CD	Communication Design	1.45	0.03	0.240	0.479	1.29	0.02	0.277	0.277	1.81	0.04	0.099	0.295
SCR	Sender Credibility	0.49	0.01	0.616	0.616	12.78	0.13	**0.000**	**0.000**	1.30	0.03	0.271	0.325
IP	Individual-Psychological Factors	2.43	0.05	0.094	0.282	2.77	0.03	0.069	0.083	0.80	0.02	0.520	0.520
KL	Knowledge & Learning	1.11	0.03	0.333	0.481	20.26	0.19	**0.000**	**0.000**	1.98	0.04	0.107	0.295
SC	Socio-Cultural & Contextual Elements	2.56	0.06	0.083	0.282	9.10	0.10	**0.000**	**0.000**	1.60	0.04	0.177	0.295
IG	Institutional and Governance Factors	0.92	0.02	0.401	0.481	7.46	0.08	**0.000**	**0.000**	1.46	0.03	0.197	0.295
Dependent variable: performance													
CD	Communication Design	2.11	0.05	0.128	0.255	4.39	0.05	**0.007**	**0.009**	1.14	0.03	0.338	0.677
SCR	Sender Credibility	1.15	0.03	0.320	0.384	19.46	0.18	**0.000**	**0.000**	0.29	0.01	0.879	0.889
IP	Individual-Psychological Factors	3.20	0.07	**0.045**	0.136	27.01	0.24	**0.000**	**0.000**	2.41	0.05	0.051	0.153
KL	Knowledge & Learning	0.80	0.02	0.454	0.454	2.17	0.02	0.120	0.120	0.27	0.01	0.889	0.889
SC	Socio-Cultural & Contextual Elements	1.46	0.03	0.238	0.358	13.94	0.14	**0.000**	**0.000**	0.52	0.01	0.715	0.889
IG	Institutional and Governance Factors	4.39	0.09	**0.015**	0.091	13.80	0.14	**0.000**	**0.000**	2.34	0.05	**0.042**	0.153
Dependent variable: importance-performance gap													

CD	Communication Design	4.00	0.08	**0.022**	0.130	1.08	0.01	0.355	0.710	1.73	0.04	0.123	0.305
SCR	Sender Credibility	0.59	0.01	0.556	0.668	0.06	0.00	0.927	0.927	1.23	0.03	0.300	0.450
IP	Individual-Psychological Factors	0.30	0.01	0.740	0.740	5.74	0.06	**0.004**	**0.012**	0.46	0.01	0.762	0.762
KL	Knowledge & Learning	2.66	0.06	0.076	0.227	21.25	0.20	**0.000**	**0.000**	1.71	0.04	0.152	0.305
SC	Socio-Cultural & Contextual Elements	1.56	0.04	0.216	0.431	0.20	0.00	0.814	0.927	0.50	0.01	0.731	0.762
IG	Institutional and Governance Factors	1.09	0.02	0.341	0.511	0.62	0.01	0.585	0.877	1.76	0.04	0.117	0.305

Note: η^2p = partial eta squared. p(adj) = Benjamini-Hochberg-adjusted p-value

APA lens: phase and temporal orientation

The relative frequencies with which subcategories were assigned to the APA phases and temporal orientation are reported in Table 7. The results indicated that most participants perceived all subcategories as relevant for all APA phases. Regarding temporal orientation, most participants assigned all but one subcategory as long- and short-term oriented, except for Disengagement & Avoidance (IP.3), which was assigned to long-term by the majority.

Table 7: APA phase and temporal orientation: Relative frequency (%) of responses assigning APA phase and temporal orientation in the whole sample (n = 90). Bold values indicate the modal value for this subcategory.

Subcategory		Phase					Temporal orientation		
		Aware	**Prepare**	**Act**	**All**	**None**	**Short-term**	**Long-term**	**Both**
Communication Design									
CD.1	Language & Style	23.3	7.8	5.6	**61.1**	2.2	30.0	18.9	**51.1**
CD.2	Format & Visualisation	27.8	16.7	6.7	**45.6**	3.3	16.7	40.0	**43.3**
CD.3	Content & Action Orientation	6.7	14.4	35.6	**40.0**	3.3	34.4	20.0	**45.6**
CD.4	Dialogue & Channel Strategy	12.2	7.8	18.9	**58.9**	2.2	33.3	15.6	**51.1**
Sender Credibility									
SCR.1	Source Attributes	16.7	4.4	6.7	**68.9**	3.3	8.9	20.0	**71.1**
SCR.2	Relational Trust	12.2	7.8	14.4	**61.1**	4.4	17.8	21.1	**61.1**
SCR.3	Communication Stance	17.8	12.2	3.3	**51.1**	15.6	5.6	38.9	**55.6**
Individual-Psychological Factors									
IP.1	Risk Perception & Cognitive Appraisal	24.4	8.9	14.4	**46.7**	5.6	25.6	23.3	**51.1**
IP.2	Motivation & Volition	11.1	16.7	25.6	**41.1**	5.6	14.4	42.2	**43.3**
IP.3	Disengagement & Avoidance	27.8	12.2	14.4	**35.6**	10.0	21.1	**44.4**	34.4
Knowledge & Learning									

KL.1	Domain Knowledge	25.6	4.4	5.6	**61.1**	3.3	7.8	34.4	**57.8**
KL.2	Experiential Knowledge	14.4	13.3	6.7	**60.0**	5.6	10.0	28.9	**61.1**
KL.3	Transfer Competence	15.6	10.0	3.3	**68.9**	2.2	5.6	31.1	**63.3**
Socio-Cultural & Contextual Elements									
SC.1	Cultural & Normative Context	20.0	11.1	4.4	**48.9**	15.6	8.9	34.4	**56.7**
SC.2	Demographic & Socio-Economic Context	18.9	10.0	7.8	**51.1**	12.2	3.3	41.1	**55.6**
SC.3	Situational & Information Environment	21.1	7.8	7.8	**58.9**	4.4	18.9	23.3	**57.8**
Institutional & Governance Factors									
IG.1	Resources & Capacity	5.6	12.2	15.6	**58.9**	7.8	16.7	18.9	**64.4**
IG.2	Political & Regulatory Framework	5.6	6.7	10.0	**64.4**	13.3	6.7	30.0	**63.3**
IG.3	Inter-Institutional Coordination	4.4	4.4	22.2	**61.1**	7.8	23.3	12.2	**64.4**
IG.4	Communication Continuity	17.8	12.2	6.7	**50.0**	13.3	4.4	46.7	**48.9**

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4. Discussion

This study examined which factors shape climate risk and adaptation communication in Alpine multi-hazard contexts, how stakeholder groups evaluate these factors, and how functions are positioned within the APA lens.

4.1 Communication factors influencing alpine RCC

In response to RQ1, the study identified a comprehensive taxonomy of communication-relevant factors spanning six thematic clusters and twenty subcategories. The results suggest that effective climate RCC extends beyond message design and early warning functionality. Communication effectiveness is also shaped by trust, psychological readiness, socio-economic conditions, institutional coordination, and long-term learning processes. This finding supports previous arguments that disaster communication should be understood as a systemic governance process rather than a purely informational intervention (Renn et al. 2011; Hansson et al. 2020).

4.2 First exploratory signals on stakeholder differences

Regarding RQ2, the findings indicate both convergence and divergence between stakeholder groups. Variation in priorities between experts, policy actors, and community stakeholders provides exploratory evidence for stakeholder-specific rationalities in climate RCC. Community respondents tended to place greater emphasis on action-oriented communication, dialogue, and trust-related dimensions, while institutional actors prioritised coordination and governance structures. These findings align with prior critiques of top-down warning systems and indicate that communication strategies that insufficiently integrate community perspectives risk reproducing communication-related vulnerability.

Contrary to traditional expectations of stakeholder divergence (Höppner et al. 2010; Baudoin et al. 2016; Scolobig et al. 2017; Mehta et al. 2022), mixed-design ANOVAs detected no significant between-group differences in importance ratings. This cross-stakeholder convergence specifies prior research (Scolobig et al. 2017; Mehta et al. 2022) by suggesting that stakeholder differences manifest at the level of concrete action and responsibility allocation rather than in the conceptual recognition of which factor categories are influential. This observation is consistent with the broader shift from deficit-model thinking towards a recognition of distinct but structurally comparable rationalities (Höppner et al. 2010; Renn et al. 2011; Carlton and Jacobson 2016).

On the performance dimension, policy actors descriptively reported higher perceived performance and narrower gaps than experts and community members. Although this trend did not reach significance after Benjamini–Hochberg correction due to limited statistical power (n = 19 policy actors), it provides an exploratory signal of organisationally specific perception patterns.

If the pattern stabilises in further research, the implication would be substantive rather than methodological: actors mandated to design, operate, and evaluate inter-institutional coordination and communication continuity would, on this reading, perceive these systems differently from the stakeholders these systems are designed to serve. That is a question about the inclusiveness of evaluation processes in RCC governance, a question with direct implications for the equity dimension of SDG 10, taken up in Section 4.4. Alpine RCC is not a linear top-down process but the result of a multi-level arrangement spanning national meteorological services, federal and regional warning centres, district and municipal authorities, and emergency response organisations. Each organisation operates according to its own area of responsibility, evaluative logic and communicative culture. Quality is typically assessed against internal process indicators rather than community-level outcomes, and no evaluative instance systematically captures communicative quality across levels. The perceived performance divergence between policy actors and community stakeholders appears structurally embedded in this governance architecture; thus, it reflects a vertical evaluation gap rather than individual bias. Alternatively, these initial exploratory signals may be attributable to cognitive perceptual biases. In particular, the availability heuristic (Kahneman and Tversky 1973) of the exchange between the stakeholder groups to date. This points to a structural deficiency in two-way communication: Cashore et al. (2019) show that perceptual biases in stakeholder dialogue can only be systematically addressed if biases in problem framing are made explicit and deliberatively negotiated; otherwise, the exchange remains at the level of divergent descriptions of symptoms rather than advancing toward shared problem frames and innovative solutions.

In RQ3, the respondent assignment of factors across the APA dimensions suggests that communicative functions are not perceived as temporally isolated. Preliminary patterns indicate overlap between short-term warning and long-term adaptation needs, supporting the argument that preparedness and response communication draw on structurally similar mechanisms. Rather than functioning as separate domains, warning and adaptation communication appear to form an interconnected continuum. This provides exploratory empirical support for the APA-lens as an integrative analytical heuristic.

4.3 APA functions and temporal orientation

Across all twenty subcategories, respondents selected 'equally for all three goals' as APA phase; across nineteen, 'both equally' as temporal orientation. Two methodological qualifications apply (Graf et al. 2026a). First, the factor set in Study 1 was derived under an APA-structured workshop protocol, framing the assignment as a consistency rather than a spontaneous emergence test. Second, the explicit wording of the integrative options ('both equally'; 'equally for all three goals') makes a generalised safe-response reading across all items implausible. With these qualifications in mind, the integrative response pattern indicates that practitioners and community members do not apply the phase-discriminatory logic that institutional structures impose – separating meteorological warnings, civil protection, and long-term adaptation – even though the underlying communication factors operate beyond these institutional silos.

The findings have two implications that, in this reading, extend beyond the APA-lens itself. First, they provide empirical support for the position that RCC is a continuous function across the risk governance cycle rather than a phase-bound activity, a position Renn et al. (2011) advance theoretically by treating communication as "a constant companion to all phases of the risk governance cycle rather than a separate stage", and which the present data corroborate from the perspective of practitioners and community members. Second, if integrative perception is the practitioner's default, then research designs that examine warning and adaptation communication as separate domains may systematically miss the structural overlap that the present findings make visible. The APA-lens, in this reading, functions less as a phase-discriminatory diagnostic instrument and more as an integrative grammar that makes the hybrid character of climate risk and adaptation communication analytically visible (Graf et al. 2026a), a corrective to readings that treat APA primarily as a classification scheme.

They further demonstrate that disaster preparedness requires more than technical warning systems(Scolobig et al. 2015; Hansson et al. 2020; Scolobig et al. 2022). In this regard, the study contributes to SDG 10 by highlighting communication-related vulnerability as an overlooked dimension of disaster inequality. Rural Alpine populations are heterogeneous, and factors such as socio-economic conditions, demographic differences, communication literacy, and institutional access shape preparedness unevenly (Wachinger et al. 2013; Maidl et al. 2021).

The study demonstrates that effective climate action in Alpine multi-hazard governance requires integrating immediate hazard-warning communication with long-term adaptation messaging, treating equity and adaptive-capacity concerns under SDGs 10 and 13 as operationally interlinked rather than separate normative aims.

4.4 Empirically validated taxonomy of influence factors

The convergence of importance ratings across stakeholder groups indicates that these factors are not contested among experts, policy actors, and community stakeholders. The implementation gap reported in Study 2 runs counter to this evaluative agreement. In the Alpine multi-hazard context, the salient research question is therefore no longer the identification of further relevant factors, but the conditions under which an evaluatively shared factor set fails to translate into perceived implementation quality.

Existing component frameworks, while analytically robust at the message level (Fathollahzadeh et al. 2023) and the communication-related vulnerability level (Hansson et al. 2020), do not address the institutional and socio-cultural conditions that shape the implementation of RCC strategies in multi-level governance contexts. The two additional clusters: Institutional and Governance Factors (IG) and Socio-Cultural and Contextual Factors (SC), close this gap. That both clusters receive importance ratings above the midpoint across stakeholder groups suggests, in this reading, that institutional and socio-cultural conditions are not a context surrounding RCC, but a co-

constitutive part of how RCC functions in multi-level governance settings. This reading aligns RCC analytically with system-oriented rather than message-oriented framings (Renn et al. 2011).

The cross-source merging procedure (139 → 111 items) further indicates substantial conceptual overlap between practitioner and research categories, suggesting that the divide between academic and practice-based RCC knowledge may be smaller than disciplinary boundaries suggest. The structurally consequential finding of the IPA analysis is that no subcategory escapes the gap. A perceived implementation deficit running through all clusters, from message design and sender credibility through individual psychology and knowledge to socio-cultural and institutional conditions, is not consistent with a factor-specific gap. It is consistent with a systemic implementation deficit cutting across the entire architecture of climate risk and adaptation communication in the Alpine context.

Taken together, the validated taxonomy and the systemic implementation gap, in this reading, re-frame the policy question for climate risk and adaptation communication in multi-hazard governance: not as a question of identifying the right factors, but as a question of why an evaluatively shared knowledge base does not translate into perceived implementation quality. Identifying this question, rather than answering it, is what the present study contributes; this re-framing stands independently of the more exploratory signals discussed in Sections 4.2 and 4.3.

4.5 Implications for SDG 10 and SDG 13 in disaster preparedness policy

The cross-stakeholder convergence on the importance provides an equity-relevant empirical baseline in line with SDG 10 Target 10.2, which calls for the social, economic and political inclusion of all (United Nations, 2015). Communication-related vulnerability, in the heuristic developed by Hansson et al. (2020), is reproduced when communication systems fail to recognise the conditions and capacities of affected populations. The convergent recognition of the factor categories across experts, policy actors, and community stakeholders – the latter deliberately oversampled in the present study to address SDG 10 considerations – indicates that the equity problem lies not in disagreement over *what* matters in climate risk and adaptation communication. The factor set itself is recognised across stakeholder positions; the equity problem lies elsewhere, in implementation, access, and the inclusiveness of governance processes.

This implementation deficit operationalises what SDG 13 addresses through Target 13.1 and 13.3 (United Nations, 2015), and the Sendai Framework (Priorities 1 & 4, UNDRR, 2015), which positions awareness-raising and early warning as core capacities for climate adaptation. The two "concentrate here" factors (CD.2, KL.3), and the three largest importance–performance gaps (IP.3, KL.3, CD.2) identify concrete leverage points where targeted resource allocation would yield the most immediate policy impact.

The first exploratory signal on the performance dimension extends the SDG 10 equity argument to a further layer. If, as the present data tentatively indicate, actors mandated to design, operate, and evaluate inter-institutional coordination and communication continuity perceive these systems differently from the stakeholders these systems are designed to serve, then the inclusiveness of evaluation processes themselves becomes an SDG 10 Target 10.2 question – extending the inclusion principle from communication content to communication governance. This reading would be consistent with people-centred disaster risk reduction principles, which call for the systematic inclusion of affected populations in the evaluation of warning and adaptation systems (UNDRR 2015; Scolobig et al. 2022). The present study can identify the structural pattern; a larger, better-balanced sample would be required to test whether the observed divergence in evaluations between policy actors and community stakeholders is systematic.

Several practical implications emerge. First, communication strategies should prioritise participatory and dialogue-based formats rather than one-directional information transfer. Second, governance actors should address persistent implementation gaps, particularly in areas rated as highly important but insufficiently realised. Third, future preparedness policies should integrate short-term warning and long-term adaptation communication more systematically, particularly in climate-sensitive mountain regions.

4.6 Alpine Multi-Level Governance

The Alpine region is characterised by a multi-layered governance architecture encompassing supranational frameworks, including the Alpine Convention (1991) and the EU Strategy for the Alpine Region (EUSALP), as well as national legislation, which, as in the Austrian context, is then translated into various communication formats through a federal system. One of the overarching objectives across these regulatory frameworks is fostering cross-level collaboration and the systematic use of synergies, an objective that is inherently communicative in nature and requires socially and culturally appropriate dialogue. Historically developed institutional identities and organisational structures hinder communication even when there is normative consensus at the supranational level. The fragmentation of risk communication in the Alpine region is not primarily due to a regulatory gap, but rather to a cultural and organisational one. This is shown by the persistence of fragmented risk communication practices across the Alpine region. Years of efforts to harmonise these practices, as seen in the European Avalanche Warning System (EAWS), also serve as evidence of fragmentation stemming from path-dependent organisational cultures. This is why the Institutional & Governance Cluster is important. The identification of a sociocultural cluster in this taxonomy is consistent with the regulatory shift toward participatory disaster risk reduction.

5. Limitations

The findings should be interpreted with several boundaries in mind. First, subgroup comparisons should be interpreted cautiously due to unequal stakeholder representation, particularly among policy actors (n = 19 of 90 total). The present study was designed as an exploratory diagnostic assessment rather than a confirmatory population model. Consequently, statistically non-significant subgroup differences may still indicate substantively meaningful trends (reduction of in sensitivity, Bonferroni–Holm correction) relevant for practice and future research.

Second, the cross-sectional design captures perceived implementation gaps at a specific point in time. Communication needs and preparedness capacities are likely to evolve under changing hazard regimes and repeated exposure to crises. Communication fatigue dynamics cannot be observed in a single measurement occasion. The study, therefore, provides an empirical baseline for the longitudinal assessment of how communication priorities shift over time and across events.

Third, the APA assignment procedure captures stakeholder perceptions of communicative function rather than objective communication effects. The operationalisation of Aware–Prepare–Act as measurable constructs – beyond perceptual assignment – remains an open research task. While this limits causal interpretation, it offers an important practitioner-oriented insight into how different actors conceptually organise warning and adaptation communication in applied settings.

Fourth, consistently high importance ratings across subcategories indicate broad recognition of climate RCC as a critical governance function. The use of a data-centred IPA partially mitigates the reduction in variance and allows differentiation in perceived implementation quality, thereby retaining practical diagnostic value.

Fifth, the regional focus on rural Alpine areas in Austria and Bavaria reflects a deliberate contextual choice given the climate sensitivity and multi-hazard exposure of these settings. Future comparative studies could examine transferability to other Alpine and non-Alpine hazard environments, particularly regions facing accelerating climate adaptation pressures.

Sixth, the moderate subcategory-level inter-rater reliability (Fleiss' kappa = 0.504; substantial at the cluster level, kappa = 0.643) reflects the conceptual demand for twentyfold differentiation. The findings at the subcategory level are robust, but the interpretive boundaries between adjacent subcategories within 'Communication Design' should be considered.

Finally, while the study structurally integrates dimensions relevant to SDG 10 through demographic, socio-economic, and resource-related factors, the sample size (a cross-sectional community sample of n = 51) does not yet permit systematic intersectional analysis across dimensions such as age, disability, migration background, or socio-economic vulnerability. This represents an important avenue for future disaster preparedness research, particularly as climate-related hazards increasingly intersect with existing social inequalities. Replication in other Alpine regions and in comparable multi-hazard settings – including hazards beyond the climate-related domain, such as technological or compound risks – would test the taxonomy's transferability. Beyond the research domain, the validated factor set offers a practical reference for the reflective evaluation of existing communication strategies: emergency plans, warning protocols, and adaptation communication programmes can be examined against the taxonomy to identify whether central influence factors are systematically addressed, and where implementation falls short.

Taken together, these boundaries do not diminish the study's contribution. Rather, they position it as an empirically grounded foundation for developing more inclusive, climate-sensitive, and stakeholder-responsive disaster communication strategies in line with SDG 10 and SDG 13.

6. Outlook & Conclusion

This study provides one of the first empirically grounded assessments of climate risk and adaptation communication in Alpine multi-hazard settings through a stakeholder-sensitive lens, aiming to identify and validate the factors that shape effective climate risk and adaptation communication strategies in Alpine multi-hazard contexts. By integrating practitioner knowledge, literature-based evidence, and stakeholder evaluation, it developed

a validated taxonomy of communication factors and identified systematic implementation gaps across the communicative system.

Study 1, a taxonomy of six clusters and twenty subcategories, generated from two practitioner workshops and a literature scan drawn from a global scoping review, and supported by importance ratings above the scale midpoint across all subcategories and all three stakeholder groups, provides a starting framework for cross-context comparison rather than a region-specific instrument.

Study 2, designed as a first exploratory application of the validated factor set in a quantitative survey context, complements this taxonomic contribution in three ways: 1) a consistent implementation gap across the entire taxonomy, with the most pronounced gaps in cognitive (IP.3), competence-related (KL.3), and design-related (CD.2) dimensions; 2) empirical support for the holistic conception of the APA-lens, repositioning it as an integrative grammar for hybrid warning–adaptation communication rather than as a phase-discriminatory diagnostic; 3) a first exploratory signal that policy actors may perceive the performance of governance-related and individual-psychological communication functions differently from experts and community stakeholders. This signal did not reach statistical significance after correction and is, in the present sample, hypothesis-generating rather than confirmatory.

The results demonstrate that effective disaster preparedness depends not only on the quality of warning systems but also on trust, institutional coordination, communicative continuity, and equitable access to preparedness capacities. The present findings indicate that such reflective evaluation is warranted across the entire taxonomy, not only for selected dimensions. While stakeholder groups broadly recognise the importance of RCC, differences in priorities suggest that one-size-fits-all communication approaches are insufficient.

In practical terms, the study argues for a shift from fragmented, reactive communication models to integrated, participatory, and climate-sensitive preparedness strategies. Dialogue resources and communication monitoring require dedicated budget allocations equivalent to those established for warning drafting.

Vertical and horizontal communication appear to be in place. However, the differing perceptions among stakeholders regarding performance point to the absence of a cross-level quality assessment, which suggests differences among stakeholders in their perceptions of performance point to the absence of a cross-level quality assessment, suggesting a lack of shared responsibility for communication rather than a failure of communication coordination per se.

Such approaches are increasingly necessary as climate change intensifies hazard exposure everywhere, particularly in Alpine regions. By empirically linking disaster preparedness, communication inequality, and adaptation governance, the study contributes directly to the implementation of SDG 10 and SDG 13. Future research should build on these exploratory findings through larger comparative samples and longitudinal assessment of how communication strategies shape preparedness and adaptive behaviour over time.

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Endnotes

[1] The APA structure organised both workshops and the literature scan, but did not pre-determine cluster formation in Stage 2, which proceeded inductively from the substantive content of the factors. Therefore, the APA-lens as methodology will be described in study 2.

[2] Ethical considerations. Workshop participation was voluntary. Workshop 1 participants provided written informed consent via the attendance list, which explicitly stated the research purpose and the analytical use of the discussion content. Workshop 2 participants provided documented oral consent at the start of the online session, including consent for audio recording and for the use of anonymised content. All workshop materials were pseudonymised prior to analysis. The full institutional data protection framework, including DPO certification (reference 75/26, 16 April 2026), is reported in the Ethical Approval section.

[3] The online repository for this study is available at https://osf.io/2xtek/overview?view_only=55527015017c4cb9b1205aec1743ed9a. During peer review, access is provided via this anonymised view-only link. The repository will be released publicly under a persistent identifier (DOI) upon acceptance.

[4] Operational definitions are abbreviated; the complete codebook with primary and secondary theoretical anchors, inclusion/exclusion criteria, and boundary case rules is provided in Supplementary Material S1.

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Figure legends

Figure 1. Sequential mixed-methods design. Study 1 identifies influence factors on climate risk and adaptation communication through two practitioner workshops and a targeted literature scan and categorises them into a taxonomy of six clusters and 20 subcategories via directed content analysis with three independent raters. Study 2 evaluates these factors across three stakeholder groups in an online IPA survey with respondent-assignment to APA (Stage 3), with divergence analysis across groups, phases, and temporal horizons.

Figure 2. Taxonomy of influence factors on climate risk and adaptation communication in Alpine multi-hazard contexts. Treemap visualisation of N = 111 factors across six thematic clusters (colour-coded) and twenty subcategories (rectangle area proportional to item count). Subcategory codes and operational definitions are provided in Table 1; subcategory-level distribution. Operational definitions are abbreviated; full definitions, including inclusion/exclusion criteria and theoretical anchors, are provided online (see S1_Supplementary_CodingBook[3]).

Figure 3. Importance–performance matrix of the 20 subcategories identified in Study 1 (data-centred crosshair based on grand means of importance and performance across all subcategories; Subcategories are colour-coded by thematic cluster. Quadrants represent relative diagnostic priority: Concentrate Here (higher relative importance, lower relative performance); Keep Up the Good Work (higher relative importance and performance); Low Priority (lower relative importance and performance); Possible Overinvestment (lower relative importance, higher relative performance). Full operational definitions are provided in Table 1.
*[Abbreviations **CD**: CD.1 = Language & Style; CD.2 = Format & Visualisation; CD.3 = Content & Action Orientation; CD.4 = Dialogue & Channel Strategy. **SCR:** SCR.1 = Sender Attributes (perceived); SCR.2 = Sender–Receiver Trust Relationship; SCR.3 = Communicative Disposition. **IP:** IP.1 = Risk Perception & Appraisal; IP.2 = Motivation & Action Readiness; IP.3 = Disengagement & Avoidance. **KL**: KL.1 = Domain Knowledge of Risk; KL.2 = Experiential Knowledge; KL.3 = Communication & Transfer Competence. **SC:** SC.1 = Cultural & Normative Context; SC.2 = Demographic & Socio-economic Context; SC.3 = Information Environment & Media Context. **IG:** IG.1 = Resources & Capacities; IG.2 = Political & Regulatory Framework; IG.3 = Inter-institutional Coordination; IG.4 = Communication Continuity & Process Quality.]*

Figure 4. Mean ratings and standard errors for the cluster *Institutional & Governance Factors* by stakeholder group (scientific experts, *n* = 20; policy actors, *n* = 19; community stakeholders, *n* = 51). Subcategories: IG.1 = Resources & Capacities; IG.2 = Political & Regulatory Framework; IG.3 = Inter-institutional Coordination; IG.4 = Communication Continuity & Process Quality. Ratings on five-point Likert scales (1 = not important at all / not implemented at all; 5 = very important / implemented very well). The figure visualises the exploratory between-group trend reported in Section 3.2 (mixed-design ANOVA: significant before but not after Benjamini–Hochberg correction); the pattern is interpreted as hypothesis-generating rather than confirmatory.

Data availability

All data and materials supporting the findings of this study, including the anonymised survey dataset, analysis scripts, coding documentation, manuscript figures, and the Supplementary Information, are deposited on the Open Science Framework. During peer review, access is provided via an anonymised, view-only link (https://osf.io/2xtek/overview?view_only=55527015017c4cb9b1205aec1743ed9a), also provided in the submission system. The repository will be released publicly under a persistent identifier (DOI) upon acceptance.

Author contributions (CRediT)

Author 1: Conceptualisation; Methodology; Validation; Formal analysis (Study 1); Investigation; Resources; Data curation; Writing – original draft; Writing – review & editing; Visualisation; Project administration; Author 2: Conceptualisation; Methodology (research question refinement); Formal analysis (Study 2); Data curation; Writing – original draft (Study 2 chapter; Sections 3); Writing – review & editing; Visualisation. Author 3: Conceptualisation; Methodology; Validation; Investigation; Resources; Writing – original draft (Sections 4, 6); Writing – review & editing; Supervision; Funding acquisition; Author 4: Conceptualisation; Validation; Writing – original draft (Sections 4, 6); Writing – review & editing.

Competing interests The authors declare no competing interests.

Ethics Declaration

The empirical research conducted for this study complies with the ethical principles set out in the Declaration of Helsinki (1975, as revised in 2013), the European General Data Protection Regulation (GDPR; EU 2016/679), and the Austrian Data Protection Act (DSG 2018)[5]. At the University of Leoben, formal Institutional Review Board approval is not mandated for non-medical social-scientific research; data protection compliance for empirical studies in this domain is reviewed and certified by the institution's officially designated and legally responsible Data Protection Officer (DPO). The research design, data collection methodology, and data processing protocols of the present study were reviewed and certified by the DPO of the University of Leoben, Dr Daniel Stanonik LL.M., on 16 April 2026 (institutional reference 75/26). Participation in both the practitioner workshops and the survey was strictly voluntary; all participants received comprehensive information regarding the purpose, duration, and scope of data processing prior to data collection and documented informed consent. In accordance with Articles 5(1)(c), 6(1)(a), 9(2)(a), 15–22, and 89 of the GDPR, all collected data were anonymised or pseudonymised to ensure the confidentiality of the participants. The DPO certification may be obtained upon request.

Use of generative AI

During the preparation of this manuscript, the authors used the following AI-assisted technologies: DeepL (DeepL SE) and Anthropic Claude (Opus 4.7) for language refinement, and as a sparring partner for methodological structuring and argumentation development; Grammarly (Grammarly Inc.) for grammar and style checking; and AI-assisted academic search tools for literature retrieval support. All AI-supported outputs were reviewed, edited and verified by the authors. All calculations, coding assignments, statistical analyses, and interpretive decisions were carried out by the human research team after critical review of AI-generated suggestions. No generative AI was used to create or modify images or figures in this manuscript.

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Figures

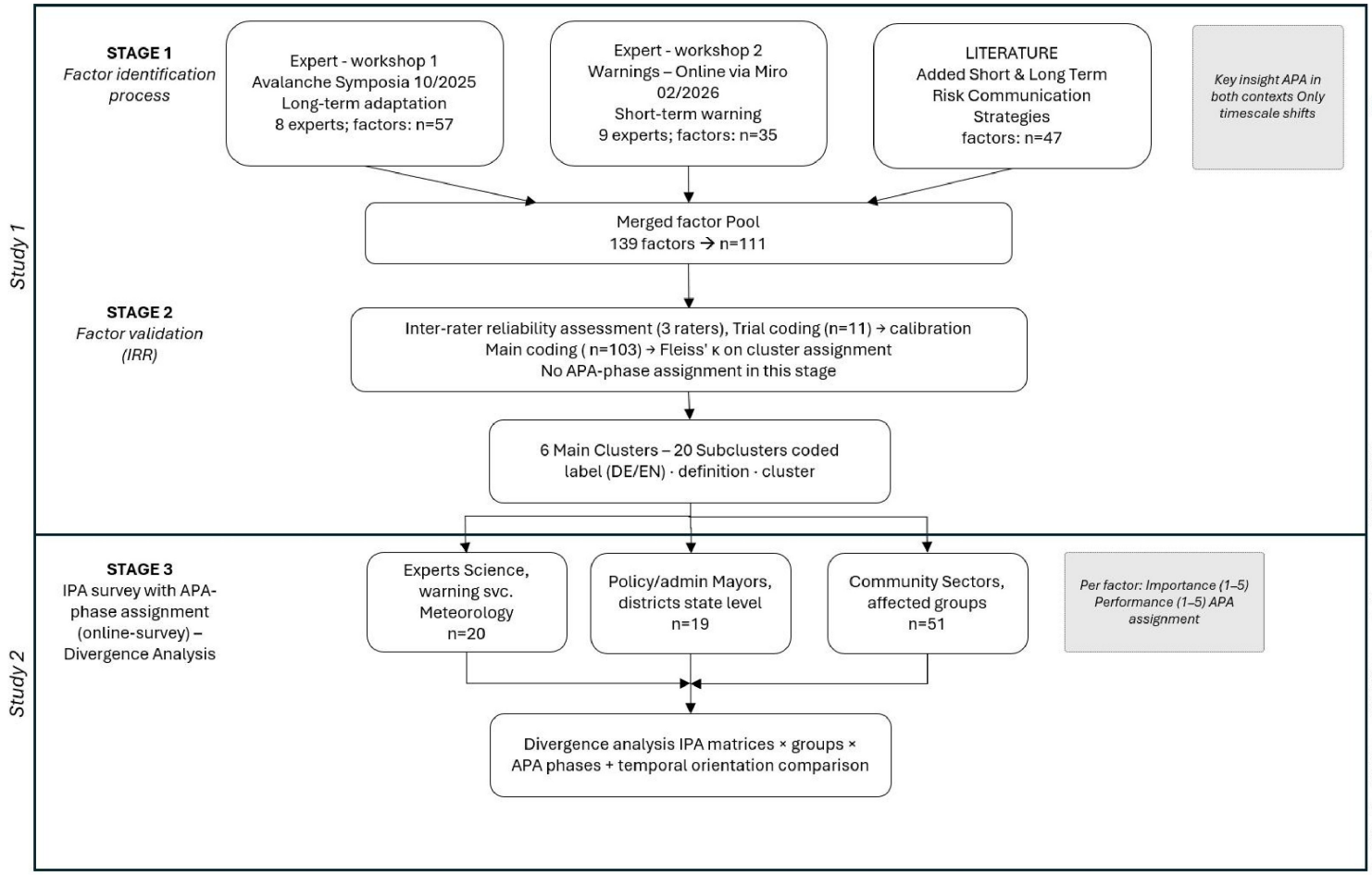


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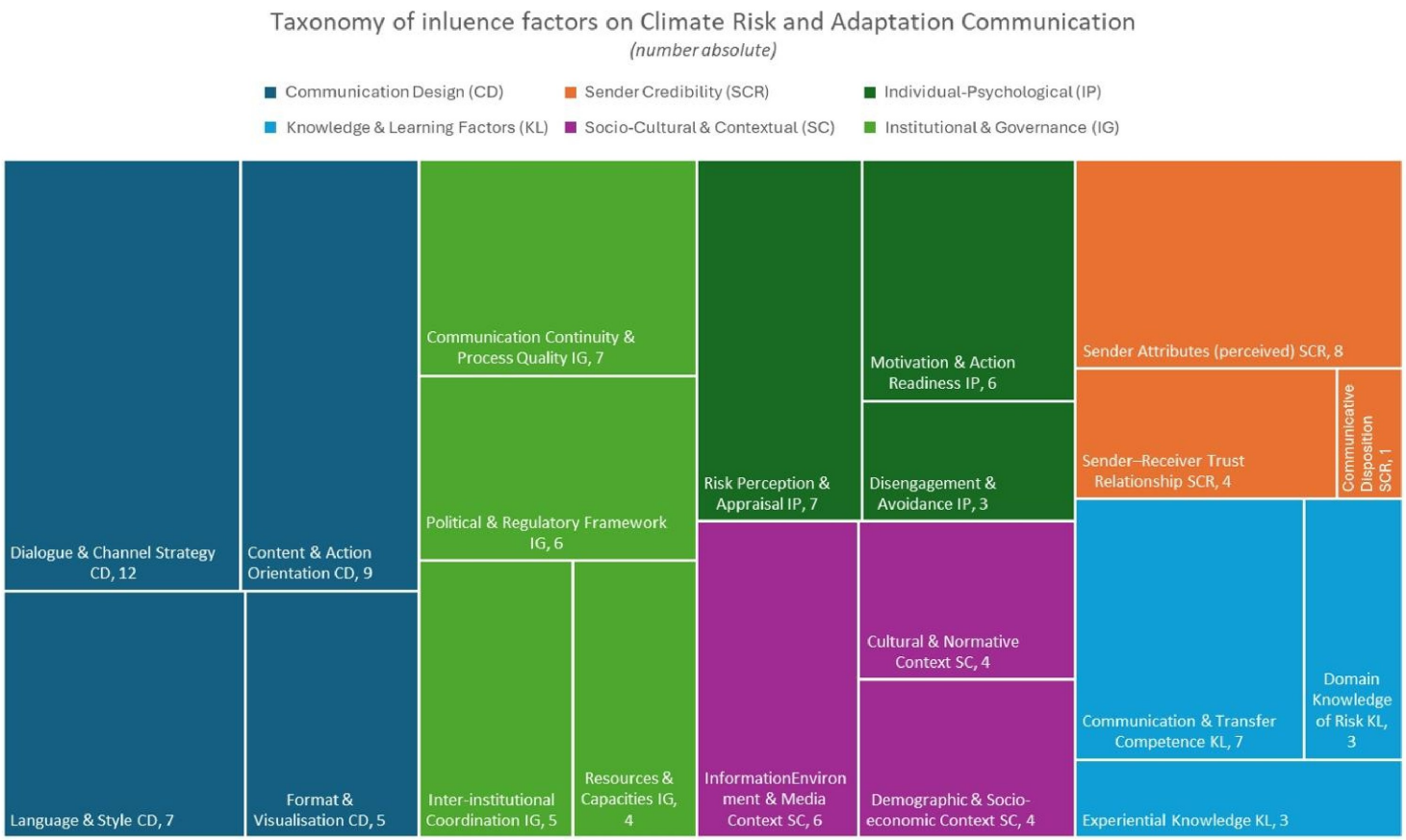


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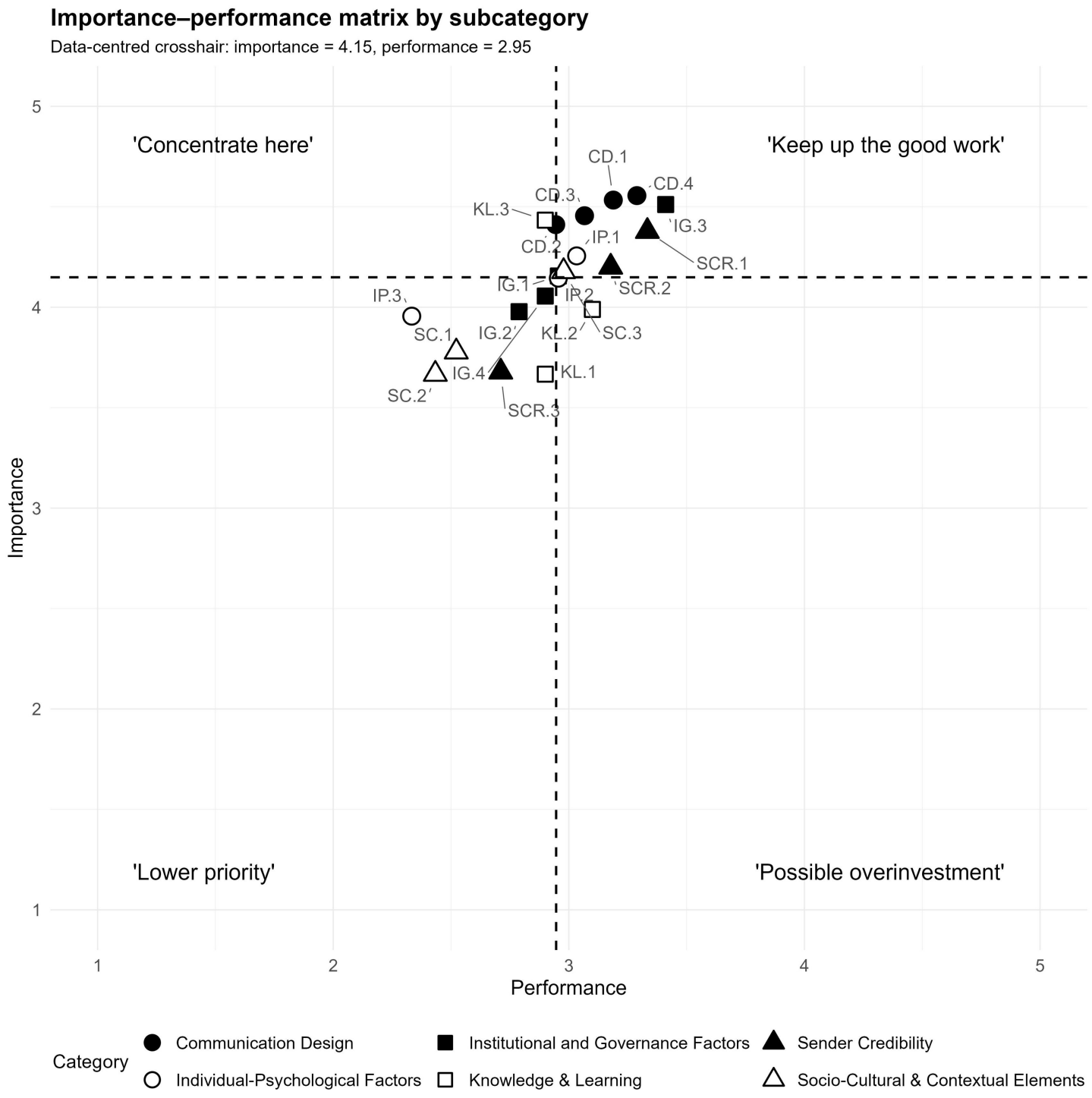


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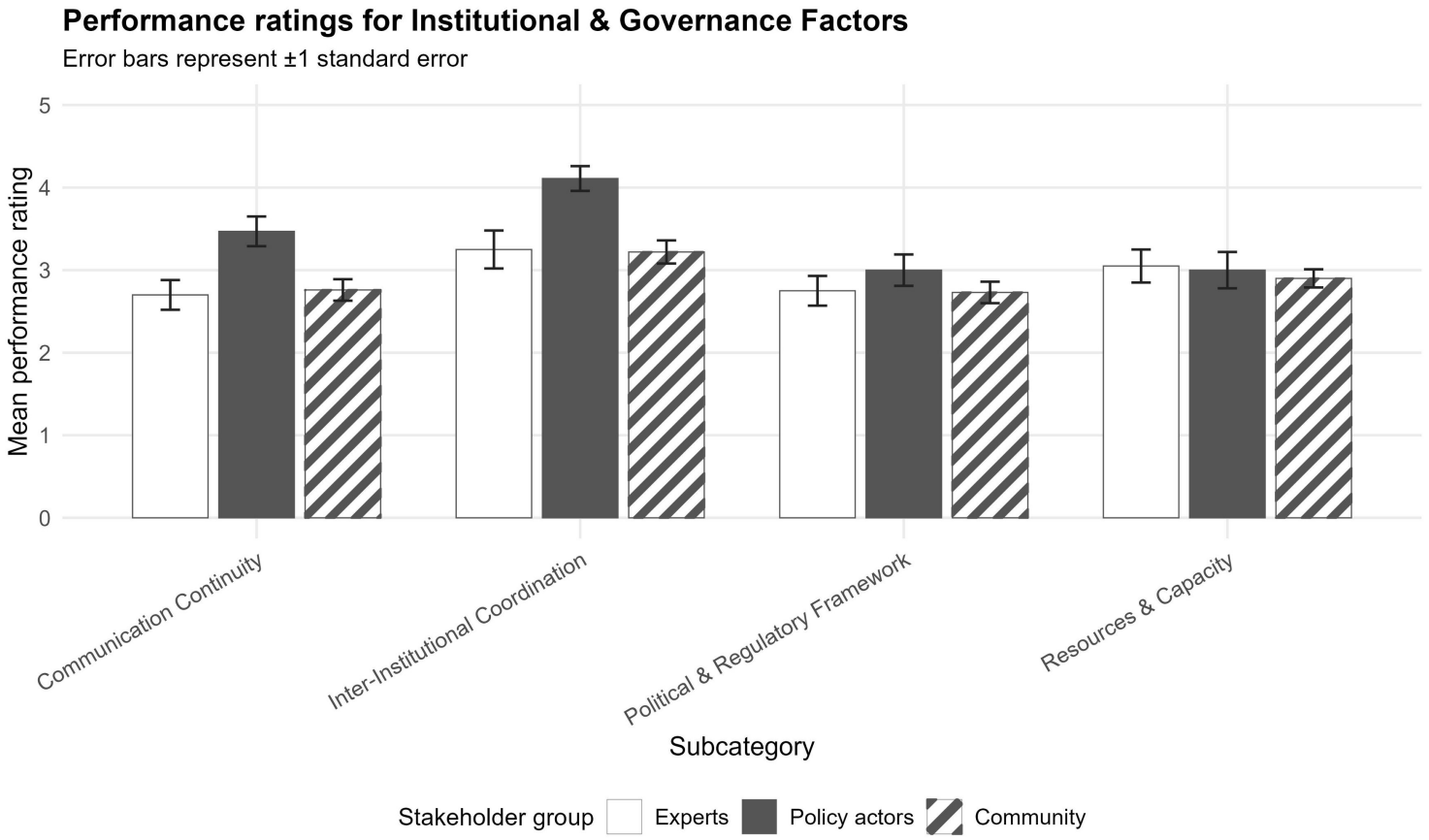


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