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**Title:** Expert agreement on key elements of transformational adaptation to climate risks

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**Abstract:**

**Transformational adaptation (TA) to climate risks has gained broad interest. While existing case studies and frameworks discuss key dimensions and elements that constitute TA to distinguish it from 'business as usual' or 'incremental' adaptation, a universally accepted definition of the concept remains elusive. Here, we used a three-round Delphi study with experts from across the globe, to ascertain the level of agreement on key elements of TA, and to assess differences across expert types, geographical focus, and administrative levels. We find broad agreement on 13 elements that are important in a definition of TA: root causes, climate resilience, time-horizon, diversity of knowledge, depth of change, distributive justice, context specificity, multi-scale, restructuring, persistence, maladaptation, avoiding lock-ins,**

**and systemic change. However, notable differences exist in what expert subgroups value as important elements. Clarifying what TA entails is crucial for developing effective policies and strategies, ensuring meaningful progress in addressing climate change.**

## **Content**

Observed weather and climate impacts have increased globally and current adaptation efforts to reduce future risks are insufficient as hard and soft limits have been reached or are expected to be reached in the near future.<sup>1</sup> Transformational adaptation to climate risks (TA) is increasingly discussed as a key concept to scale-up adaptation action as climate change continues to intensify. The latest IPCC Working Group II report stressed the importance of implementing TA across different sectors, regions, administrative levels, and societal groups<sup>1</sup>, defining it as “Adaptation that changes the fundamental attributes of a social-ecological system in anticipation of climate change and its impacts”.<sup>2</sup> Since the early 2010s, the concept of TA has gained traction in the scientific literature as a distinct approach, contrasting with more incremental or ‘business-as-usual’ forms of adaptation<sup>3,4</sup>. Increasingly the concept has found its way to policymakers and politicians around the world. In the context of the international climate negotiations, for example, Parties have picked up on the scientific calls for TA, and are discussing it particularly in relation to the Global Goal on Adaptation under the Paris Agreement<sup>5</sup>. In the European Union, TA is at the heart of EU Mission on Adaptation to Climate Change<sup>6</sup>, and the African Union’s Climate Change and Resilient Development Strategy and Action Plan prioritises TA to enhance resilience across Africa<sup>7</sup>.

Attempts to characterize TA in the academic literature have resulted in a plethora of different attributes, enabling conditions, and conceptual framings, as well as a wide array of normative assumptions about what TA entails, why it is needed, and how it should be achieved.<sup>8–20</sup> Nevertheless, it remains largely unclear what distinguishes it from, and how it is situated amongst, other forms of adaptation. Moreover, its potential political implications, for example in relation to international climate finance<sup>21</sup>, are not yet well understood.

The diversity of views is not inherently problematic, especially not in an academic context, but it poses challenges in policy, political, and practical contexts. Concepts shape communication, structure ideological and normative views, and influence the framing of issues, thereby affecting public discourse and political processes.<sup>22,23</sup> A common understanding of TA would help to move beyond rhetorics to practice as political debates, policy decisions, and legal interpretations depend on how key concepts like transformational adaptation are understood.<sup>24</sup> It also strengthens analytical precision, allowing for consistent comparison and rigorous analysis across cases and contexts, something critically important in the context of the second Global Stocktake under the Paris Agreement and future implementation of the UAE Framework for Global Climate Resilience.

Here, we present the results of the first-ever Delphi study aimed at investigating the extent to which an international panel of experts can agree on the key elements of TA. Delphi is a structured method used to gather expert opinions on a complex issue, with the aim of allowing experts to achieve agreement.<sup>25</sup> The method is particularly useful to form well-considered collective judgments and may mitigate biases like groupthink and dominant personalities.<sup>26</sup> The three-round Delphi process used here involved an iterative, anonymized consultation with researchers and practitioners working on (transformational) adaptation to climate risks from across the globe (our experts), incorporating controlled opinion feedback in round two (i.e., a summary of results from the first round). Experts were asked to indicate their position on a spectrum between “researcher” (those studying TA) and “practitioner” (those involved in policy or political spheres and who discuss, decide or implement TA), using a 5-point scale. In round one, experts rated the relevance of 27 elements frequently identified in the academic literature, provided qualitative justifications for their ratings, and suggested missing elements. In round two, experts re-evaluated the elements for which there was little agreement in round 1, considering the controlled opinion feedback. Moreover, they rated the relevance of a few additional elements that were suggested by multiple experts in round one. In the third round, experts

evaluated two definitional statements derived from earlier responses. See Online Methods for more details.

### ***International panel of experts on adaptation***

As shown in Table 1, 99 experts participated in the first round of the Delphi study, with 64 and 52 experts remaining in the second and third rounds respectively. Experts' focus covered all geographical regions, with a slight European over-representation. The experts also reflect a balanced mix of researchers, practitioners, and experts operating at the interface between research and practice ('mixed'). Experts with experience at various administrative levels participated, with many respondents reporting expertise at the national and local levels.

### ***Key elements of transformational adaptation***

After two rounds of the Delphi study, experts largely agreed that 13 elements are particularly relevant for defining transformational adaptation to climate risks (Table 2). These elements were identified by calculating the level of agreement of each element using the Strict Agreement ('SA') index ( $\geq 0,5$ ) and the percentage of experts ( $\geq 70\%$ ) who rated the relevance of an element with a 7, 8, or 9 ('P<sub>789</sub>').<sup>27</sup> The thresholds for agreement were placed at  $\geq 0,5$  for the SA index and at a minimum of 70% for the P<sub>789</sub> score. See also the Online Methods section.

In the first round, experts already largely agreed on the high relevance of 8 elements, with *root causes* and *climate resilience* being the highest scoring elements, both in P<sub>789</sub> scores and SA scores. In the second round, experts largely agreed on the high relevance of the following 4 additional elements that did not meet the criteria in the first round: *restructuring*, *avoid lock-ins*, *maladaptation* and *persistence*. Most notably, the P<sub>789</sub> score of the element *restructuring* increased substantially from 0.68 to 0.86. Reasons why experts changed their rating of this element after reading the justifications from others included arguments that *restructuring*: (1) is an inevitable consequence of transformation, (2) is often used as euphemism for transformational adaptation, and (3) might be more important than initially considered.

One element – *systemic* - was included in round 2 after suggestions from multiple experts in round 1. This element got the highest on P<sub>789</sub> score of all elements included in round 2. As one expert noted: "*Piecemeal solutions addressing only certain components of the system/s can render the impacts [of adaptation] ineffective, at times leading to maladaptation. ... a clear understanding of the system or systems involved, their components, intra- and inter-relationships is crucial for effective transformational adaptation*".

The distribution of relevance ratings for all 13 elements from rounds 1 and 2 in the final set illustrates the wide variation in how experts assess different aspects of transformational adaptation (figure 1). The final set reflects a broad spectrum of elements, underscoring the diversity of priorities and perspectives within the expert community. We illustrate below how these elements can be clustered, for example using a process–outcome logic. Some elements relate more strongly to outcome-characteristics of TA, such as: *depth of change*, *multi-scale*, *restructuring*, *climate resilience*, and *persistence*. Experts' elicited views suggest that these outcomes of TA need to have certain qualities: *avoid lock-ins* and *maladaptation*. Some elements have a stronger focus on process-characteristics of TA such as addressing the *root causes* that generate and perpetuate vulnerability, or incorporating long-term and intergenerational perspectives (*time-horizon*). These processes also need to have certain qualities: they should consider a *diversity of knowledge* in the process, including scientific, local knowledge, and Indigenous Knowledge. Some elements cut across both process and outcome characteristics of TA; *Context specificity* and *systemic* for example are descriptive characteristics that apply to both how adaptation is approached and what it targets. *Distributive justice*, a normative quality, likewise bridges process and outcome, reflecting the importance of fairness in both the process and outcome.

### ***Diverse views between subgroups of experts***

Despite broad agreement on the relevance of the 13 elements in the final set, notable differences emerged between response subgroups as is shown in figure 2 which captures the differences in agreement (SA-values) and level of importance ( $P_{789}$  scores) of all elements considered in this study.

Overall, the practitioners and mixed groups scored the 13 elements higher compared to researchers. Practitioners agreed more on the relevance of the elements compared to the other two groups (researcher, mixed), as reflected by higher SA values in rounds 1 and 2. Certain elements were valued more highly by practitioners compared to researchers, as reflected by the  $P_{789}$  scores. Notable differences are in the elements of *tangible actions* (practitioner:  $P_{789}=0.76$ ; researcher:  $P_{789}=0.47$ ), *empowerment* (practitioner:  $P_{789}=0.82$ ; researcher:  $P_{789}=0.53$ ), *intersectionality of vulnerability* (practitioner:  $P_{789}=0.88$ ; researcher:  $P_{789}=0.44$ ), and *deliberate actions* (practitioner:  $P_{789}=0.81$ ; researcher:  $P_{789}=0.44$ ). Despite high  $P_{789}$  scores and strong agreement amongst practitioners, few of these elements made it to the final set of 13 elements, which is largely because of the large differences in  $P_{789}$  score compared to researchers. Respondents in the mixed category typically also rated elements higher than researchers, most notably the elements *plurality of values* (mixed:  $P_{789}=0.94$ ; researcher:  $P_{789}=0.5$ ) and *deliberate action* (mixed:  $P_{789}=0.83$ ; researcher:  $P_{789}=0.44$ ).

Although there was general agreement on the top-ranking elements, there were some notable differences between the experts with a focus on Global North and Global South regions. For example, experts with a focus on the Global South rated the element *distributive justice* far higher ( $P_{789} = 0.88$ ) than those focusing on the Global North ( $P_{789}=0.67$ ). A similar pattern was observed for *social equity* (Global South:  $P_{789}=0.88$ ; Global North:  $P_{789}=0.62$ ), *intersectionality of vulnerability* (Global South:  $P_{789}=0.76$ ; Global North:  $P_{789}=0.55$ ), and *multi-actor* approaches (Global South:  $P_{789}=0.82$ ; Global North:  $P_{789}=0.57$ ), among others. Experts who reported no explicit geographical focus tended to value certain elements substantially lower than experts with a geographical focus, most notably *context specificity* ( $P_{789}=0.62$ ) and *procedural justice* ( $P_{789}=0.58$ ). On average, this group also showed lower agreement (lower SA) in their ratings.

Little evidence of substantial differences between experts at different administrative levels was found. One exception was the element *multi-actor*, which was rated substantially higher by experts with national or lower-level expertise ( $P_{789}=0.81$ ) compared to those focused on the global or regional levels ( $P_{789}=0.65$ ).

When analysing the SA and  $P_{789}$  scores independently for each subgroup, we find notable differences in which elements would have been included if only that subgroup were considered (see Supplementary Figures 2–4). For example, practitioners included 19 elements, the mixed group included 15, and researchers only 8. The lower number of elements included by researchers is mostly driven by lower SA scores, suggesting that researchers tended to agree less on the rating of each element. Across all subgroups, the element *systemic* ranked at the top of the list—except for experts with a Global South focus, where *systemic* ranked fourth, after *diversity of knowledge*, *distributive justice*, and *multi-actor*. Consequently, the 13 elements in our final set reflect areas of broader agreement on the relevance across the full group, while also indicating that different actors place emphasis on different elements. The top 7 elements in figure 2, however, are robust across all expert subgroups.

### ***Contested elements of transformational adaptation***

In the first two rounds, several elements showed high disagreement among experts (i.e. low SA score). When qualitatively analysing the justifications of experts who rated these elements as highly relevant or irrelevant, several recurring arguments emerged: (1) whether a particular element acts as a driver of TA, and (2) whether the element is essential for distinguishing TA from its counterparts. Experts had different views that could be characterised by either a more normative or empiricist position. Experts with a normative position stressed the importance of both process and outcome-related elements, emphasizing inclusive, justice-oriented approaches that address climate risks as part of a broader landscape of environmental and social injustices. In contrast, experts with an empiricist position concentrated mostly on observable outcomes and remain agnostic to the processes

that led to them. This view tends to treat TA as something separate from addressing other environmental and societal issues.

One element where these differences become clear is *shifting power*. Experts from normative positions emphasized that TA at its core should involve shifting decision-making power to marginalized actors to ensure they have larger roles in transformation, and that the root causes of vulnerability and marginalization are properly addressed. However, others with a more empiricist view remarked that although shifting power is important, it is not always a necessary attribute of TA. Another example is the element *speed of change*. Normative perspectives noted the need for rapid action that could move beyond incremental approaches, particularly given the shrinking solution space. In contrast, others warned against quick fixes, arguing that transformational adaptation requires long-term planning and durable solutions to address root causes. From an empirical perspective, speed was less relevant: what matters is whether the desired system change is ultimately achieved, regardless of how fast it occurs.

### **Definitions of transformational adaptation**

In the third round of the Delphi study, experts were presented with two definitions that were based on the 13 elements: one was a more detailed, multi-sentence version (definition D1), while the other was a single-sentence definition (definition D2), see textbox 1 and the associated box figure. Both definitions received broad support from experts and were considered useful for day-to-day practice (D1: 3.65 out of 5; D2: 3.67 out of 5). However, definition 2 received fewer negative evaluations ('disagree'). When considering the different subgroups, only practitioners expressed a clear preference for the shorter format of definition 2 in terms of perceived usefulness.

No major differences were found in the evaluation of the language or structure of the two definitions. Similarly, there were no large differences between experts with different geographical focus, expert groups, or administrative levels. The only exception was in the evaluation criterion of *Content* (across all experts). Here, experts seemed to prefer a stronger preference for the more elaborate version of definition 1.

#### **Textbox 1: definitions of transformational adaptation**

Two definitions were proposed to the panel in round 3:

**Definition 1 (D1):** "Transformational adaptation to climate risks fundamentally restructures socio-ecological systems by addressing root causes of vulnerability, ensuring climate resilience across multiple scales, and considering the long-term future. It is context-specific, prioritizes distributive justice, and is informed by diverse knowledge systems. Transformational adaptation entails profound change in societal norms and values and recognizes the systemic nature of climate risks and responses. It secures persistent commitments and avoids maladaptation and lock-ins."

**Definition 2 (D2):** "Transformational adaptation fundamentally reshapes socio-ecological systems<sup>i</sup> in an inclusive way<sup>ii</sup> to address underlying drivers of climate risk<sup>iii</sup>, enhance the capacity to cope with and recover from future impacts<sup>iv</sup>, and prevent unintended consequences now and in the future<sup>v</sup>"

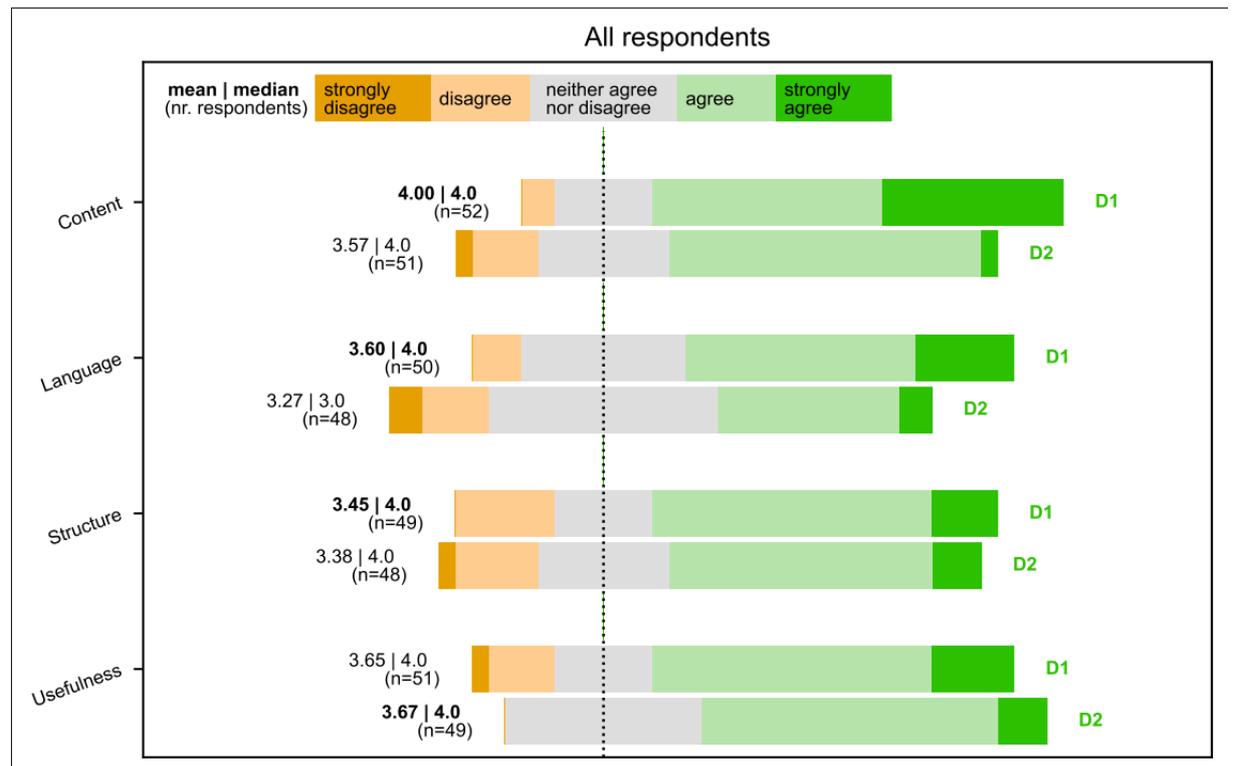
<sup>i</sup> Multi-scale, Restructuring, Depth of change, Persistence

<sup>ii</sup> Diversity of knowledge, Distributive justice, Context specificity

<sup>iii</sup> Root causes, Systemic

<sup>iv</sup> Climate resilience, Time-horizon,

<sup>v</sup> Maladaptation, Avoid lock-ins."



**Box Figure 1:** Evaluation of the two definitions based on four criteria using a 5-point scale: “Content” refers to the concepts and ideas included in the definition, ensuring completeness and relevance. “Language” focuses on clarity, readability, and tone. “Structure” concerns the way these concepts are arranged and whether the sentence flows logically. “Usefulness” captures how useful respondents felt the definition is for their daily work. D1 refers to definition 1; D2 refers to definition 2. Highest score for each evaluation criteria is highlighted in bold.

## Discussion

Transformational adaptation is increasingly at the forefront of both scientific inquiry and policy debates<sup>3,28,29</sup>. TA seems to offer a framing that resonates across diverse arenas – more, better and deeper adaptation is urgently needed to address future climate risks. The global stocktake of adaptation by Berrang-Ford et al. underscores this point, showing that few documented cases align with the aspirational characteristics associated with TA.<sup>30</sup> But since its precise meaning remains ambiguous, there is a risk that TA becomes an empty signifier.<sup>31</sup> Our study provides several insights.

First, the strong agreement on 13 key elements across all response groups suggests a shared reference point that can facilitate communication about TA across regional focus, expert types and administrative levels. Rather than serving as a fixed checklist, the elements provide a flexible way to guide adaptation design, inform policy development and implementation, and evaluate whether adaptation initiatives reflect transformational intent. Because these elements were derived from a diverse pool of experts from across the globe, they offer a pluralistic foundation that can make future debates more inclusive, structured, and reflective of multiple priorities and values that are at the heart of the adaptation debates.

At the same time, our study reveals a range of divergent perspectives across different response groups. These disagreements are not merely semantic; they arise from differences in how the concept is employed, by whom, and in what setting. For instance, those with a research focus may use the concept primarily as an analytical tool, while others with a more practical expertise seem to value additional elements in a definition, placing more emphasis on the actionable and socially grounded dimensions of transformation, likely reflecting their closer proximity to implementation realities. This heterogeneity underscores the importance of attending to positionality and purpose

when assessing how shared concepts are understood and mobilized across different knowledge systems and settings.

Following from the above, justice-related elements, particularly *distributive justice*, *social equity*, and *intersectionality of vulnerability*, were more strongly endorsed by experts with a Global South focus but not all made the final list of elements. Our finding echoes several concerns raised that dominant framings of TA may underemphasize more structural inequalities and justice issues. This reaffirms the importance of reflecting on the role of justice and equity in conceptual and practical approaches to transformational adaptation<sup>32–34</sup> and asking ‘transformation for whom’.

The comparison between the two proposed definitions of transformational adaptation reinforces the importance of clarity and usability. Both definitions were considered useful but suggest a possible trade-off between accessibility and completeness. In practice, different users may require different levels of detail for different purposes: concise definitions may facilitate communication and policy uptake, while richer formulations support analytical depth and norm-setting. Striving for one commonly agreed-upon definition may thus only work if the use and user groups are clearly defined even if the broader aspects of TA are more clearly understood.

Furthermore, an important observation is that several elements commonly highlighted in the academic literature, such as *speed of change*, *scale of change*, and *innovativeness* of adaptation measures, were discarded in round 1. One possible explanation lies in the different roles that definitions and descriptive characteristics play. While speed, scale, and innovation may frequently appear in case-based studies or theoretical discussions, they may not serve well as defining criteria for TA. For example, as several experts noted, rapid change may not always be desirable or feasible in practice, especially in politically or socially sensitive contexts. Similarly, innovation may be context-dependent and not inherently transformational unless linked to deeper systemic shifts. This highlights the importance of distinguishing between enabling conditions, core characteristics and typical outcomes. Elements like speed of change and innovation may still hold value, for example as signals of transformative change or as context-specific accelerators<sup>35</sup>, even if they are not central to a shared definition. These are key areas for future research.

In conclusion, while a single overarching definition that captures international agreement on TA may be unrealistic at this time, the identification of commonly supported elements as identified in this study provides a pragmatic and inclusive alternative. These elements offer further conceptual clarity, bridge diverse perspectives, and create a basis for assessing ambition and progress. By deepening how transformational adaptation can be recognized across scales and knowledge systems, our study provides actionable insights for integrating the concept and its elements into future international assessments such as IPCC AR7 and supporting international climate negotiations. Its findings can also support national and local actors, multilateral development banks, and communities in reflecting on the conditions under which adaptation efforts evolve in a continuum of incremental improvements to genuinely transformative change.

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**Author contributions:**

RB, DE, and EvB conceived the idea and designed the study. RB, EB, DE, JB, EvB, and JM developed the conceptual framing of the study. The methodological design was led by RB and JM, with input from DE, JB, EB, and EvB. Formal analyses were conducted by RB, EB, DE, JB, EvB, and JM. Visualisations were created by RB and JB. RB, DE, JB, and JN drafted the original manuscript. EvB, JM, FJ, ET, TL, EG, and KLE substantially contributed to editing the manuscript and provided suggestions on the data analysis.

**Competing interest statement:**

EG is a Research Scientist at Environment and Climate Change Canada but did not write this article in that capacity. The views expressed here are those of the authors and do not reflect the views of the Government of Canada or Environment and Climate Change Canada. The remaining authors declare no competing interests.

**Tables:**

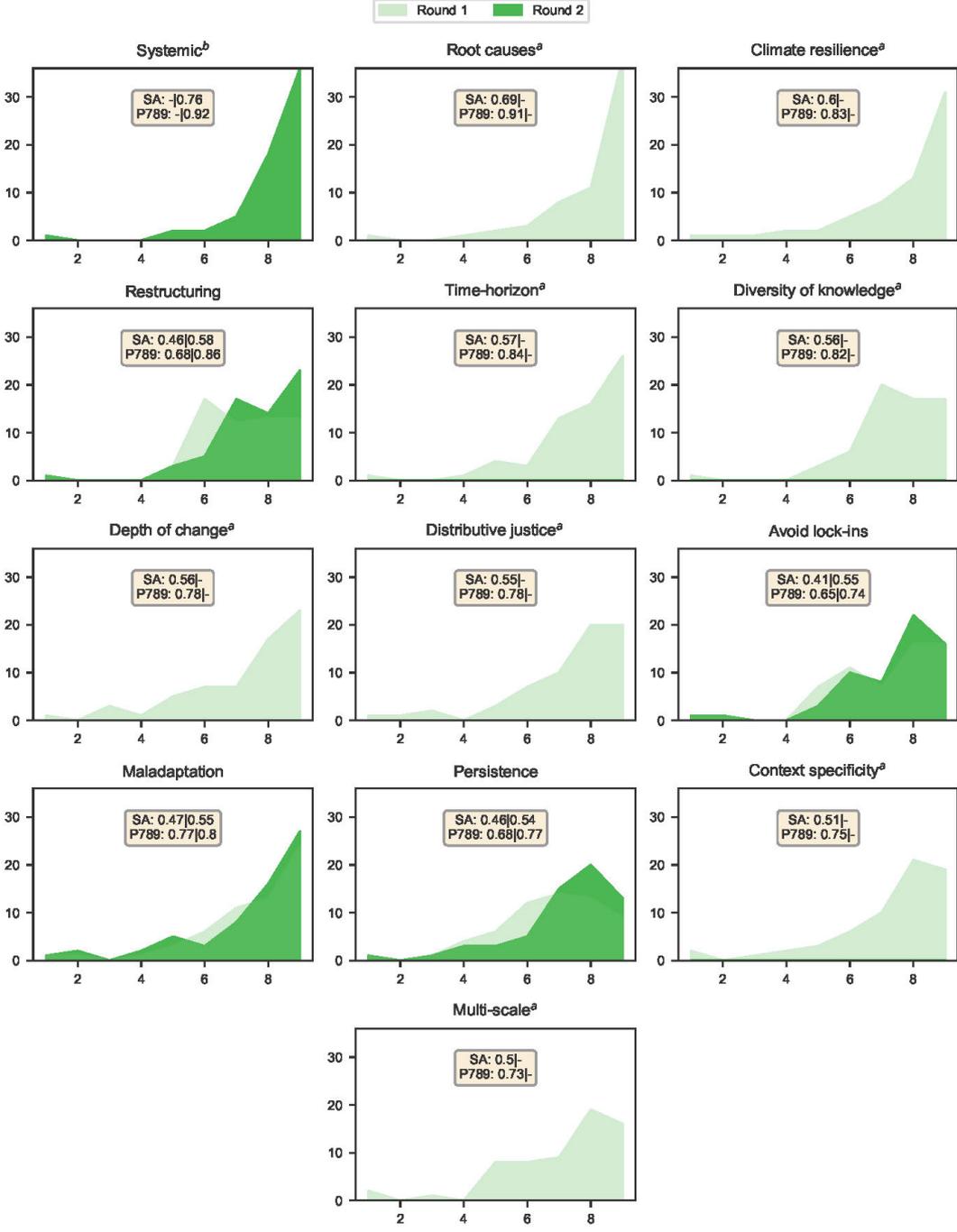
**Table 1 - Types of respondents.** All questions are self-assessments of expert-type, geographical focus and administrative level. Not all information is available in round 1 as some respondent characteristics were asked only in round 2. \*Respondents could indicate multiple options. For the analysis, the highest administrative level in their response was selected, resulting the following groups: Global/Regional (n=37) and (Sub)national (national, provincial, local and community level) (n=27).

Type	Sub-type	Round 1 (n=99)	Round 2 (n=64)	Round 3 (n=52)
<b>Expert-type</b>	Researcher	26	17	15
	Practitioner	27	17	13
	Mixed	28	18	15
	Preferred not to answer	18	12	9
<b>Geographical focus</b>	Africa		10	7
	The Americas		7	5
	Asia/Middle East		5	4
	Europe		12	10
	Oceania		4	3
	No specific region		24	21
<b>Global north/south focus</b>	Global North		21	17
	Global South		17	12
	No specific region		24	21
<b>Administrative level*</b>	Global		27	21
	Regional		20	17
	National		38	31
	Province		28	24
	Local		43	34
	Community		29	22

**Table 2:** Elements that meet the minimum criteria for being included in the definition of transformational adaptation to climate risks. Elements included in this table meet the two main criteria: strict agreement index is > 0.5, and the percentage of ratings of a 7/8/9 is > 70% of the total responses for an element. R1 and R2 indicate in which round the agreement was reached. These elements formed the basis for formulating the two definitions that were proposed to the experts in round 3 (see Box Figure 1). Supplementary table 1 contains a list of all elements included in round 1 and Supplementary table 2 contains a list of all additional elements proposed in round 2.

<b>Label</b>	<b>Description</b>	<b>Agreed</b>
<b>Root causes:</b>	Identifies and tackles the underlying environmental, societal, economic, political, and/or legal conditions that create or sustain vulnerability and risk within a certain system.	R1
<b>Climate resilience:</b>	Leads to systems and communities to withstand and recover from future climate impacts.	R1
<b>Time-horizon:</b>	Includes long-term (intergenerational) needs and future climate scenarios and socio-economic pathways.	R1
<b>Diversity of knowledge:</b>	Considers a diverse set of knowledges in the process, including scientific knowledge, local knowledge and Indigenous Knowledge.	R1
<b>Depth of change:</b>	Leads to profound change in the societal norms, values and worldviews.	R1
<b>Distributive justice:</b>	Ensures fair and equitable allocation of resources and opportunities, ensuring that those most affected by climate change, particularly vulnerable and marginalized communities, receive sufficient support and compensation.	R1
<b>Context specificity:</b>	Tailors adaptation to the unique conditions and needs of specific contexts.	R1
<b>Multi-scale:</b>	Impacts of change occur across different types of scale (e.g., trophic, spatial, jurisdictional, or sectoral scales).	R1
<b>Restructuring:</b>	Alters the core properties, functions, or interactions within the existing social, ecological, or socio-ecological systems.	R2
<b>Persistence:</b>	Secures long-term commitments and impacts, recognizing that these may not always be irreversible.	R2
<b>Maladaptation:</b>	Avoids actions that inadvertently increase vulnerability to climate impacts.	R2
<b>Avoid lock-ins:</b>	Prevents long-term commitments that limit future adaptability and flexibility.	R2
<b>Systemic:</b>	Takes into account the interconnected nature of the system as a whole, acknowledging that root causes of vulnerability are embedded within broader systemic structures and dynamics.	R2

**Figure legends/captions**



**Figure 1: Distribution of scores for the selected elements of TA ordered by SA score.** The two colours show the shift in score distribution between round 1 and round 2, where applicable. Elements marked with a <sup>a</sup> were only included in the first round and could be accepted based on the results of that round. Elements marked with a <sup>b</sup> were added in the second round based on respondents' suggestions in the first round. The x-axis shows the experts' ratings (ranging from 0 'extremely irrelevant' to 9 'extremely relevant'), while the y-axis indicates the number of experts.



**Figure 2: Scores for all responses and per response subgroup.** The colours indicate the level of the strict agreement index (SA). The values indicate the percentage of respondents rating the element with a 7, 8, or 9 (P<sub>789</sub>). The responses are clustered by type of expert (TOE), geographical focus (GEO), and administrative level (ADM). The elements are sorted by their SA across all respondents. The dashed, red line indicates which elements meet the inclusion criteria (i.e., an SA – across all respondents – of higher than 0.5 and a P<sub>789</sub> – across all respondents – of higher than 0.7). An overview of the sort order and inclusion criteria per response group is provided in supplementary figures 2-4. Elements marked with a <sup>a</sup> were only included in the first round and could be accepted or rejected based on the results of that round. Elements marked with a <sup>b</sup> were added in the second round based on respondents’ suggestions in the first round.

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## Online Methods

Supplementary figure 1 captures the general steps of the three-round Delphi study.

### Selecting elements of transformational adaptation to climate risks

Drawing on several authoritative reviews and recent publications in the academic literature<sup>10–12,18</sup>, we compiled a comprehensive inventory of elements potentially relevant for defining transformational adaptation to climate risks. To reflect the conceptual breadth of transformational adaptation, the initial overview intentionally included a wide range of elements, encompassing inputs, processes, outcomes, and impacts. This extensive list was then refined through the consolidation of overlapping elements, resulting in an initial set of 41 elements, each accompanied by a concise explanatory description. Members of the Scientific Advisory Committee provided detailed feedback, which led to further refinement of the wording and descriptions, the aggregation of closely related elements, and the reduction of the total number of items to enhance usability. The list of elements included in the first Delphi round comprised of 27 elements (see Supplementary table 1).

### Delphi survey design

A Delphi study entails a structured process of iterative, anonymized consultation, in which a study facilitator systematically solicits expert opinions across multiple rounds, providing controlled opinion feedback (i.e., a summary of the results from the previous round) that may include statistical distributions of experts' ratings and qualitative syntheses of experts' justifications.<sup>25,36,37</sup> This approach mitigates biases like groupthink and dominant personalities, allowing for more objective and well-considered collective judgments. This study employed a three-round Delphi design to facilitate experts to achieve agreement on the defining elements of transformational adaptation to climate risks, building on the research design and surveys used in previous studies.<sup>26</sup>

For each round an online survey was built using Qualtrics software<sup>38</sup>. Survey questions were written in simple English to overcome language barriers of experts. Each survey was pre-tested with 3–5 authors of this paper, revised and then launched. The three surveys can be found in Supplementary survey design 1–3.

In Survey 1, experts were first asked to self-assess their level of expertise on TA using a 5-point scale. They were also asked to indicate how they perceived their professional role—whether as a practitioner, a researcher, or a combination thereof—on a 5-point scale. Next, experts were asked to rate the relevance of 27 elements for defining transformational adaptation to climate risks. Experts could rate each element on a 9-point Likert Scale ranging from 1: 'extremely irrelevant' to 9: 'extremely relevant'. Numerical labels were provided for each answer option and verbal labels for the endpoints of the scale. An 'I don't know' option was also available. If an expert rated an element as highly relevant (8 or 9) or as irrelevant (1 or 2), a follow-up prompt requested a brief justification for their rating. Subsequently, participants were invited to suggest any additional elements they believed were missing from the initial list and provide a short description of the element.

Survey 2 began with multiple-response questions on the geographical focus (at sub-continental scale) and administrative level (ranging from global to community level) of each expert's professional engagement. Experts then proceeded to re-rate the relevance of 15 elements that were also included in survey 1 (note: based on round 1, eight elements already met the criteria for being included in the definition of TA and four elements already met the criteria for being excluded from the definition of TA). The survey presented controlled opinion feedback in the form of a summary of group responses for each of the 15 elements. A histogram was used to visualize the distribution of experts' ratings, consistent with best practices in Delphi methodology.<sup>37</sup> Additionally, a synthesis of experts' justifications (for rating an element as highly relevant (8–9 score) or highly irrelevant (0–2 score)) was presented. Finally, each expert was also shown their own rating from survey 1, enabling direct comparison with the group response. Experts were invited to reflect on this feedback and, if appropriate, revise their initial ratings. An open text box allowed for additional comments. To reduce the risk of conformity bias or withdrawal of minority views, the survey explicitly stated that alignment

with the group response was not expected. In the final section, participants assessed the relevance of four additional elements that had been proposed in the previous round (see Supplementary Table 2).

Survey 3 presented two candidate definitions of transformational adaptation to climate risks. Experts were asked to evaluate each definition in terms of its content, structure, and language, as well as its perceived usefulness in their professional context. These assessments were made using 5-point Likert scales with both numerical and verbal anchors: from 1 ('strongly disagree') to 5 ('strongly agree') for content, structure, and language, and from 1 ('very useless') to 5 ('very useful') for practical relevance. A 'no opinion' option was included to account for uncertainty or limited applicability. Participants were also invited to justify their ratings in accompanying text fields.

### **Participant selection and recruitment**

Experts on transformational adaptation to climate risks are a small but rapidly emerging group. We therefore took a broad understanding of who is considered an expert. The first survey was designed to target a broad range of participants and included a question on the self-declared level of expertise on transformational adaptation to climate risk. Participant selection was therefore opportunistic, following three complementary approaches (Supplementary figure 1). First, we identified a list of authors of scientific papers that were included in the four authoritative reviews of the topic. Second, we used the extensive network of the authors and Scientific Advisory Committee to identify possible experts, which included both academic networks such as from the Intergovernmental Panel on Climate Change (IPCC) and World Adaptation Science Programme (WASP), as well as relevant professional networks. Third, we collected the names and contact details of the participants - mostly national level negotiators and experts - of the fifth workshop under the Glasgow-Sharm el-Sheikh work programme (GLaSS) on the global goal on adaptation workshop which focused on transformational adaptation to climate risks (March, 2023). Fourth, we disseminated calls for contributions via social media platforms (X and LinkedIn), inviting interested individuals to participate by contacting one of the researchers and submitting a brief statement of their expertise. For this group, we conducted a basic relevance check to confirm that they were actively working on adaptation to climate risks. The final list included 377 possible expert participants. Experts were considered to include both practitioners and researchers, or those occupying roles along this spectrum. Recruitment occurred between August and September 2024.

### **Survey implementation**

The surveys were implemented in three rounds: Survey 1: 24 October 2024 – 21 December 2024; Survey 2: 16 January 2025 – 21 February 2025; Survey 3: 31 March 2025 - 25 April 2025. Experts were invited through a personal announcement e-mail with an information sheet and an opt out link. After two weeks a reminder was sent to those experts that did not (fully) complete the survey. A few days before the deadline a final reminder was sent.

To calculate the response rate for the survey, we considered only the invitations that were successfully delivered to participants. Of the 377 initial invitations sent, 33 were undeliverable (bounce-backs), leaving 344 valid invitations. Out of these, 99 participants completed the first survey, resulting in a response rate of approximately 30% which is considered acceptable for online surveys<sup>39-41</sup>, especially considering that, in the first invitation, experts were informed about participating in multiple rounds of surveys. From the 99 experts who completed the first survey, 64 experts completed the second survey, and 52 experts completed the third and final survey<sup>42</sup>.

### **Data analysis**

To evaluate the degree of agreement on the relevance of each element, we calculated the Strict Agreement (SA) index<sup>27</sup> in survey rounds 1 and 2. This index represents the proportion of expert pairs that provided identical or closely aligned ratings, relative to the total number of possible expert pairs within the sample. Agreement was defined as either an exact match in ratings (e.g., 8 and 8) or adjacent values (e.g., 7 and 8). An exception was made for the neutral midpoint rating of 5 ("neither relevant nor irrelevant"); in this case, only expert pairs in which both assigned a 5 were considered to be in agreement (i.e., combinations such as 4 and 5 or 5 and 6 were not classified as agreement). For

an element to be included in the definition of TA we formulated the following criteria: SA > 0.5 AND % 7/8/9 > 70%. We also excluded elements based on insufficient agreement criteria: SA < 0.4 OR % 7/8/9 < 50%. For the additional elements that were suggested in survey 1, only the elements that were suggested by at least four experts and that were qualitatively sufficiently different from the existing list of elements, were included in survey 2.

Justifications provided for high and low relevance ratings, as well as suggestions for additional elements in Survey 1, were initially analyzed using a large language model (LLM), GPT-4o (version June 2024), and subsequently reviewed and refined by members of the author team through two iterative rounds of discussions. Model-generated summaries were compared to the original participant explanations and adjusted as necessary. The final output consisted of a set of concise, representative justifications for each element, distinguishing between high ratings (scores 8–9) and low ratings (scores 1–2). Open-ended text data in which experts explained their justification for their ratings was also analysed using thematic analysis to identify the main areas of contestation of the elements that experts did not agree on. To identify possible explanations for shifts in ratings between survey 1 and survey 2, we qualitatively explored the elements for which we found a large difference.

Based on the 13 elements that met the acceptance criteria in surveys 1 and 2, the research team, together with members of the Scientific Advisory Committee, developed two candidate definitions of transformational adaptation to climate risks through multiple iterations. The first consisted of a multi-sentence formulation incorporating all accepted elements in an interconnected narrative. The second offered a single-sentence definition using umbrella terms to group related elements, supported by footnotes that clarify each term. Four evaluation criteria (content, structure, language, usefulness)<sup>26</sup> were compared using descriptive statistics, both between the two definitions, as well as for different expert types.

Demographic and contextual data from the surveys were analyzed using descriptive statistics. Respondents were categorized into three expert types based on self-assessment: researchers (scores 1–2), practitioners (scores 4–5), and hybrid or mixed roles (score 3). Countries were classified into Global North and Global South focus, and geographical focus was grouped into three categories: (i) global or supra-national (regional), (ii) national or subnational, and (iii) those without a specific spatial focus. Given the limited number of respondents and distribution of the data, we preferred descriptive statistics over statistical tests.

### **Limitations**

This Delphi study has several limitations. First, the survey was administered only in English, which may have limited participation from non-English-speaking experts and reduced linguistic diversity in responses. Second, we did not collect additional background information from participants, such as their professional roles or institutional affiliations, which could have provided deeper insights into the perspectives represented. Third, because the overall population of experts working on transformational adaptation is not well defined, it is difficult to assess how representative our sample is of the broader community. This challenge is amplified by our focus on researchers and practitioners, while recognizing that other societal groups (such as citizens, journalists, Indigenous Peoples, and businesses) may also play important roles and whose perspectives were not explicitly included in this Delphi study. Finally, while the sample size is acceptable for a Delphi study<sup>40,41</sup>, it does not allow for statistical analyses beyond descriptive summaries.

### **Ethics statement**

This study was approved by the Wageningen University and Research (WUR) Research Ethics Committee for review of non-medical studies with human subjects (WUR-REC, approval number 2024-153), in accordance with the Dutch “Code of ethics for research in the social and behavioural sciences involving human participants”.<sup>43</sup> The recruitment method and Delphi survey instrument were designed to provide participants with information about the study, and consent was obtained before participation and at the start of the first Delphi survey.

### **Data availability:**

Anonymized dataset is available through the following reference: Biesbroek, R. (2025). Experts agreement on key elements of transformational adaptation to climate risks [Dataset]. DANS Data Station Social Sciences and Humanities. <https://doi.org/10.17026/SS/WAWCQ4>

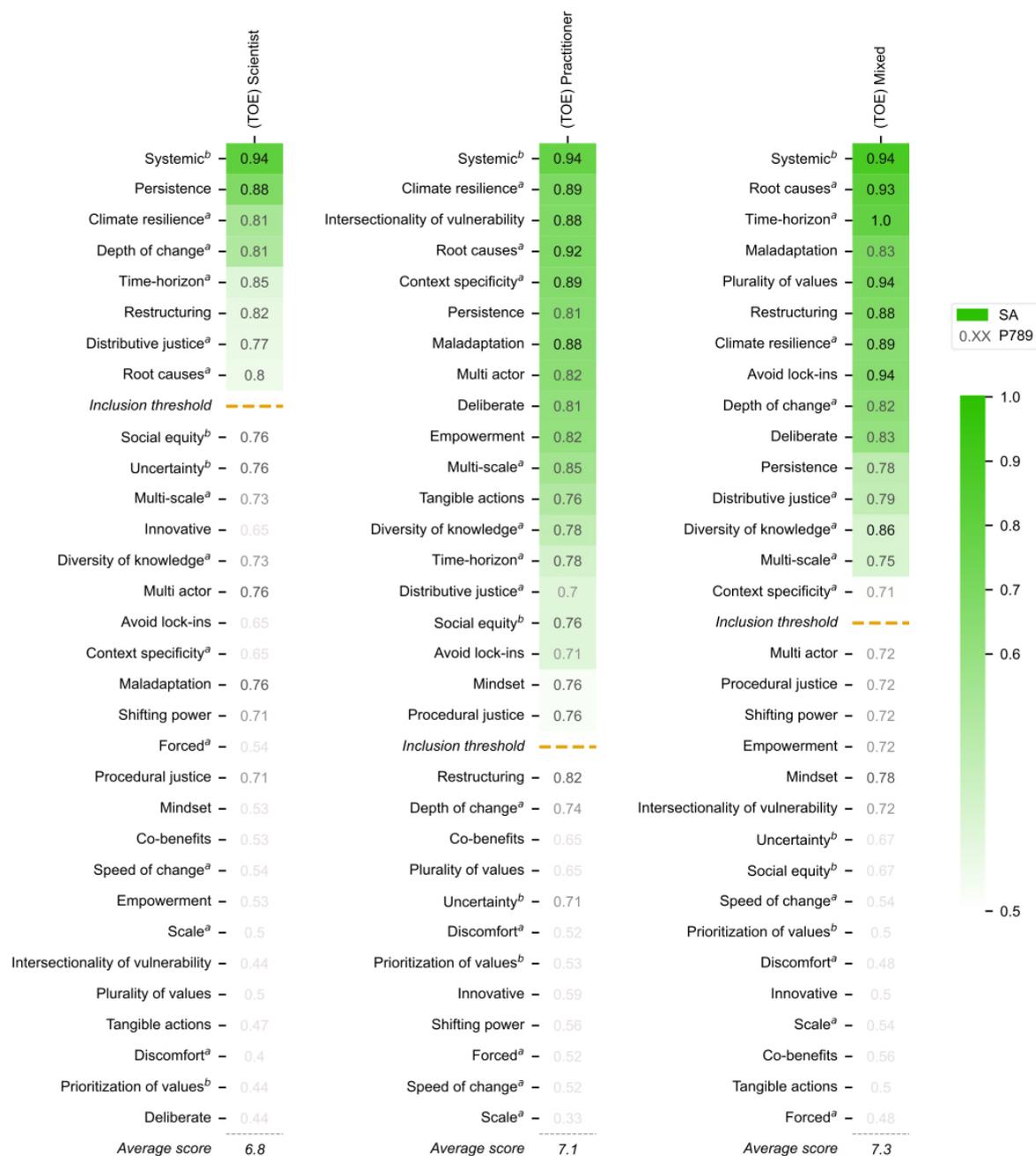
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## Extended Data Figures



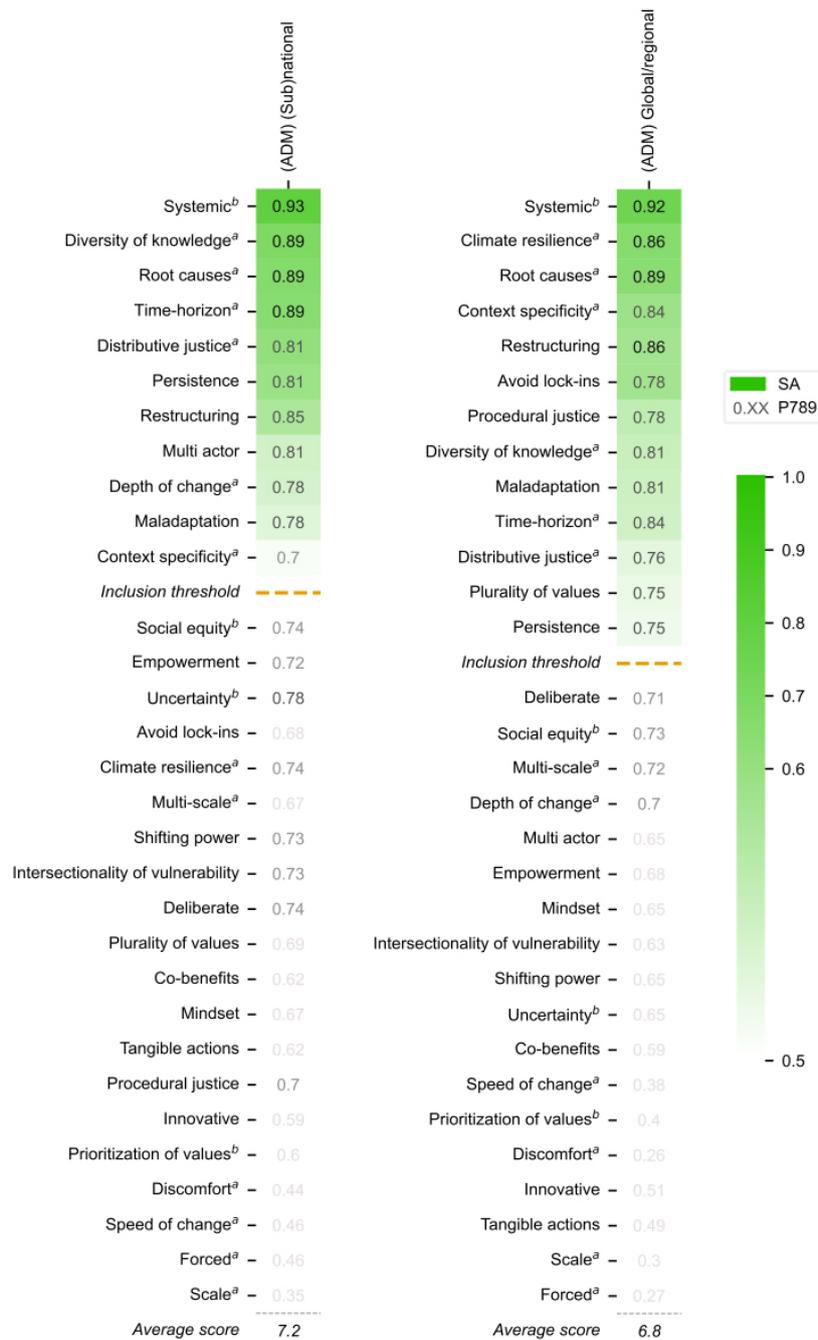
**Extended Data Fig. 1** | Evaluation scores per cluster (group). Evaluation (per cluster) of the two definitions based on four criteria using a 5-point scale: “Usefulness” captures how useful respondents felt the definition is for their daily work. “Content” refers to the concepts and ideas included in the definition, ensuring completeness and relevance. “Structure” concerns the way these concepts are arranged and whether the sentence flows logically. “Language” focuses on clarity, readability and tone.



**Extended Data Fig. 2 |** Scores per type of expert (TOE). The colours indicate the level of the strict agreement index (SA). The values indicate the percentage of respondents rating the element with a 7, 8, or 9 (P789). The responses are clustered by type of expert (scientist, practitioner, mixed). The elements are sorted by their SA for each subgroup. The dashed line indicates which elements meet the inclusion criteria. Elements marked with a a were only included in the first round and could be accepted or rejected based on the results of that round. Elements marked with a b were added in the second round based on respondents' suggestions in the first round



**Extended Data Fig. 3 |** Scores per geographical region (GEO). The colours indicate the level of the strict agreement index (SA). The values indicate the percentage of respondents rating the element with a 7, 8, or 9 (P789). The responses are clustered by geographical region (Global North, Global South, no region). The elements are sorted by their SA for each subgroup. The dashed line indicates which elements meet the inclusion criteria. Elements marked with a <sup>a</sup> were only included in the first round and could be accepted or rejected based on the results of that round. Elements marked with a <sup>b</sup> were added in the second round based on respondents' suggestions in the first round.



**Extended Data Fig. 4 |** Scores per administrative level (ADM). The colours indicate the level of the strict agreement index (SA). The values indicate the percentage of respondents rating the element with a 7, 8, or 9 (P789). The responses are clustered by administrative level ((sub)national, global/regional). The elements are sorted by their SA for each subgroup. The dashed line indicates which elements meet the inclusion criteria. Elements marked with a a were only included in the first round and could be accepted or rejected based on the results of that round. Elements marked with a b were added in the second round based on respondents' suggestions in the first round.