

A climate impact taxonomy operationalizing IPCC physical driver and risk concepts

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Abstract

Strengthening the handshake between physical climate science and adaptation communities is essential for producing actionable, integrated risk information. Our climate impact taxonomy links 35 Climatic Impact-Drivers to eight Representative Key Risks, with metadata on climate impact characteristics, relevant subsystems, and adaptation and mitigation linkages. This prototype taxonomy enables researchers, practitioners, and policymakers to develop adaptation strategies and direct support towards the most urgent, evidence-based priorities across IPCC-aligned dimensions.

Full Text

In its Sixth Assessment Report (AR6), the Intergovernmental Panel on Climate Change (IPCC) strengthened the link between the physical science assessed in Working Group I (WGI) and the climate impact, adaptation, and vulnerability assessments in Working Group II (WGII). Specifically, the Climatic Impact-Drivers (CIDs) framework was introduced in WGI ^{1,2} to establish community standards for climate indicators and facilitate climate impact and risk assessment. However, these developments have not yet produced prominent and systematically applied cross-Working Group products combining physical climate indicators directly with risk metrics, which could more consistently inform vulnerability assessments and adaptation planning. In particular, adaptation practitioners and policymakers would benefit from products that create a shared language across domains, translating abstract physical climate indicators (e.g., mean temperature changes) into actionable information (e.g., heat stress on ecosystems). Such integrative products could support risk and impact assessments across regions, sectors, and time scales, help prioritize support, and guide forward-looking, holistic adaptation strategies ³. Enhancing the accessibility and usability of information for end users and delivering tailored outputs, such as region-specific insights adapted to diverse stakeholder needs, could further increase the value of IPCC products, an aspect to consider during the ongoing AR7 cycle. Additionally, streamlining the scientific assessment process for report authors and providing structured protocols for mapping and organizing scientific literature at the interface of climatic impact-drivers and risks could improve the efficiency of the assessment process. For example, by incorporating machine-learning-based evidence synthesis, AR7 could significantly accelerate literature mapping and enhance the consistency of information synthesis⁴.

To address this gap, we have developed a climate impact taxonomy that systematically pairs each of the 35 CIDs as specified in WGI Figure SPM.9 ⁵ with the eight Representative Key Risks (RKR) introduced in WGII Chapter 16 ⁶. CIDs represent physical climate conditions that directly affect elements of society or ecosystems—for example, coastal flooding (Fig. 1a)—while RKR define eight clusters of key climate-related risks that are projected to become severe in a warming climate, encompassing impacts on ecosystems, human systems, and socio-economic conditions (Fig. 1b). Connecting these two frameworks establishes a direct link between physical climate changes and the resulting risks for natural and human systems. Each unique RKR–CID combination is enriched with structured metadata

describing spatial scale, type of change, temporal character, and the IPCC assessment of relevant subsystems. The metadata also include examples of identified research needs, adaptation linkages outlining illustrative responses by risk component, along with relevant targets aligned with the United Nations Framework Convention on Climate Change (UNFCCC) Global Goal on Adaptation^{7,8}, mitigation linkages, and critical global warming levels. Furthermore, the taxonomy links to relevant WGI and WGII chapters of IPCC AR6 and approved chapters for AR7⁹, guiding users toward the appropriate sources for further information. The resulting filterable lookup table enables exploration across a number of dimensions for a more holistic impact and risk perspective. We illustrate the taxonomy for one RKR–CID combination in Fig. 1c.

Analysis of the taxonomy metadata indicates that more than half of RKR–CID combinations manifest primarily at regional scales, reflecting the fact that many climate impacts are determined by unique regional boundary conditions regarding exposure and sensitivity (see Fig. 2). An almost even split between impacts from changes in extreme events (such as heatwaves, heavy precipitation events, or tropical cyclones) and those associated with changes in the climate mean (including gradual changes in temperature, precipitation trends, and sea-level rise) highlights the importance of building capacity to adequately respond to individual extreme events and the need for planning on decadal to centennial timescales.

The IPCC assessment of CID relevance for natural and human systems helps to understand the linkages between CIDs and sectoral subsystems and how well these are established in the scientific literature¹⁰. This information can guide scientists and practitioners to subsystems that should be considered for risk assessments. This information can also be used to inform research funding decisions by identifying which linkages are already well established and where critical gaps remain. For the RKR ‘Terrestrial and ocean ecosystems’, for example, heat-related CIDs are highly relevant for temperate and boreal forests, whereas there is no/low confidence in the link between heat-related CIDs and coastal seas. It must be noted that there are limitations to the interpretation of IPCC AR6 assessed relevance levels, as there is insufficient information available to distinguish robustly between low confidence and no data.

To establish a more intuitive connection between the climate impact and adaptation domains, we provide illustrative responses tailored to each RKR–CID combination within the adaptation linkage taxonomy metadata for each of the three components comprising the overall IPCC risk definition (hazard, vulnerability, and exposure)¹¹. For the CID ‘Coastal flood’, for example, a hazard-focused adaptation response for the RKR ‘Terrestrial and ocean ecosystems’ could involve expanding nature-based defenses such as mangrove restoration and sediment traps. In contrast, for the RKR ‘Critical infrastructure, networks & services’, the installation of modular flood defenses such as surge barriers would be more suitable. Similarly, the transition to heat-tolerant crop varieties can reduce the vulnerability of the food system (RKR ‘Food security’) to the CID ‘Extreme heat’, while the establishment of cooling centers would be a vulnerability-focused adaptation response for the RKR ‘Human health’. This highlights the need for a nuanced understanding of potential responses tailored to local conditions.

The adaptation linkages metadata also identify relevant targets from the Global Goal on Adaptation^{7,8}, which will form a core element of the adaptation assessment framework in AR7¹² and can further guide investment decisions and help prioritize adaptation interventions.

To more intuitively link the RKR–CID mapping with global mitigation requirements under the Paris Agreement, illustrative sectoral emission reduction potentials are provided alongside Global Warming Levels (GWLs) at which individual impact-risk combinations become critical. These metadata are based on IPCC AR6 assessment information, where available, and are further aggregated based on expert judgment. Just under half of the RKR–CID combinations already become critical when global warming exceeds 1.5 °C, while a similar proportion of RKR–CID combinations emerges as critical beyond 2 °C. Plausible explanations for this share of impacts only becoming critical at the 2 °C level include longer durations and chronic impact characteristics. Additionally, those RKR–CID combinations may also capture more complex phenomena, which are still less understood and/or difficult to detect at 1.5 °C. Overall, these results reinforce the dual imperatives of strict mitigation to limit warming and proactive adaptation to manage both near-term and longer-term risks.

The proposed taxonomy is currently a prototype with some limitations. For example, many RKR–CID combinations overlap in terms of their characteristics—such as the CIDs for the RKR ‘Coastal socioecological systems’ and the ‘Coastal’ CIDs for other RKRs—complicating the interpretation of the corresponding metadata analysis results. The mapping also cannot capture compound CIDs, which exhibit unique, event-specific characteristics and influence multiple risk categories, thereby exceeding the operational capacity of a two-dimensional lookup table. Furthermore, while the inclusion of global warming levels supports a more explicit linkage between the Paris Agreement Long-Term Temperature Goal and the IPCC assessment, regional temperature changes may diverge significantly from these global averages¹³. Therefore, a future version of the taxonomy could consider assessing regional temperatures—either in addition to or instead of global warming levels—to enhance the relevance of information for regional and localized risk assessments and adaptation planning.

The metadata compilation and subsequent classifications are based on expert elicitation efforts rather than on systematic, quantitative diagnostics. Although the taxonomy has undergone rigorous quality control, it remains a first version subject to improvements. For this, we envision a collaborative approach that invites and involves the wider research community. To this end, an online version of the taxonomy is accessible at <https://climate-impact-taxonomy-werning2025.streamlit.app>, enabling researchers and practitioners to provide feedback and suggestions that will enhance subsequent versions of the taxonomy.

Ultimately, the taxonomy provides a structured framework that facilitates the connection between WGI physical climate change drivers and the corresponding WGII risk assessment, offering several possible applications. Providers of climate services, for instance, can use the taxonomy to build tailored risk dashboards by filtering RKR–CID entries relevant to a specific region or sector and combining them with real-time or model data to better inform decision-making. Adaptation planners can consult the

adaptation linkages metadata to refine assessments of early warning, monitoring, risk management, or vulnerability reduction needs, depending on local context. At the policy level, the taxonomy, if developed further, can help assess how mitigation efforts—such as phasing out coal or reducing deforestation—cascade through reduced CIDs and specific RKR, highlighting co-benefits and opportunities that span multiple domains of societal well-being.

By providing a machine-readable, metadata-rich lookup table, this climate impact taxonomy prototype lays the groundwork for more coherent and actionable climate impact assessments. We anticipate that future iterations will yield a more robust and granular tool, more directly supporting integrated adaptation and mitigation responses closely aligned with both physical-science evidence and real-world risk management needs.

Declarations

Data and code availability

The taxonomy dataset in xlsx spreadsheet format is available for download on Zenodo (doi: 10.5281/zenodo.17711316)¹⁵. Additionally, an online version of the taxonomy has been created, which can be accessed using the following link: <https://climate-impact-taxonomy-werning2025.streamlit.app>. The code used to generate the online version is available on GitHub (https://github.com/mwerning/streamlit_taxonomy).

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Author contributions

A.N., M.W., and E.B. developed the concept of the study and created the climate impact taxonomy. M.W., E.B., M.A., C.F.S., S.M., L.A.L., V.L., E.M., A.T., and A.N. participated in discussing and improving the study throughout its development. The manuscript was written jointly by M.W. and A.N. with contributions from all authors. M.W. and V.L. produced the figures. The online version of the taxonomy was created by M.W. with contributions from V.L. All authors reviewed and approved the final version of the manuscript.

Competing interests

The authors declare no competing interests.

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Methods

The taxonomy was developed by integrating two IPCC AR6 concepts: the Climatic Impact-Drivers (CID) framework² introduced in WGI and the Representative Key Risks (RKR)⁶ from WGII. Each of the 35 CIDs, which are categorized into seven CID types (Fig. 1a), was systematically paired with the eight RKR (Fig. 1b), resulting in 280 initial RKR–CID combinations. Each of the combinations was evaluated for plausibility, and a total of 17 combinations—such as the combinations of the RKR ‘Water Security’ with the ‘Open Ocean’ CIDs—were excluded. The final dataset comprises 263 unique RKR–CID combinations that were enriched with metadata across five metadata dimensions.

First, climate impact characteristics for each combination were compiled for spatial scale (local, regional, global), temporal scale (minutes to hours, hours to days, days to weeks, weeks to months, months to years, years to decades, decades to centuries), and type of change (change in climate mean, change in climate extremes).

Second, climate impact assessment metadata were added, comprising the IPCC AR6 assessment of CID relevance for natural and human subsystems (none/low confidence, low/moderate relevance, high relevance) for natural and human systems. The evidence is gathered from IPCC AR6 WGI Table 12.2¹⁰, with core subsystems (referred to as assets in the table) directly linked to RKRs and complementary subsystems added from relevant other sectors. The complete mapping is included in the README section of the taxonomy. When specific RKR–CID combinations could not be directly traced in Table 12.2, N/A is used. For example, there is no assessment of natural systems for the RKR ‘Critical physical infrastructure, networks & services’, while human systems have not been assessed for the RKR ‘Coastal socioecological systems’. In total, 188 and 52 of 280 RKR–CID combinations do not have an assessment of natural systems and human systems, respectively. This information is complemented by examples for both natural and human systems, as well as illustrative research needs and examples of modelling approaches.

Third, adaptation linkages were introduced using illustrative adaptation responses by risk component, which follow the IPCC AR6 definitions (hazard focused – physical climatic event/process, vulnerability focused – susceptibility and capacity to cope, exposure focused – presence of assets/people in harm’s way)¹¹. While adaptation responses focusing on hazard could be measures such as reducing the intensity of or interaction with a hazard (e.g., through barriers or buffers) through environmental or engineering actions, measures focusing on the vulnerability component of risk could, for example, make systems more resilient (e.g., through retrofitting) and are rooted in social, technical, or institutional action. Adaptation responses addressing the exposure component of risk could be to change the spatial or temporal patterns of exposure (e.g., through zoning or relocation) through planning or governmental

action. The adaptation responses are complemented by relevant targets from the Global Goal on Adaptation^{7,8}.

Fourth, exploratory mitigation linkages were covered using the critical global warming level qualifier and a sectoral emissions reduction potential example.

Finally, IPCC AR6 chapter references were compiled to trace the assessment used for the high-level taxonomy metadata. Additionally, an outlook for potential relevant IPCC AR7 chapter references was added.

The compilation of the metadata was based on expert elicitation and rigorous quality control, which systematically evaluated each RKR–CID combination to ensure methodological consistency and factual accuracy. The analytical capabilities of large language models (LLMs) were tested for the preliminary generation of the metadata, including OpenAI’s ChatGPT4, ChatGPT4-mini, and ChatGPT4o-mini¹⁴. While these models were constrained to exclusively draw upon authoritative and trusted sources, such as the IPCC and the UNFCCC, the quality of the outputs was inconsistent, and, in the majority of cases, the LLM-generated metadata were revised or replaced.

As our expertise doesn’t encompass in-depth knowledge of all related fields, a collaborative approach is proposed, involving the wider research community to elevate this first draft of the taxonomy into a trusted and community-vetted resource. For this purpose, an online version of the taxonomy has been developed (<https://climate-impact-taxonomy-werning2025.streamlit.app>). The online version allows easy exploration of the data, including the option to filter the data in various ways, and is accompanied by information explaining the data and providing examples of how it can be used. It also features the option to submit feedback on the taxonomy and its contents using a feedback form. On submission, an issue in the GitHub repository containing the code for the online app (https://github.com/mwerning/streamlit_taxonomy) is automatically generated, allowing to track the feedback and the subsequent changes to the taxonomy file. Once changes to the taxonomy are made and a new GitHub release is created, a new version is automatically created on Zenodo.

Figures

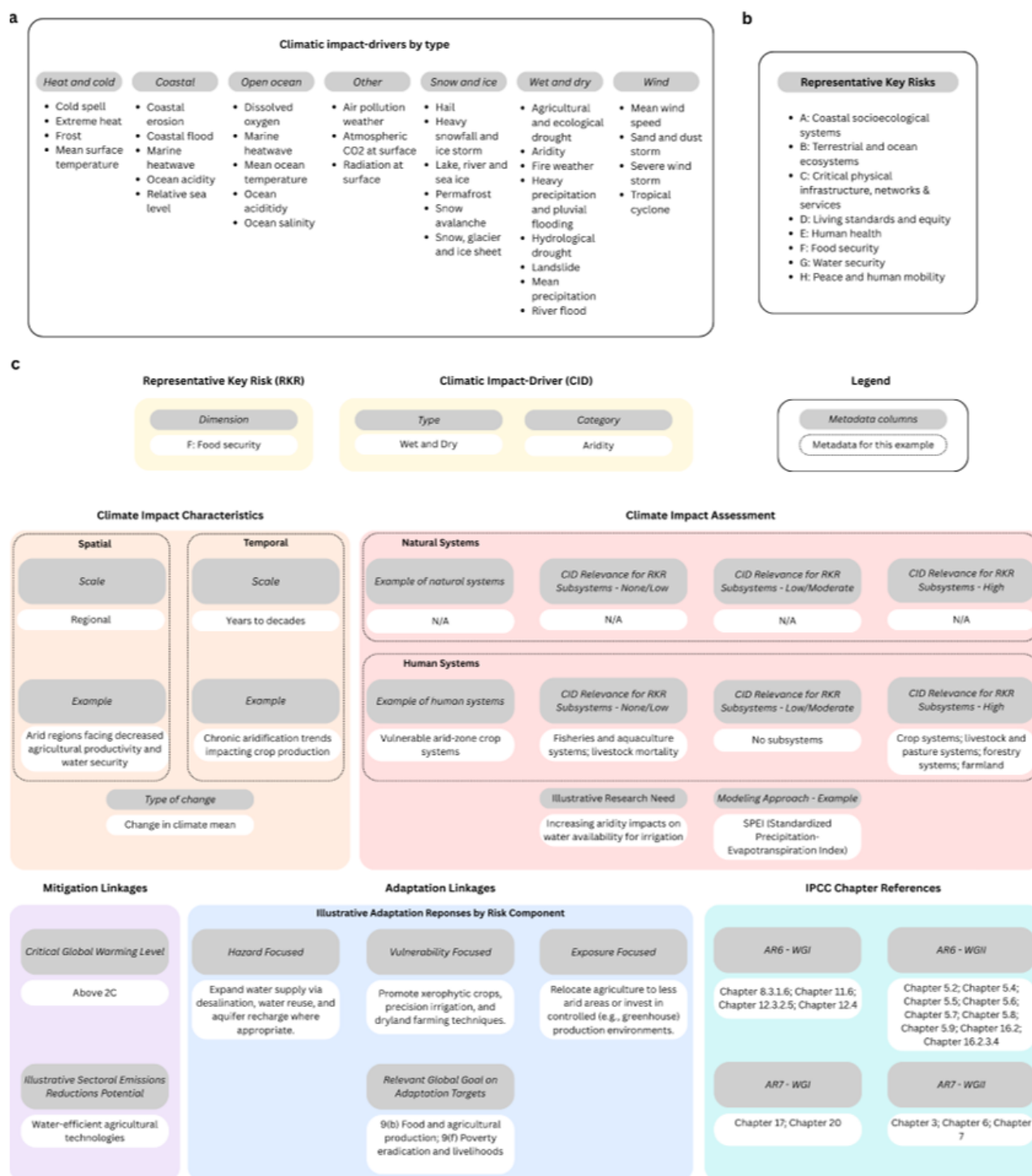


Figure 1

Schematic overview of the climate impact taxonomy and its underlying concepts. Overview of the Climatic Impact-Drivers grouped by CID types from IPCC Working Group I² (a) Overview of the eight Representative Key Risks from IPCC Working Group II⁶ (b) Climate impact taxonomy example for one unique pairing of Representative Key Risk (RKR) 'Food Security' and Climate Impact-Driver (CID) 'Aridity'. Pairings are

enriched with metadata grouped into five categories: climate impact characteristics, climate impact assessment information, mitigation linkages, adaptation linkages, and IPCC chapter references (c).

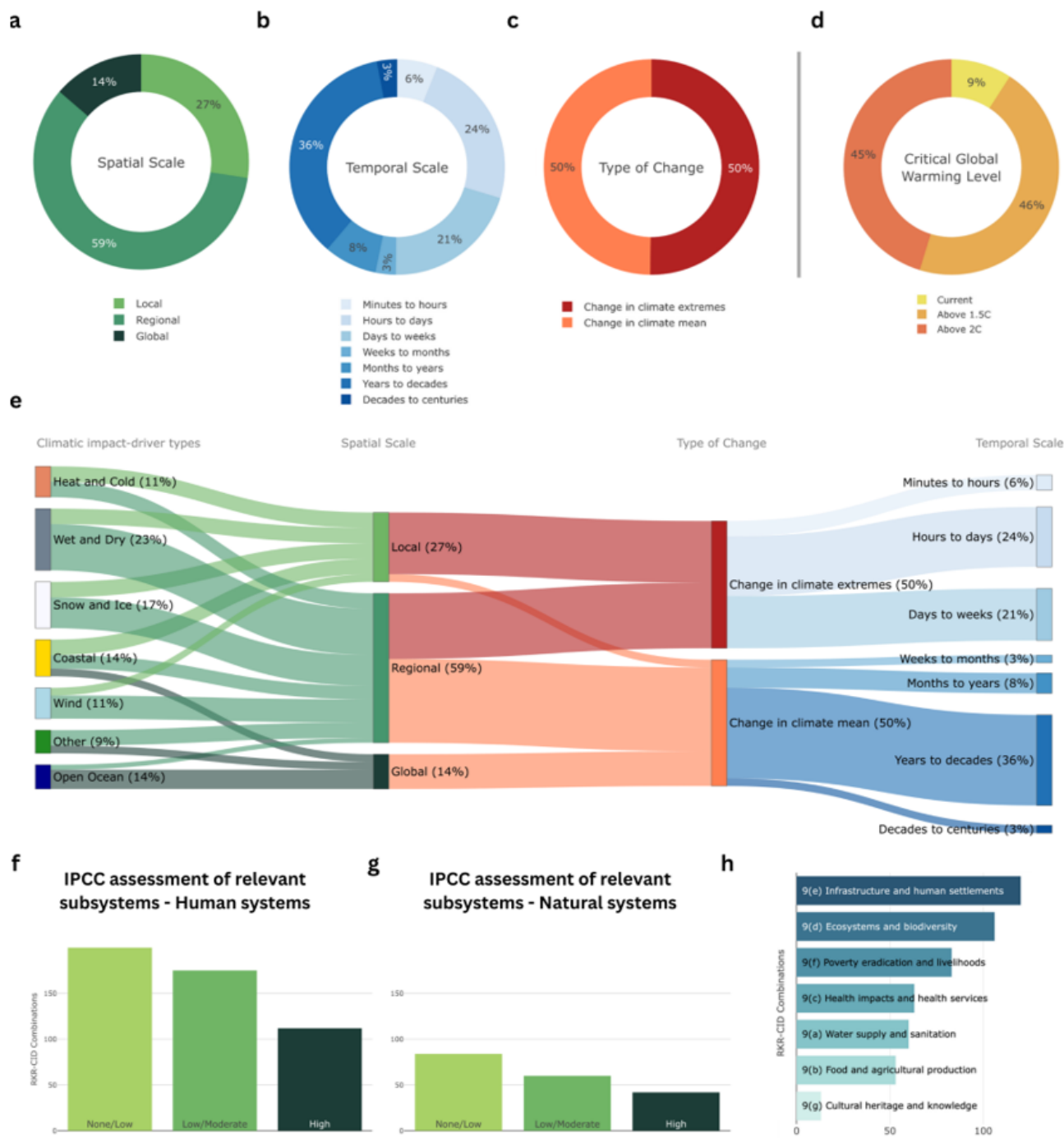


Figure 2

Quantitative analysis of climate impact taxonomy metadata at the global level. Proportions of spatial scale (a), temporal scale (b), type of change (c), and critical global warming level (d) for the RKR–CID combinations in the taxonomy. Mapping of climatic impact-driver categories to spatial scale, type of

change, and temporal scale (e). Number of RKR–CID combinations with subsystems that have been assessed by the IPCC to have none/low, low/moderate, or high relevance to natural systems (f) and human systems (g). Distribution of Global Goal on Adaptation targets associated with the RKR–CID combinations in the climate impact taxonomy (h). Results do not represent the probability or frequency of climate impacts.