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Assessing climate-related non-economic loss and damage and rethinking the relation between L&D and adaptation

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Abstract

The international discourse on loss and damages (L&Ds) under the climate convention is ongoing. Significant attention has been given to a dedicated fund to assist vulnerable countries to recover from climate related L&D. While much of the political discussion focuses on the amount of funding needed and who should pay, less attention is given to risk reduction initiatives eligible for the L&D funding mechanisms. There is also an emerging need to link L&D funding with adaptation (funds) which is not yet being given enough consideration. Against this background, the paper presents different dimensions of L&D for example on severity and compensability, and provides a new perspective that goes beyond the current discourse of economic versus non-economic or direct versus indirect L&D. A global analysis is complemented with a set of L&D related case studies to explore both conventional economic dimensions of L&D, and under-represented dimensions, such as population displacement and human mobility, territory and cultural heritage. These cases highlight how different types of L&D are articulated in climate related initiatives. The cases point towards the need to better connect L&D and adaptation strategies and funding to strengthen climate resilience. The paper informs the ongoing international debate on L&D, highlighting the importance of understanding its different dimensions, the effectiveness of climate-related policies across countries and the need to rethink the concept of L&D as compensation, since this falls short of supporting climate resilience. Recommendations emphasize national and local level monitoring, funding tools and international cooperation.

1. Introduction

Loss and damage (L&D) gained momentum at COP27 in Sharm El Sheikh, Egypt, where the decision to establish a fund was made. The L&D fund then became operational through financial pledges at COP28 in the United Arab Emirates, where the international community agreed on some of the key conditions for the L&D Fund (e.g. interim hosting by the World Bank, sources of funding, and the composition of the board) to support the most vulnerable countries and developing nations affected by climate change-related losses and damages (Salimi Turkamani 2024). Despite the rapid institutionalization of the L&D agenda, assessments of climate-related losses and damages remain largely dominated by conventional economic perspectives (Parker *et al* 2015, James *et al* 2019). Current recovery mechanisms prioritize physical and tangible dimensions of L&D; while underestimating medium- and long-term

impacts associated with intangible losses, such as the erosion of culture, identity, and social cohesion. We argue that better accounting for different dimensions of L&D, on severity and compensability is essential to advance current debates, which often focus on narrow distinctions such as economic versus non-economic or direct versus indirect losses and damages or on compensation schemes like insurance. A multidimensional perspective (see figure 1) can for example help to better understand L&D cascading impacts, such as how the loss of rainforest and habitats can trigger population displacement and, over time, to the erosion of culture and identity.

However, the international discourse on L&D remains highly polarized, particularly regarding legal responsibility for contributing to the funding system, the appropriate scale of finance, and governance arrangements. For instance, some scholars, including Heilinger and Kempt (2025), approach the L&D debate from a climate justice perspective with a long historical lens, emphasizing that the current climate crisis is largely driven by the cumulative greenhouse gas emissions of industrialized countries, which account for around 80% of global emissions. At the same time, financial 'compensation' is criticized as an insufficient response, as many climate-related losses are non-economic—such as impacts on cultural heritage and health—and difficult to quantify but essential to societal well-being (Albro 2024). Also, whether compensatory approaches to L&D contribute to long-term climate resilience remains contested (see section 5).

There is growing recognition that L&D finance should extend beyond compensation and adopt a more proactive approach that prioritizes resilience-building. In this context, stronger integration between L&D finance and adaptation funding is essential to address the full continuum of climate impacts, from risk reduction and preparedness to recovery and long-term transformation. However, such integration remains largely absent from current L&D discourse due to fragmented financial architectures, political constraints, and divergent financing modalities, despite the scale and urgency of needs in vulnerable countries (Albro 2024). Other scholars argue that L&D funds should remain separate from adaptation finance. While this might be politically true, available resources for L&D, adaptation and development cooperation are shrinking, making synergies between these funding streams increasingly important.

Many countries in both the Global North and Global South are already paying in reality millions of Euros to compensate for losses and damages after extreme events. Hence, linking recovery and L&D finance with resilience goals is essential to move beyond a simple L&D compensation. Consequently, this paper moves away from the dominant discourse by (i) identifying major gaps in the current programmatic mechanisms of the L&D funding architecture, and (ii) proposing potential pathways to strengthen the long-term resilience-building orientation of its *modus operandi*.

Moreover, addressing L&D arising from extreme and slow-onset events (e.g. sea-level rise) requires international cooperation. While early initiatives—such as the Alliance of Small Island State's insurance proposal in the 1990s, the establishment of the Warsaw International Mechanism in 2013, and the operationalization of the L&D Fund at COP27–COP28—marked progress, international cooperation has since weakened. Nevertheless, climate-related L&D are a global challenge affecting all countries, regardless of development level, and effective responses depend on international cooperation through the transfer of expertise, financial support, and joint strategies to reduce risk.

Following a global assessment, the paper builds on five case studies from Asia, Africa, Europe and the Pacific to illustrate how different dimensions of L&D manifest in different contexts. The cases examine which losses and damages are typically captured and quantified, as well as those that are omitted or remain poorly defined. They further demonstrate that compensation for L&D with respective L&D funding schemes after extreme events alone is not sufficient to build and strengthen climate resilience. Against this background, the paper discusses (1) underlying conceptual foundation framings, (2) different dimensions of L&D, particularly under-represented dimensions, and (3) the need to go beyond damage compensation approaches in L&D funding schemes and to rethink the relation between L&D and adaptation.

2. Theoretical and conceptual aspects

The concept of L&D lacks a universally accepted definition but is broadly understood as the adverse effects of climate change that persist despite mitigation and adaptation efforts (Warner and van der Geest 2013).

The UNFCCC further defines L&D as the actual and/or potential manifestations of climate change impacts that negatively affect human and natural systems, including both extreme and slow-onset events (UNFCCC 2012). Roberts and Pelling (2018) distinguish between 'L&D' as experienced impacts on the ground—often shaped by local vulnerabilities, and 'L&D' (with capital 'L&D') as a global policy agenda. Conceptual divisions also exist: 'loss' is often seen as irreversible (e.g. permanent disappearance of ecosystems, loss of life or cultural heritage), while 'damage' is repairable (e.g. harm to infrastructure or homes) (Lusk 2017, Page and Heyward 2017). L&Ds are often divided into economic L&D and non-economic or intangible L&D (NELD) (Boyd *et al* 2017). Economic losses encompass the loss of physical structures, resources, goods and services that are

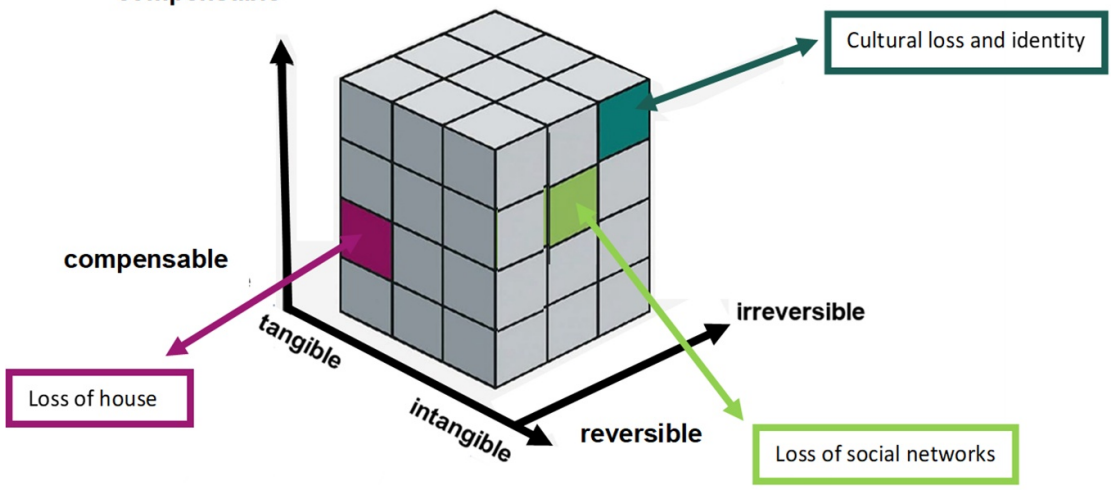


Figure 1. Different dimensions of loss and damage along axes of severity and compensability (*Source*: own figure).

commonly traded in markets, such as the housing or food markets. Non-economic losses refer to L&D for which (i) economic value can be indirectly estimated but is imperfect or ethically challenging to quantify via market mechanisms, or (ii) cannot be quantified or expressed through market-based mechanisms (e.g. cultural heritage, biodiversity, or human lives) (UNFCCC 2013a, 2013b, IPCC 2022). For example, the loss of 'social networks' cannot be captured in monetary terms, since they are intangible and not (directly) compensable with money. However, with community support programs after extreme events, social networks can be restored or reformed and thus are partially compensable. Hence, their loss is in part reversible over time and with support. Among other things, this can depend on the age of those concerned, with younger people more likely to develop new networks. In contrast, the loss of identity is irreversible and non-compensable (see figure 1).

These definitions of L&D remain fluid, shaped by scientific, legal, and policy discourse. Boyd *et al* (2017) proposes four framings or categories for L&D: as (i) preventable via adaptation and mitigation, as (ii) a risk management issue, as (iii) indicative of limits to adaptation, and as (iv) existential. These distinctions underscore the complexity of L&D and the need for nuanced, multidimensional responses in both policy and practice. Through a climate justice lens, L&D is framed as an issue of equity and responsibility, emphasizing that those least responsible for climate change (particularly communities in the Global South) are the most affected (Heilinger and Kempt 2025). This perspective advocates for reparative justice, including financial compensation and accountability mechanisms. Roberts and Pelling (2018) stress the ethical and legal dimensions, highlighting global inequalities and historical emissions. However, the L&D agenda is politically polarized, with tensions between the Global North and South. The failure to meet promised adaptation financing (UNEP 2022) and limited access to funds like the adaptation fund and green climate fund (Wang and Rai 2015, Khan *et al* 2020) further exacerbates this divide, risking a loss of legitimacy in global climate negotiations. The withdrawal of the US from the Paris agreement and from international development aid further questions these international cooperation mechanisms and poses challenges to climate support funds (MacNeil 2025).

Insurance-based responses have gained prominence in the discourse on how to deal with L&D. However, these approaches also face criticism. While offering quick payouts for disasters, they largely overlook slow-onset events (e.g. sea-level rise), non-economic losses and marginalized communities (Gewirtzman *et al* 2018, McNamara *et al* 2021).

Even if we only consider the assessment of economic losses and damages or the economic dimension of L&D, there is a need to further explore whether market prices used in damage assessments can adequately quantify the funding needed for recovery. An important argument for the establishment of the L&D fund under the UNFCCC was that the funding should address the residual costs that cannot be avoided through adaptation and mitigation (UNFCCC 2013a). However, it is not clear that such L&D funding can sufficiently strengthen climate-resilient development without being linked with adaptation (goals) and adaptation funding. The current financial landscape for climate change frequently isolates L&D funding from adaptation finance, leading to disparities in addressing the needs of vulnerable nations, which necessitate a comprehensive and integrated approach.

Emerging demands to establish links between these funds are also increasing due to the limitations of adaptation measures and the unavoidable consequences of L&D stemming from anthropogenic climate change. However, L&D funds also need to contribute to medium- and long-term adaptation, since the pure compensation of experienced L&D in many cases does not allow for building climate resilience or reducing future losses and damages. Finally, L&D funds should, when possible, also contribute to mitigation, for example, when infrastructure or private heating systems that were destroyed are rebuilt (e.g. see case study number 4 in this paper). The lack of explicit criteria defining L&D funding complicates the monitoring and coordination of financial flows alongside other climate finance streams such as adaptation and official development assistance.

While adaptation focuses on anticipating and reducing adverse impacts, L&D initiatives aim to prevent, reduce and address unavoidable and irreversible consequences. This conceptualization and relation between both concepts and funding schemes need to be critically revisited if we aim to develop integrated approaches for climate resilient development (IPCC 2022) and building back better (UNDRR 2017).

3. Methods

The paper combines both quantitative and qualitative methods to meet two objectives: to present selected global patterns of non-economic L&D (quantitative); and to identify different types of L&D at the subnational scale (qualitative). For example, quantitative analysis is used to evaluate global L&D across various categories, including loss of life, the number of people affected or displaced by climatic hazards and cultural heritage sites at risk. This assessment is complemented by qualitative case studies at the regional level that explore different types and dimensions of L&D. A document and literature analysis was used for the case studies, since post-impact quantitative assessments of L&D tend to capture solely economic and physical losses and damages. In addition, qualitative methods using document and literature analysis, were key to identifying major gaps in the current programmatic mechanisms of the L&D funding architecture.

3.1. Document and literature analysis

The assessment is based on a (preliminary) review of academic publications and gray literature, including policy documents that set out the rules for establishing the L&D fund and guidelines for post-disaster L&D assessment. The analysis of literature focused on the operationalization of the new L&D funding structures (see UNDP 2023) and examines whether and how L&D dimensions were considered in determining funding needs. A search was carried out in the web of science using search terms such as 'non-economic', 'non-material', 'non-monetary', 'non-financial', 'non-marketable', 'intangible', 'harm', and 'residual risk'—in combination with the term 'L&D'. The document analysis encompassed, for example, the examination of guidelines for post-disaster recovery and the reporting of losses and damages after disasters.

3.2. Quantitative data for the international analysis

The quantitative data on fatalities and populations affected by climate-related hazards, such as floods, droughts, storms, extreme temperatures, and wildfires, were collected from the emergency event database (EM-DAT) of the center for research on the epidemiology of disasters for the period between 2008 and 2023 (EM-DAT 2025). Information on climate-related displacement was obtained from the internal displacement monitoring center (IDMC) of the Norwegian Refugee Council (IDMC 2025). Displacement data is only available for the period 2008–2023, so EM-DAT data for the same period was used.

Both data sources have limitations, including underreporting of smaller or slow-onset events, inconsistencies in loss estimates, and gaps in monitoring some regions. Political sensitivities and difficulties in distinguishing climate-related impacts and displacement from other causes pose additional challenges. Nevertheless, EM-DAT and IDMC remain among the most widely used global datasets for multi-hazard and cross-country analysis in climate risk research with the highest quality, comprehensibility, consistency and reliability (see e.g. Huggel *et al* 2015, Muhamad *et al* 2021, Kageyama and Sawada 2022, Ceola *et al* 2023, Mester *et al* 2023a, 2023b, 2025, Delforge *et al* 2025). This data has a national scale resolution, making comparison between countries and regions possible.

We also used a wide range of data gathered for measuring human vulnerability based on the world risk index (see Birkmann *et al* 2022) and the inform risk index, primarily focusing on vulnerability and lack of coping capacity (EC-DRMKC 2025). A combined vulnerability index (see Birkmann *et al* 2022, IPCC 2022) was employed to relate it to information on L&D associated with climate hazards (e.g. displacement, deaths, population affected, and cultural heritage sites). Vulnerability assessments are different from (hazard) exposure mapping (see Birkmann *et al* 2022). In addition, countries are organized by income groups to explore potential links between global patterns of L&D, income capacity, and vulnerability (see table S1 in section 1 of supplementary material that contains a list of countries categorized according to income groups, vulnerability classes and their index values). In our global comparative analysis reported below, we applied both descriptive and inferential methods (see section 2 of supplementary material).

3.3. Qualitative data focusing on selected case studies

The qualitative data used in the five case studies came primarily from published work or gray literature and findings from our own research. The case studies were selected to (1) represent countries with different economic development levels, geographies and governance systems; (2) show a diversity of water-related hazards, including sea level rise (Solomon Islands and Fiji), flooding (Benin, Pakistan, and Germany), and typhoons (China); and (3) a focus on intangible or non-economic losses, which are less represented in conventional L&D assessments. The different patterns of L&D provide an opportunity for cross-comparison of the cases. In addition, the cases provided information on how losses and damages were assessed, addressed and compensated. (Note that this information was not available in the same way for L&D regarding heat stress.) Hence, the qualitative data from selected case studies provide new insights about different L&D dimensions and also show that some dimensions are often omitted in conventional L&D reports.

4. Global patterns of L&D

In this section, we provide an overview of selected L&D dimensions and their spatial distribution at the national scale resolution. Emphasis is given to non-economic L&D, particularly (a) loss of life due to climate-related hazards, (b) population displacement, (c) the population affected, and (d) cultural heritage sites at risk. These L&D dimensions and their spatial distribution globally are examined below in terms of human vulnerability, country income groups and country profiles (see table 1 and additional information in section 3 of supplementary material). Global hotspots for specific dimensions of L&D are also identified. The results offer guidance for the sub-national case studies.

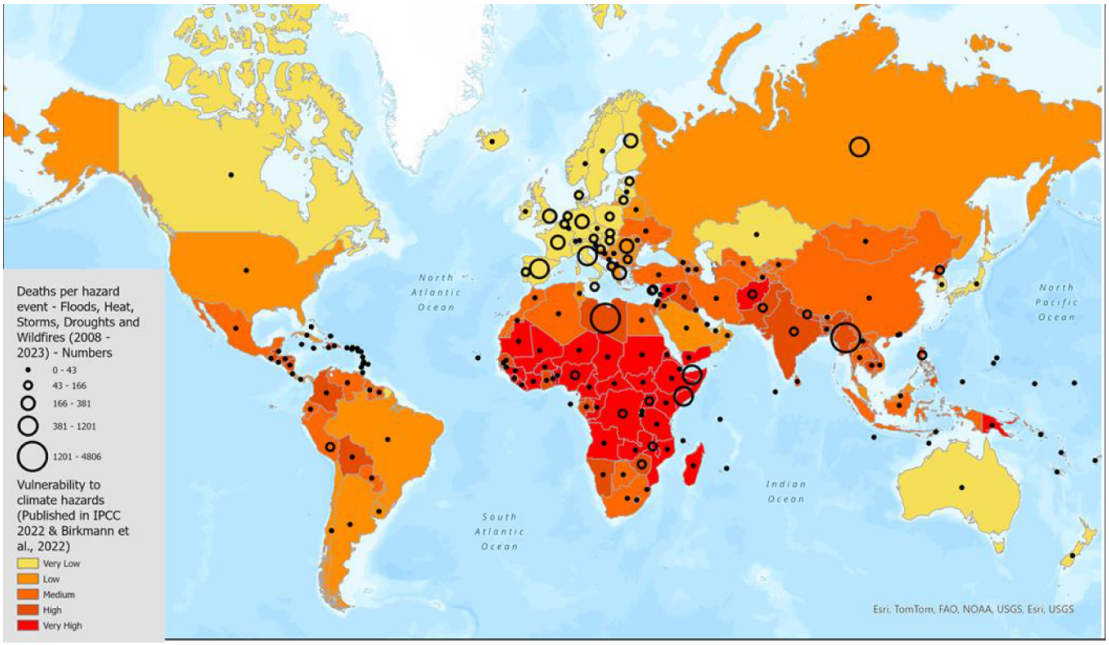
(a) Climate hazards have caused about 500 000 deaths across 5000 events between 2008 and 2023 (EM-DAT 2025). The global assessment shows that mortality per hazard event is nearly twice as high in countries with high and very high vulnerability (figures 2(a) and (b)). In absolute numbers, these countries account for just over half (55%) of climate hazard-related deaths in EMDAT, while countries with very low vulnerability account for only a quarter (23%). Along a similar line, low and lower-middle-income countries account for half (53%) of the hazard-related deaths, while high-income countries account for about a quarter (26%) of the total fatalities due to climate-related hazards (see figures 2(a) and (b)). The analysis reveals that the global death pattern from 2008 to 2023 includes not only the most vulnerable countries but also European nations, particularly due to heat-related deaths (see EM-DAT 2025 and figure 2(a)).

(b) Global analysis of population displacement due to climate change shows a significant impact in the most vulnerable countries (see figures 2(c) and (d)). In terms of the absolute number of displaced people due to climate-related hazards, countries with large populations dominate: China (82.15 million displaced), the Philippines (59.68 million), India (56.27 million), Pakistan (24.3 million) and Bangladesh (18.5 million) have the highest values from 2008 to 2023. However, when considering the proportion of the population displaced (as a percentage) between 2008 and 2023, it is the highly or very highly vulnerable countries in Africa and elsewhere that suffer most from this phenomenon. For example, in Somalia and South Sudan, 36% and 23% of the total population were displaced, respectively. In Asia, this figure is 52% and 11% for the Philippines and Bangladesh, respectively. An alternative representation using a displacement rate per 100 000 population produces the same spatial patterns and relative country rankings (see figure S1 in the section 2 of supplementary material).

The proportion of the total population displaced between 2008 and 2023 in 'very highly vulnerable countries' is eight times higher than in countries considered to have very low vulnerability. Similarly, in low-income countries, displacement is four times higher than in high-income countries. Of the 10 countries that rank highest in terms of the percentage of people displaced, six are small island developing states (SIDSs). Their size and coastal context make it more likely that most of the country and the population will be impacted by extreme events (see figures 2(c) and (d)). Most of these small island countries are classified as low to lower-middle income states with vulnerability levels from medium to very high. Worldwide, it is estimated that up to 216 million people will be displaced by 2050 due to climate-related hazards, with a large proportion of these likely to be in Africa, East Asia and the Pacific (Clement *et al* 2021).

(c) In terms of population affected by climatic hazards, our analysis (see figures 2(e) and (f)) highlights that hotspots predominantly consist of countries classified as low and lower-middle-income, as well as those with high or very high vulnerability to climate change. On average, more than 10 million people affected between 2008 and 2023 by climate-related disasters belong to countries categorized with very high vulnerability or low income. In contrast, in high-income and low-vulnerability countries, the number of affected people was about 0.3–2.6 million during the same period. Vulnerability levels greatly influence the number of people affected in each climate hazard event. From 2008 to 2023, countries with very high vulnerability had 36 times more

(A) Global map of deaths per climate hazard event (2008–2023) and human vulnerability



(B) Average deaths per climate hazard event (2008–2023) by vulnerability class and income group

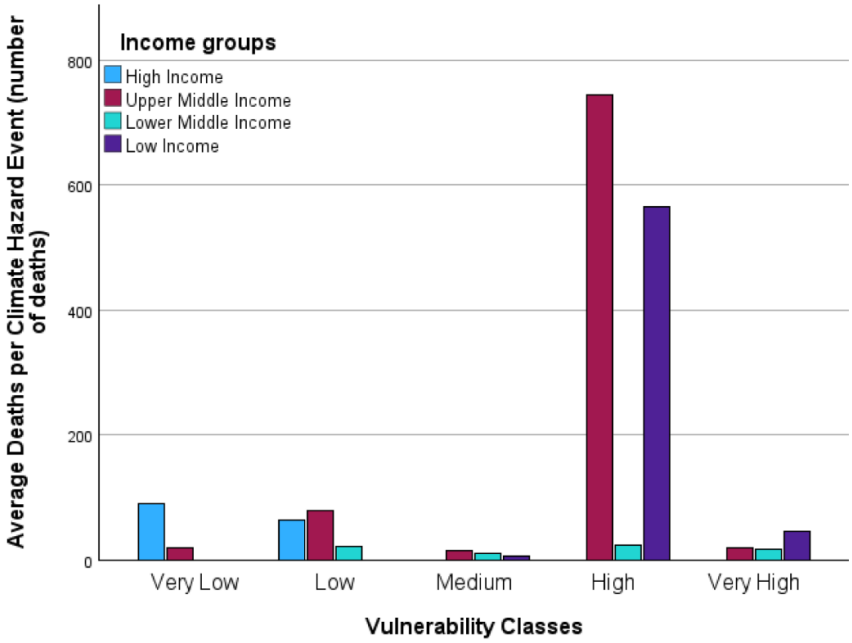
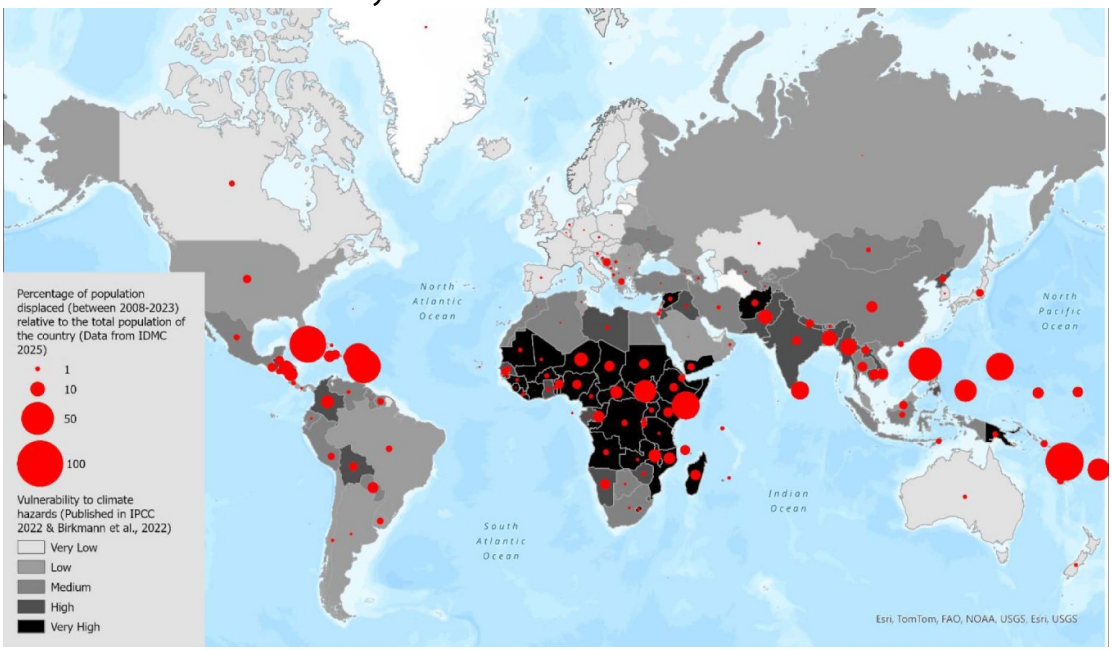


Figure 2. Global patterns of selected dimensions of loss and damage along vulnerability classes and income groups of countries. (A) Global map of deaths per climate hazard event (2008–2023) and human vulnerability, (B) Average deaths per climate hazard event (2008–2023) by vulnerability class and income group, (C) Population displaced relative to national population (2008–2023) and human vulnerability, (D) Average number of people displaced by climate hazards (2008–2023) by vulnerability class and income group, (E) Global map of population affected per climate hazard event (2008–2023) and human vulnerability, (F) Average population affected per climate hazard event (2008–2023) by vulnerability class and income group, (G) Cultural heritage sites at risk overlaid on the global human vulnerability mapIn this context, the term 'climate influenced' refers specifically to the role of hazards, which are considered a key trigger for displacement according to the data source. However, we also acknowledge that displacement processes are often driven by various factors.

(C) Global map of population displaced relative to national population (2008-2023) and human vulnerability



(D) Average number of people displaced by climate hazards (2008–2023) by vulnerability class and income group

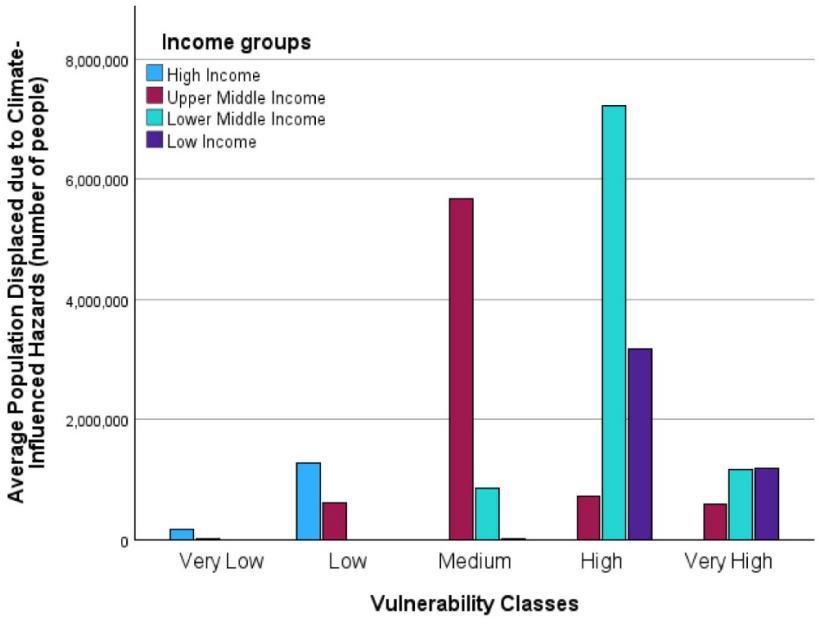
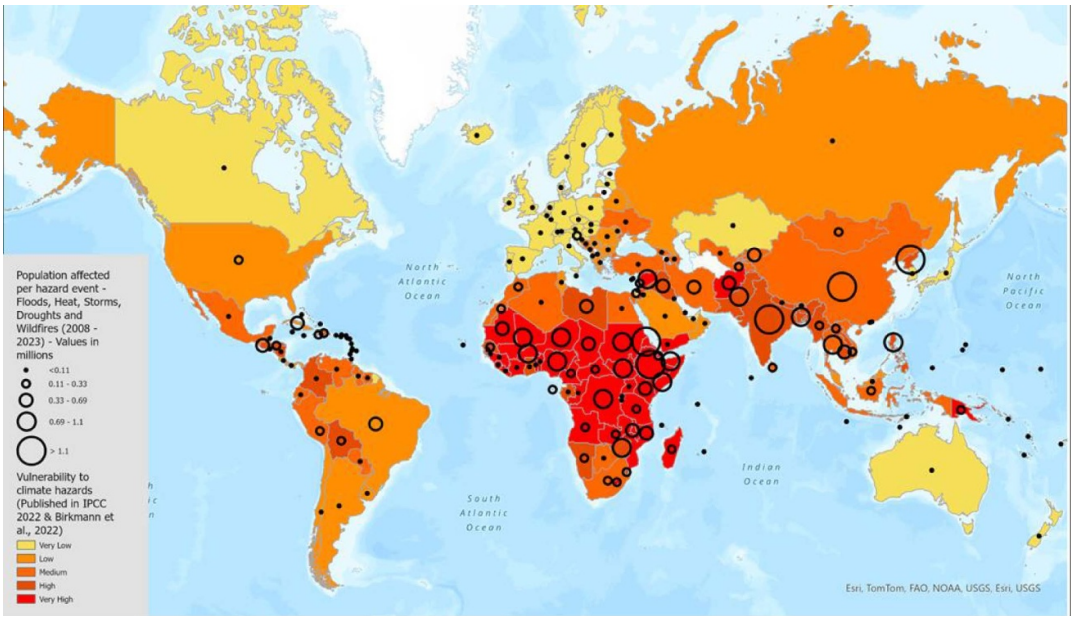


Figure 2. (Continued.)

impacted individuals than those with very low vulnerability. In low-income countries, the affected population was six times higher than in high-income countries. China, classified as having medium vulnerability, had around 2.7 million people affected per event and therewith ranks highest in terms of people affected (not people killed). Pakistan classified as highly vulnerable ranks among the top ten for people affected by climate hazards between 2008 and 2023.

(d) the global analysis of cultural heritage sites at risk due to climate change (see figure 2) also underscores that most of the cultural heritage sites at risk are located in regions with high to very high vulnerability, particularly across Sub-Saharan Africa, the Middle East, and parts of South Asia. Several sites in Europe and the Mediterranean also appear in regions classified as medium vulnerability. However, it also important to note that there are various cultural heritage sites in other world regions that are negatively

(E) Global map of population affected per climate hazard event (2008–2023) and human vulnerability



(F) Average population affected per climate hazard event (2008–2023) by vulnerability class and income group

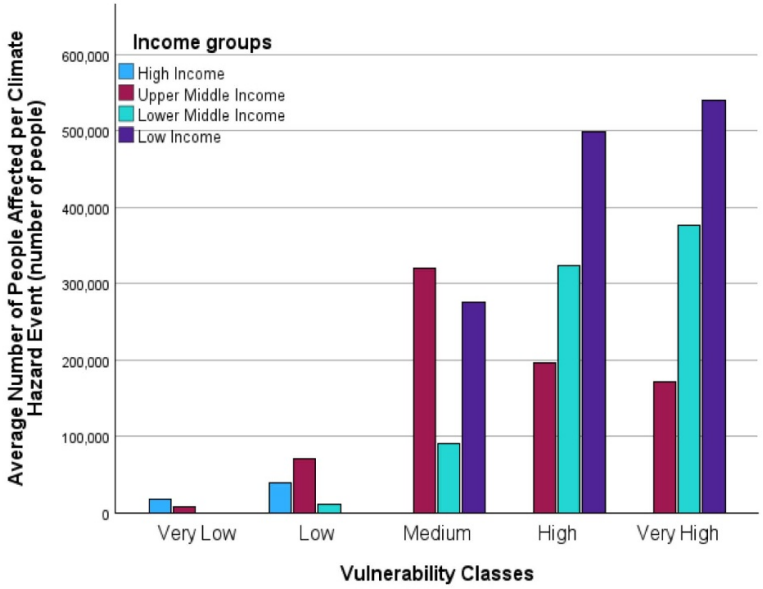


Figure 2. (Continued.)

impacted by climate change, but not listed as 'sites at risk' within the UNESCO classification. All maps show proxy indicators for different dimensions of non-economic L&D.

The global assessment reveals that the most vulnerable and least wealthy countries are disproportionally affected by both economic and non-economic L&D. For example, the majority of cultural sites at-risk are situated in countries that are highly or extremely vulnerable (see figure 2). The concentration of cultural sites at risk in these country groups is likely to stem from a high exposure to climate hazards and their limited ability to adapt to their impacts (Chen *et al* 2025). The data presented highlights UNESCO's highest-level of cultural heritage sites. It is important to note that many valuable sites, such as those significant to indigenous heritage in regions like Australia, are not included in this list. UNESCO does offer several other categories for cultural heritage, but this analysis prioritizes sites specifically classified by UNESCO as 'at risk'. The current list and accompanying map also underscore a need

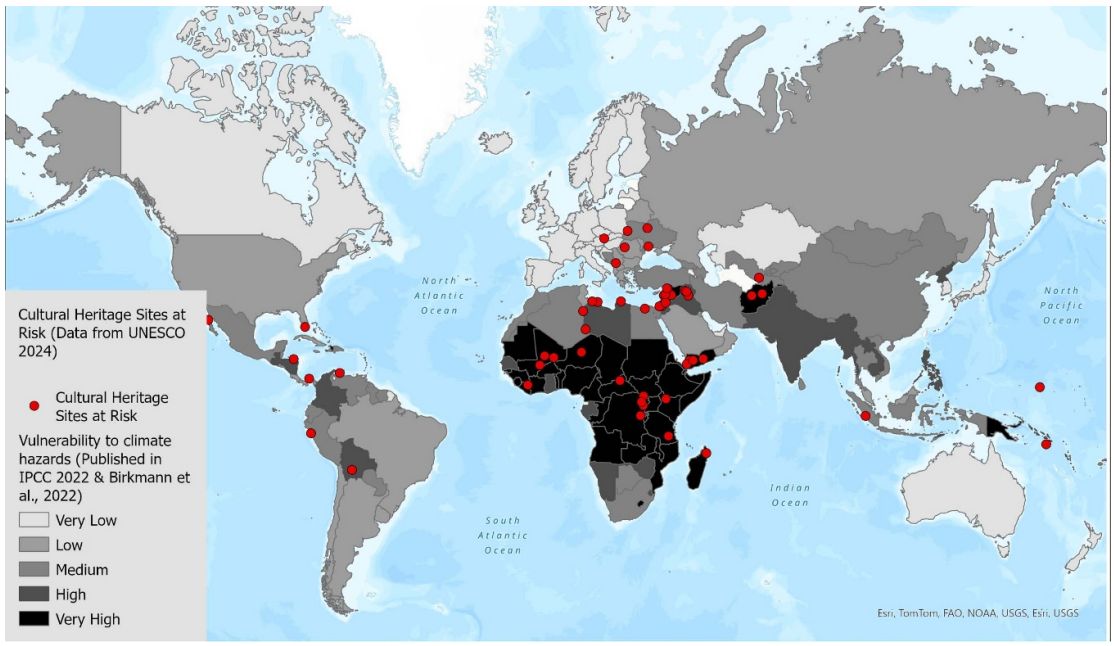


Figure 2. (Continued.)

to further improve and expand monitoring systems to better account for diverse and vulnerable heritage sites around the world.

The non-parametric Kurskal–Wallis test (see table S2 in section 2 of supplementary material) shows that the variation in deaths and displacement between income groups and vulnerability classes is statistically significant, with severe non-economic losses and damages in low-income, highly vulnerable countries. However, there are significant differences between the various dimensions and their spatial distribution. For example, displacement from climate hazards is severe in vulnerable island states like Dominica, Cuba, Sri Lanka, and the Philippines. Global hotspots for this type of L&D are in Central America, Africa, Asia, and Oceania.

The number of people affected per climate hazard event is highest in the most vulnerable countries, with Africa being a key hotspot, followed by South Asia. The L&D dimension of fatalities due to climate related hazards is also linked to the level of human vulnerability. However, we also see high levels of fatalities reported in Europe, largely because of heat stress where elderly are most vulnerable and most adversely affected (Rai *et al* 2019, Winklmayr *et al* 2022). It is important to note that EMDAT records do not capture the true scale of heat-related deaths in these regions in the global south (as indicated by the limitations of such data sources in the section 3). Despite this limitation, the data still indicate that loss of life, displacement, and populations affected are significantly higher in low-income and highly vulnerable countries, although the magnitude of heat-related fatalities may be substantially higher than reported.

Overall, the global assessment, and supporting data, often mask critical nuances in how L&D, exposure, and vulnerability interact within individual country groups. In addition, some limitations of the data used become visible (e.g. regarding cultural heritage sites at risk). Nevertheless, the data highlights stark disparities and underscores that loss of life, displacement, and populations affected are significantly higher in low-income and highly vulnerable world regions. However, the loss of life from extreme events, especially heatwaves in Europe, shows that specific climatic hazards also impact developed countries significantly.

5. Sub-national and local case studies

Following our global assessment (section 4) we examine five case studies to explore the manifestation of L&D at the local and sub-national scales. The case studies represent losses and damages from different hazard types, particularly floods, sea-level rise and storms. The countries involved represent different income groups ranging from low-income countries like Benin, to lower middle income countries like Solomon Islands and Fiji and Pakistan to upper middle-income countries like China and high-income countries like Germany. They also represent a range of governance systems, although these do not form part of the analysis.

Table 1 provides an overview of the case studies, the country in which they are located, the L&D

Table 1. Overview of case studies: countries, loss and damage dimensions and hazard type.

Case study	Country (world-region)	Loss and damage dimensions	Hazard type (year)
1	China (Asia)	Sectoral losses (e.g. agriculture, forestry, and energy) Loss of life, loss of human health, ecosystems and coastal resources	Storms (2024)
2	Solomon Islands/Fiji (Pacific)	Loss of life Loss of tradition and culture Large losses and damages within the healthcare system Losses in terms of social and mental health Loss of livelihoods	Flooding /SLR (various years between 2015–2025)
3	Benin (Africa)	Loss of life; loss of place/culture	Flooding (2010)
4	Germany (Europe)	Loss of life Economic losses in different sectors Loss of social networks Losses and damages in terms of mental and social health Loss of education time due to school closing	Flooding (2021)
5	Pakistan (Asia)	Loss of life Loss of place, culture, health, and education Loss of livelihoods	Flooding (2022)

dimensions and the related hazard. The table shows that case studies come from different contexts, offering an opportunity to document contrasting manifestations of L&D across different climatic conditions and geographies.

The countries rank differently on the core indicators discussed in the previous section (see section 4). While Fiji and Pakistan rank relatively high in terms of population displaced due to climatic hazards as a percentage of the total population, Benin and Solomon Islands are placed in the middle and Germany shows low values. However, in terms of fatalities between 2008 and 2023 Germany ranks quite high due to heat related deaths. Fatalities per hazard event are also high in Pakistan, while the number is significantly lower in Fiji and Solomon Islands. In terms of people adversely affected Pakistan, Benin and Fiji rank quite high and therefore have faced severe losses and damages in terms of people adversely affected (see section 3 of supplementary material).

5.1. Sub-national case studies

5.1.1. China—super typhoon Yagi

Climate change, particularly the escalating frequency and severity of extreme events along with compound risks, has already led to widespread adverse impacts on both natural and human systems in China. Recent research shows that about 27% of the direct economic losses caused by extreme events can be attributed to human-induced climate change. This direct loss is further amplified through industrial chain transmission, triggering indirect economic losses of up to 12.8 billion USD, bringing the total climate change-related economic loss to 24 billion USD, equivalent to 2.14 times the direct loss. In terms of disaster types, typhoons had the highest proportion (81%) attributable to climate change (Wang *et al* 2025, Wang and Xiang 2025). In 2024, the average surface temperature in China once again reached a record high, and the 10 warmest years in China since 1901 all appeared in the 21st century (Climate Change Centre of China Meteorological Administration 2025).

The super typhoon Yagi that caused severe losses and damages is the strongest experienced in China in autumn since meteorological records began, and it is also the strongest typhoon in China in the past 10 years. It affected more than 5.4 million people, four people died and it was extremely destructive causing direct economic losses of 10 billion USD (approx. 8.6 billion Euros), accounting for almost one tenth of Hainan province's GDP in 2023 (Ministry of Emergency Management of the People's Republic of China 2025). Much attention has been dedicated to economic losses in sectors such as agriculture, while few assessments have been conducted on non-market sectors such as human health, ecosystems, and coastal resources (Wang *et al* 2025, Wang and Xiang 2025). The number of people adversely affected is also captured as an indicator for non-economic losses, however, limited information exists on tangible and non-compensable losses and damages. Yagi has caused not only physical and economic

losses, but also is perceived as a warning on how climate change affects human living conditions and the environment.

5.1.2. Solomon Islands and Fiji—sea-level rise and flooding

SIDS, including Pacific Island Countries are inhabited by predominantly rural populations with limited resources including freshwater and sanitation, transport and other infrastructure, healthcare facilities, and market access—making them very vulnerable to climatic hazards (MacDonald *et al* 2017). In terms of exposure, the South-west Pacific Island Countries and Territories are seen as the world's most exposed to natural hazards (Walsh *et al* 2019). Losses and damages from climatic hazards are increasing and in combination with high levels of human vulnerability and exposure pose an existential threat for some communities (IPCC 2019, Jolly 2019, Oppenheimer *et al* 2019, Pacific Islands Forum 2022, Duvat *et al* 2021a, Duvat *et al* 2021b). Most assessments of L&D by international organizations and national aid agencies use readily available data and include what is countable—focusing on officially recorded losses and damages. However, many processes where losses and damages occur are not captured in official data. For example, the informal sector is usually not sufficiently captured. This is problematic, since e.g. in Solomon Islands 85% of women and 77% of men were engaged in the informal economic sector (Woo *et al* 2019).

Intangible and non-compensable losses and damages are highly relevant in these countries (Handmer *et al* 2025). For many Pacific Islanders, the human and non-human world are inseparable (Teaiwa 2015, Monson 2023). People are not simply 'guardians' of specific places, but are genealogically related to, and responsible for them (Teaiwa 2015). Hence, the 'health' of land- and sea-scapes, and the maintenance of cultural heritage and practices, is directly related to mental and physical wellbeing (McNamara and Westoby 2011a, 2011b, Yates *et al* 2022).

Reports from these countries underscore that irreversible and non-compensable losses emerge. For example, when some Samoan communities relocated due to climate hazards, they lost their ways of life permanently (Humanitarian Advisory Group 2024). This also means that land and the related connections to people are irreversibly lost. This has wider implications (see section 3.2 of supplementary material), for example, different linguistic groups are being brought closer together in fewer habitable areas, resulting in a decline in the use of indigenous languages. Finally, the SIDS and PICs are examples where climate-related losses and damages also encompass severe disruptions to health-related infrastructure (Hadwen *et al* 2015) (see also section 3.2 of supplementary material).

5.1.3. Benin—flooding

Of the West African countries affected by severe flooding in 2010, Benin was among the hardest-hit (Tazen *et al* 2019). Non-economic losses encompassed 46 reported deaths with approximately 180 000 people displaced and 55 000 houses damaged (OCHA 2010, Zahiri *et al* 2016, Behanzin 2022). While annual flooding is common in the country during the rainy season, climate change has induced shifts in rainfall patterns (Li *et al* 2016). Rapid and uncontrolled urbanization in flood-prone areas along with poor management of drainage infrastructure have compounded its impacts. The 2010 floods were the worst the country had experienced since 1963 (Hounguè *et al* 2021). Communities from most impacted locations (e.g. in Southern Benin, see Ozer (2019) were relocated. These responses to the flood disaster contributed to indirect damage, such as livelihood and income losses after the move. This meant severe additional losses in terms of livelihood security and income generation for about 1000 small-scale farmers who make their living from fishing and agriculture. Additional challenges emerged when people had to build their new houses with material that would not withstand future extreme rainfall and floods (Ahouangan *et al* 2014), see also section 3.3 of supplementary material). Conflicts with other communities in the new area emerged and caused problems in terms of access to water and healthcare leading to an outbreak of waterborne diseases among children (Gemenne and Blocher *et al* 2017).

5.1.4. Germany—heavy precipitation and flooding

Severe floods in central Europe and Germany in the summer of 2021 due to heavy precipitation caused more than 180 fatalities and widespread destruction of entire regions. The Ahr Valley in Germany was one of the most adversely affected areas with more than 135 deaths and major destruction (Wenzel *et al* 2024). This event was particularly severe because the region has a high proportion of older people and much critical and sensitive infrastructure (services) was highly exposed to the flood. That means various critical infrastructure, such as electricity, communication and water supply, were hit and unavailable during the flood disaster. The flood destroyed several hundred houses and major infrastructure. The amount of waste after the flood was 400.000 tons which is equivalent to 40 years of normal waste produced in the region. While some studies exist on how flooding impacted different dimensions of health (including trauma) and the environment, the conventional reporting of L&D in Germany is focused on fatalities and economic losses in the private and public sectors, infrastructure damages, and L&D in agriculture and forestry (see e.g. BMI and BMF 2021).

The federal government of Germany and the federal states affected established a reconstruction fund of 30 billion euros. Most of the initial reconstruction funding was dedicated towards L&D compensation rather than strengthening medium and long-term climate resilience in reconstruction (Birkmann *et al* 2023). For example, supporting climate resilience and adaptation in reconstruction requires, in part, the modification of structures and areas that were neither destroyed nor directly impacted. Today, modifications to the funding schemes make it easier to finance reconstruction on alternative sites or to higher protection standards (see section 3.4. of supplementary material).

5.1.5. Pakistan—flooding

In Pakistan, extreme floods in 2010 and 2022 caused over 3000 fatalities, affected nearly 50 million people, displaced around 20 million for both short and long durations, destroyed over 3 million homes and over 3 million hectares of cropped area, and resulted in economic losses of US$28 billion (Jamshed 2021, Jamshed *et al* 2021, Qamer *et al* 2023). In addition to their medical function, health facilities play an important role in children's nutrition. It was estimated that 13% of these facilities across the country were compromised due to the 2022 flooding, resulting in a substantial increase in malnutrition (Weibel and English 2022, Akthar and Reid 2024). Further, an eight-fold increase in dengue cases and a three-fold increase in malaria cases were reported during the 2022 flood compared with previous years, causing significant health related losses. More than 27 000 schools were destroyed, making education opportunities inaccessible for more than 2 million people (UNICEF 2022). Prolonged school closures heighten the risk of children permanently dropping out of education (UNICEF 2022). Severe damaged also occurred to agricultural crops and loss of land due to erosion. In response, the government announced compensation for affected people based on the extent of damage to houses and farmland, and a citizens' damage compensation program was launched to support flood-affected populations (see section 3.5 of supplementary material). However, funding schemes have predominantly addressed economic and tangible losses and damages (McNamara and Jackson 2019). Additional funding for strengthening resilience and building back better was often lacking (Clark *et al* 2018). Existing compensation packages for L&D also in part reinforced existing socio-economic inequalities (see section 3.5 of supplementary material).

6. Discussion, recommendations and conclusion

The selected five case studies from Africa, Asia, Europe and Oceania highlight the multi-faceted nature of climate related L&D at a sub-national level that cannot sufficiently be captured by economic metrics alone. These cases show that in many regions, existing methods and data mainly focus on the economic and tangible, rather than on non-economic and intangible losses and damages. In this regard, significant data and methodological gaps still exist.

The case studies indicate that while economic aspects of L&D assessments are important for decision-making, focusing solely on them can be misleading. Most of the L&D dimensions outlined in the case studies and the global assessment encompass a combination of direct and indirect impacts. Moreover, similarities between the case studies can be found. For instance, climate-related L&D significantly affect communities, including the loss of cultural identity, traditions and heritage, as well as emotional and psychological challenges for those impacted (Pearson *et al* 2023). There are also intangible, non-economic and indirect losses and damages from relocation.

Observed L&D patterns also result from events of unprecedented magnitude, such as the typhoon in China or the Ahr-Valley floods in Germany. Consequently, the frequency and magnitude of climate related extreme events might also challenge the conventional idea of compensation payments after disasters, in that some losses such as from relocation or loss of land might not be able to be compensated. This is particularly the case in Benin and the Pacific islands, but is increasingly experienced very widely. Another issue is the scale of losses combined with the challenges of attributing individual responsibility for climate change, which makes it difficult to design effective compensation systems (Effiong *et al* 2024). However, attribution of some climate extremes to specific entities might soon become possible (Quilcaille *et al* 2025). More generally, the conventional approach too often fails to reduce future risk.

The case studies show that present measures to address L&D are designed to compensate losses, promoting reconstruction and relocation projects rather than investing in resilience building for the long-term. This would require the consideration of adaptation and resilience goals and funding that can also be used in part for improving non-affected structures. A robust connection between the compensation of L&D and the enhancement of long-term resilience must

also be reflected in the respective L&D and adaptation support finance schemes. More in-depth assessments of the intangible dimensions of L&D are usually absent and only partially considered in reconstruction funding schemes (Arosio *et al* 2024). There is also a crucial need to better account for the indirect damages that occur not immediately during or after the extreme event, but rather later and at a distance from the direct impact observed.

6.1. Specific recommendations

a) Improve existing monitoring and assessment tools

International negotiations must focus on improving funding and ensuring that all direct and indirect, tangible and intangible, L&D are considered and acknowledged by governments and the international adaptation funding schemes. As an important basis, there is also a need to improve monitoring tools at different scales. This encompasses on the one hand an improved consideration of the multifaceted nature of L&Ds in monitoring and reporting systems, and on the other hand, linkages are needed between global assessments and local L&D case reporting tools. The case studies revealed specific loss types that occur in certain cases and regions, which should be considered and monitored, even if they are not relevant for all countries. Furthermore, the examples from countries that have advanced monitoring and warning systems for extreme events and climatic hazards (compared e.g. to many developing countries)—such as China and Germany—show, that systematic monitoring and documentation of various L&D dimensions after extreme events is not actually in place, particularly in terms of non-economic L&D. We find that monitoring systems focus primarily on the economic dimensions of losses and on direct impacts. Consequently, there is a need to strengthen tools that assess different dimensions of L&D, particularly non-economic and indirect L&D. In addition, tools are needed to assess how measures to buffer and reduce L&D affect local communities, businesses, and recovery processes.

b) Linking L&D with adaptation

Currently, recovery funding for L&D predominantly emphasizes immediate tangible economic and physical losses (e.g. needs assessment), often neglecting the longer-term effects of intangible losses like cultural or identity losses (Tietjen and Gopalakrishnan 2023). Discussions around creating a global L&D fund under the UNFCCC should integrate principles of 'Building Back Better', particularly focusing on the element of time. Addressing the need to build back swiftly is crucial. Effective and quick distribution mechanisms are similarly important as mechanisms that ensure that resilience and adaptation goals are also considered within reconstruction strategies and L&D funding schemes. To ensure that L&D funding also supports the reduction of potential future L&D and strengthens community resilience, it is crucial that affected communities receive support to develop resilience measures to better prepare for future events and are not limited to compensation payments for experienced losses and damages.

Rather than focusing on restoring conditions to what communities experienced before climate-extreme events, we argue that a portion of the funding should be allocated to implement resilience standards and adaptation (adaptation goals). Various insurance and social protection systems can help buffer losses but typically provide very limited funding for enabling transformative changes, such as improving physical structures (e.g. higher resilience standards for key infrastructure) or livelihoods. Additionally, affected countries require integrated approaches, which will necessitate new forms of cooperation and collaboration. This involves not only working through national governments but also fostering partnerships with local entities and regional organizations.

c) L&D funds need to account for complex and cascading risks

In contexts of increased frequency, unpredictability, and intensity of extreme weather events such as flooding, people at risk for example living in small island states face a triple health burden. These events contribute to (i) a greater burden of water-related infectious diseases (e.g. cholera, typhoid fever) or injuries (Fleming *et al* 2019); (ii) heightened mental health challenges resulting from emotional distress, post-traumatic stress disorder, anxiety, etc, caused by damage, destruction, including to sources of food and water, and relocation due to extreme weather events, as well as reduced social networks from displacement and loss of place and identity (Song *et al* 2025a, 2025b); and due to both (i)–(ii), an increased demand for and pressure on public health systems, while (iii) the health system has less capacity to respond due to overstretched resources and damaged infrastructure. While this situation is not unique to small island states, it is particularly prevalent in contexts where extreme conditions affect vulnerable populations. Their added vulnerability at the frontline of climate change makes this triple burden a pressing issue. Thus, funds aimed at addressing L&D should adopt more integrated approaches that go beyond tallying individual losses.

6.2. Acknowledging knowledge gaps

Monitoring underrepresented dimensions of L&D is crucial, yet a knowledge gap remains regarding how specific support schemes under the L&D Fund can aid resilience building, especially when losses due to climate change cannot be monetarily compensated. Assessments of underrepresented dimensions of L&D should involve consultation with the affected communities to ensure a proper understanding of local framing and how these values impact on their lives.

In addition, climate-attributable L&D may be misestimated for several reasons: (i) lack of reliable data and the limitations of methods, e.g. our displacement analysis relies on nationally aggregated displacement counts based on the IDMC (2025) dataset and does not account for differences in population structure. As a result, the reported indicators represent crude, rather than population-standardized, measures. Future studies could refine these comparisons when the necessary data become available. This would help to study displacement in terms of various types of vulnerability groups, (ii) consideration of only direct damage, excluding indirect losses, and (iii) overlooking slow-onset events in most countries.

6.3. Conclusion

Present recovery funding that addresses L&D is mainly focusing on physical and tangible L&D dimensions, while underestimating medium and long-term impacts of intangible losses, such as loss of culture or identity. Furthermore, a key issue for L&D funding is that it needs to do more than compensate for L&D. Much as compensation is needed, many things that are lost or damaged are difficult to replace, restore, or monetize. Hence, the risk of L&D needs to be reduced through adaptation and building resilience. L&D funds should be readily available for this purpose. This could and should be done immediately.

Data availability statement

The data cannot be made publicly available upon publication due to legal restrictions preventing unrestricted public distribution. The data that support the findings of this study are available upon reasonable request from the authors.

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