

Finance for Loss and Damage: a comprehensive risk analytical approach

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The climate policy discourse on Loss and Damage has been considering options for averting, minimizing and addressing critical and increasingly systemic climate-related risks in vulnerable countries. Research has started to identify possible finance sources and mechanisms, but stopped short of positioning those options along a comprehensive risk management framework in line with the whole scope of Loss&Damage. Building Taking a risk analytical perspective, we present a comprehensive Loss and Damage finance taxonomy and framework made up of three pillars: finance for transformational risk management to reduce risks and adapt to climate change, risk finance to provide insurance and other risk transfer for residual risks in vulnerable countries as well as curative finance for potential unavoidable loss of ecosystems and livelihoods. We apply this taxonomy and sets of finance options to recently identified limit-prone sectors and regions that are projected to experience soft and hard limits as a consequence of slow-onset climate-related phenomena.

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Averting, minimizing and addressing climate-related risks

Climate change is increasingly leading to significant and systemic risks associated with slow-onset hazards (e.g. drought, sea-level rise, desertification, glacial retreat) and sudden-onset events (e.g. floods, storms) with vulnerable countries having to shoulder a large part of the burdens imposed. Scientific evidence provided by the Intergovernmental Panel on Climate Change (IPCC) as part of its

6th assessment cycle has shown that climate change will continue to worsen existing poverty, exacerbate inequalities and unsettle livelihoods, thus increasingly become systemic in terms of disrupting systems even incurring a potential for collapse in some systems. First reported evidence on soft and hard adaptation limits, strongly characterized by slow-onset climate change, has underlined the need for strong responses on mitigation, adaptation and residual risks as well as considering transformational adaptation, which includes efforts that reach beyond standard adaptation and risk management practice [1–3].

The Loss and Damage¹ (L&D) climate policy discourse has been debating options and solutions for dealing with such climate-related risks affecting vulnerable countries and communities. The discourse started already in the early 1990s, and over the last few years has gained substantial traction after institutionalization under the UNFCCC through the Warsaw Mechanism on Loss and Damage (WIM) and an Executive Committee (WIM ExCom) [4] as well as the Paris Agreement through Article 8. This Article of the Paris Agreement broadly defined the remit of L&D to be to ‘recognize the importance of averting, minimizing and addressing loss and damage associated with the adverse effects of climate change, including extreme weather events and slow onset events...’ [5].

Finance for Loss&Damage (L&D) has strongly moved into the spotlight. In fact, discussions regarding the role of finance started the Loss & Damage deliberations. In 1991 a proposal by the Alliance of Small Island States (AOSIS) proposed a mechanism for compensation and insurance for losses from climate-induced sea-level rise [6]. Over the years, both compensation and insurance proposals have received ample attention, with the latter seeing implementation through the G20 and V20 InsuResilience Global Partnership [7] and explicit attention to insurance through the Fiji Clearing House for Risk Transfer established in 2017. High level discussions have further proceeded at UNFCCC’s latest, 25th Conference of the Parties in Madrid in 2019 (COP25). COP25, among

¹ While capitalized singular form *Loss and Damage* has been used to refer to policy discourse, small letter and plural *losses and damages* are related to current (incl. observed impacts) and projected risks (see Ref. [44]). Analysts have also made a distinction between damages as physical impacts and losses as adverse monetary effects. We refer to risks as actual and potential damages and losses throughout the discussion.

others, suggested that the WIM ExCom ought to work more closely with the UNFCCC Standing Committee on Finance as well as the Green Climate Fund (GCF), the largest multilateral fund, in order to consider options for including Loss and Damage in GCF strategic planning [8].

Research, policy and practice have increasingly informed the discourse on finance and risk finance including insurance, with key questions in need of further attention [9]. A lot of focus has been put on risk finance (see Refs. [10–15,16]). A limited number of academic papers have discussed potential finance sources and relevant funds and institutions [17–19,2021] A recent UNFCCC technical paper [22,23] has worked towards a rationale and overview of sources of finance for Loss and Damage. The report builds on an increasingly strong focus on comprehensive risk management² as emergent in the discourse in order to present a general typology for Loss and Damage including risk assessment, risk reduction, risk transfer, risk retention, social protection, recovery and rehabilitation, and transformational measures. The report focussed largely on the aspect of minimizing risks through adaptation and risk management, but did not further discuss means of how to address residual risks. However, understanding that the nature of a full set of necessary measures (minimising and addressing). for tackling risks and any soft and hard adaptation limits needs further attention, L&D negotiators, international climate funding and donors have been grappling with comprehensive approaches that can find support by a majority of Parties.³

Three issues particularly merit further scrutiny and provide the point of departure of our discussion. First, a comprehensive risk management perspective for L&D needs concrete clarification and operationalization incl. roles for slow and sudden-onset hazards. Second, the role of ‘addressing’ L&D needs to be deliberated including considerations for the scope and scale of residual risks and any soft and hard adaptation limits. Third, a distinction between financing *sources* (national and international), which may generate additional funding for supporting interventions in vulnerable countries, and risk financing *mechanisms* (insurance etc.), which use risk transfer and other measures to absorb residual risks (but are not necessarily additional finance), needs attention.

Tackling these three issues, this paper works towards a systematic and comprehensive risk-based framework for L&D finance options for minimising and addressing risks,

² Comprehensive climate risk management has been one of the core areas spelt out by UNFCCC decision 3/CP.18, which suggested: ‘. . . d) Implementing comprehensive climate risk management approaches, including scaling up and replicating good practices and pilot initiatives.’

³ As *averting* focusses on climate mitigation and achieving the Paris ambition of net zero emissions by mid-century, we do not further dwell on this line of climate response.

which we apply to key systems at risk. Methodologically, the framework builds on three analytical strands: (i) we use a L&D risk taxonomy developed by Verheyen and Roderick [24] as accepted by many analysts and parties in the L&D discourse to break climate-related risk down into avoided, unavoided and unavoidable risks, (ii) a risk management framework as operationalized in practice through the risk layering approach serves to operationalize comprehensive risk management for L&D and finance (see [25,26,27]), which we (iii) link through empirical review with possible risk management and L&D finance sources and mechanisms (see Refs. [20,22,23]).

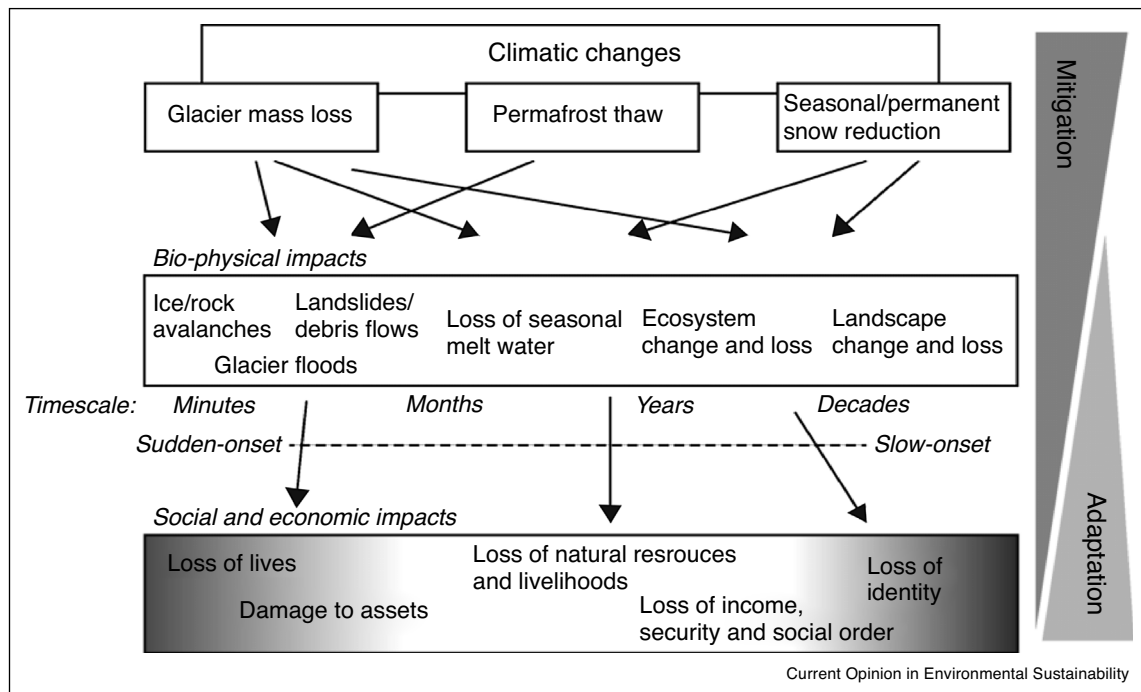
Thus integrating different strands of the L&D discourse and building on the state of the art in climate risk science as reported by the IPCC, we apply our approach to concrete vulnerable systems and associated, largely slow-onset risks and limits, by using the following finance options: risk management finance for supporting measures that reduce risks and help to adapt to climate change, risk finance for covering unavoided residual risks as well as curative finance for any unavoidable residual losses of ecosystems and livelihoods. We apply our approach to recent evidence on soft and hard limits, as largely driven by slow-onset events (including compound hazards) as presented in IPCC [1]. Our conceptual and empirical clarification coupled with case applications may further inform the L&D discourse with regard to further debating and deciding on a systematic role of finance in line with the whole scope of the debate.

The remainder of the paper is organised as follows. Section ‘Loss&Damage and risk: a taxonomy’ develops a taxonomy of risks in the context of L&D. Section ‘Loss and damage finance options: towards a systematic framework’ discusses salient available and proposed finance options, and integrates those into a L&D finance taxonomy. Section ‘Application: risk management and finance options applied to key limit-prone systems at risk’ applies the framework and links finance options to a number of recently examined key sectors and systems projected to experience soft or hard adaptation limits largely driven by slow-onset risks. We end with qualifying our approach and suggesting next steps for the L&D policy discourse.

Loss&Damage and risk: a taxonomy

A number of the issues associated with discourse remain controversial and there are various perspectives on what exactly L&D might refer to. Yet, three key discursive strands associated with ‘averting, minimising and addressing,’ differentially emphasized by negotiation parties and analysts, can be identified as having emerged as central lines of the debate [28,29,30,31]: (i) Many parties and analysts have called for increased attention to the sensitivity of key social and natural systems affected by

Figure 1



Spectrum of sudden- and slow-onset hazards and relevant impacts in the context of climate change (focus on risks in mountain regions). Source: Ref. [32].

climate change, thus underlining a need to respond with stringent climate mitigation policies that limit warming to $1.5^{\circ}\text{C}/2^{\circ}\text{C}$ in order to avoid irreversible and systemic risks from proliferating (*avert*); (ii) predominantly higher income and Annex I countries have proposed to consider extending support for further risk reduction and adaptation interventions that reduce risk and finance residual risks, particularly for vulnerable regions and countries (*minimise*); (iii) Non-Annex I countries are in basic agreement with the *minimising* suggestion, but from the outset of the discourse have called for considering burden sharing options, including compensation arrangements, for potentially or actually unavoidable and irreversible climate risks (*address*).

Overall, some consensus has emerged that a large part of the discourse is about residual risks including actual current and potential future impacts that are 'beyond adaptation.' For example, the recent UNFCCC technical paper of 2019 suggested that 'initial technical findings . . . on loss and damage led to an acknowledgement in the UNFCCC process that loss and damage includes, and in some cases involves more than, that which can be reduced by adaptation.' [22,23, p. 7].

A comprehensive view on climate-related events

A distinction generally, and in the Loss and Damage discourse specifically, has been made between slow

and sudden-onset hazards and associated risks as well as the support to be made available for responding to these risks. Increasingly, and as proposed here, analysts have suggested to think about a continuum of sudden and slow-onset hazards, ranging from climate-related processes unfolding over timescales from hours to days (landslides, storms, floods) to weeks and months (droughts, heat waves), to years (sea-level rise and impacts), and decades (glacial shrinkage). Also, a need for addressing the negative impacts arising from the interaction between slow and sudden-onsets processes through compound events, for example, rising sea levels leading to increasingly severe sea surge events, is becoming more and more evident [32] (see Figure 1 for a visualization of the risk continuum in mountain regions).

For both slow and sudden onset event risk the IPCC [1] and multi-authored volumes [29,33] have found that some soft and hard limits to adaptation may already emerge as global warming exceeds 1.5°C respectively 2°C (see also discussion in Section 'Application: risk management and finance options applied to key limit-prone systems at risk'). Analysts have emphasised the role of transformational adaptation for extending soft adaptation actions that focus on systemic change to address the root causes of risk, including equity and poverty factors, so that a breaching of limits is prevented or at least postponed [34]. Hard limits, however, imply that available adaptive

technologies and actions are physically infeasible at all, leading to irreversible impacts. For the latter, support, including finance, first and foremost would involve to assist affected communities or countries for instances where hard limits are transgressed, but also support for relocation such as for climate refugee schemes [35].

A taxonomy of risks relevant to Loss&Damage

In order to translate the L&D language of ‘averting, minimising and addressing’ into risk-relevant terminology, we build on Verheyen and Roderick’s (2008) widely discussed taxonomy of risks being or becoming *avoided*, *unavoided* and *unavoidable*, which we connect to relevant sets of interventions associated with climate adaptation (CCA), disaster risk reduction (DRR) and L&D policy domains (see Table 1).

Avoided risks are defined as those that have been and will be avoided by stringent emissions reductions (mitigation), which is at the heart of the Paris Agreement climate ambition (which we do not further discuss here due to our focus on managing and addressing risks), as well as well targeted incremental and transformational DRR and CCA. Unavoided risks are, and often cannot, be reduced due to socio-economic constraints and trade-offs (finance, governance, political economy) [36]. Unavoidable losses and damages arise at the limits of adaptation and are often seen as central to the discourse surrounding L&D [24,37]. Such adaptation limits have been defined by Klein *et al.* [38] as loci at which available risk management (DRR and CCA) actions can no longer guarantee key actor objectives or system’s needs in the presence of intolerable risks [39]. These limits can be soft – requisite technology or finance may not be available currently yet there may be potential for overcoming limits in the future through technological innovation; limits may be hard – adaptive technologies and actions are not physically feasible making further adaptation impossible leading to irreversible losses and damage (see also Ref. [40]).

Loss and Damage finance options: towards a systematic framework

With the Warsaw International Mechanism on Loss and Damage (WIM) established at the nineteenth Conference of the Parties (COP 19) in 2013 and through Article 8 of the 2015 Paris Agreement, L&D has become a formal part of the UNFCCC [41]. Yet, in stark contrast to a substantial body of literature on finance for addressing climate change mitigation (see, e.g. UNEP’s Emissions Gap reports, [42]) and adaptation (see, e.g. UNEP Adaptation Gap reports [43]), finance for L&D remains ‘the elephant in the room.’ Since its inception, the WIM has had two work-plans with diverse action areas, but neither the initial 2-year workplan nor the current 5-year rolling workplan have included a mandate to go beyond exploring the sources of and modalities for accessing finance for L&D [2022,23,44].

A finance taxonomy for Loss&Damage

The UNFCCC [22] technical paper represents a step forward for L&D in the context of risk analysis and management as it presents finance options linked to stages of risk management in terms of assessing, reducing, transferring and retaining risks. However, while acknowledging that L&D may involve more than what can be covered by adaptation, the technical paper stops short of covering the whole scope of L&D actions and finance required and does not cover the issue of addressing unavoidable risks. Recognizing this gap, we build on the Loss&Damage risk taxonomy presented above along the whole continuum of avoidable, unavoidable and unavoidable risks in order to advance towards a L&D framework that acknowledges all different aspects relevant to L&D.

We base our suggestions on a broad perspective of risk management as conceptualised and practised through the risk layering approach, which has been proposed to further inform the implementation of disaster and climate risk management approaches [25,26]. Risk layering is an applied method widely used in (re)insurance practice to identify risk segments (‘layers’) to support decision-making for risk cedents in terms of risk bearing (tolerable risk), risk transfer (intolerable risk associated with a chance for systemic impacts) to insurance markets, and risk retention for high-level risk which (re-) insurance would not pick up due to the massive loss potential [45]. For such high-level risks, private sector agents, countries or subnational entities (if they insure) have generally relied on national or international loss distribution and compensation [46].

With climate change affecting traditional risk management and insurance practice, the issue of transformational adaptation is seeing attention [47,48]. Transformation in this context may generally suggest ‘business’ as usual risk management will not suffice due to an increasing loss potential or exceedingly large uncertainty; examples include coastal or riverine flooding in a warming climate becoming increasingly destructive and systemic in terms of large-scale impacts rippling through interconnected social systems eventually requiring to plan for retreat of people and infrastructure; or, pervasive drought and heat in agriculture may mean farming households will be hard pressed (combined with other push and pull factors) to consider strongly diversifying livelihoods towards non-farming income or completely abandoning agriculture (see Ref. [49]). While this may thus technically involve moving away from the source of risk, procedurally transformation adaptation has also been linked to tackling the root causes of vulnerability with a justice and poverty-focussed lens [34].

Figure 2 visually matches (residual) risks to three risk layers with colouring from green to red indicating risks

Table 1

A taxonomy of climate-related risks and associated policy actions

Types of risks	Avoided	Unavoided (residual)	Unavoidable (residual)
Description	Avoidable risks that <i>have been and can further be avoided and reduced</i> by climate change mitigation and/or adaptation	Avoidable risks that <i>have not been and will not be avoided or reduced</i> with further mitigation and/or adaptation measures (due to technical and financial constraints) even though avoidance would be possible	Risks that <i>cannot be avoided</i> through further mitigation and/or adaptation measures
Interventions associated with risk management and L&D	CCA&DRR for incremental-L&D for transformational risk management: Minimising and addressing (intolerable) risks <i>ex-ante</i> through risk reduction and risk financing		Curative L&D: Addressing unavoidable risks

Source: Classification further developed from Ref. [26] based on Ref. [24].

becoming increasingly significant and systemic. Risk management for tolerable risk (indicated in green) is needed where risk is to be further avoided through risk reduction ('risk management layer incl. incremental and transformational risk management'); unavaoided residual risk can be transferred through risk finance involving insurance-related instruments ('risk finance layer'); finally, increasingly intolerable risks, if risk reduction or finance/insurance may not suffice to push soft limits, and once hard limits are reached, will require curative efforts involving compensation, such as for forced migration and displacement⁴ ('curative finance layer'). Thus, we are put into a position to – generically – identify context-specific risk portfolios composed of the three layers for managing incremental and transformational risk, risk finance for residual unavaoided risks and curative finance for residual unavaoidable risks. In terms of policy, we further suggest that DRR and CCA policy and support would largely cover risk management and risk finance layers, whereas L&D would overlap to include risk finance for vulnerable countries with less developed insurance markets, but also deal with transformational risk management and importantly support curative responses.

For example, for coastal islands affected by compound risk (see Table 3 also), this may mean for certain areas and levels of warming and risk, dykes and insurance will offer protection and cover against coastal flooding, sea surge and drought&heat largely building on national and international DRR&CCA support while the risk finance layer may also draw on support from L&D; in other areas and for exacerbating levels of warming with soft limits being reached, off-coastal strategic retreat for some communities and livelihood transformation may be required (e.g. due to increasing salinization of agricultural areas). At one stage – for hard limits beyond holding the line – with risks drastically increasing and compounding, climate risks

⁴ Compared to *voluntary* and *planned* migration or retreat as well as livelihood transformation, which we consider to be part of transformational risk management.

may force complete abandonment, for which curative (e.g. financial and legal support) will be required.

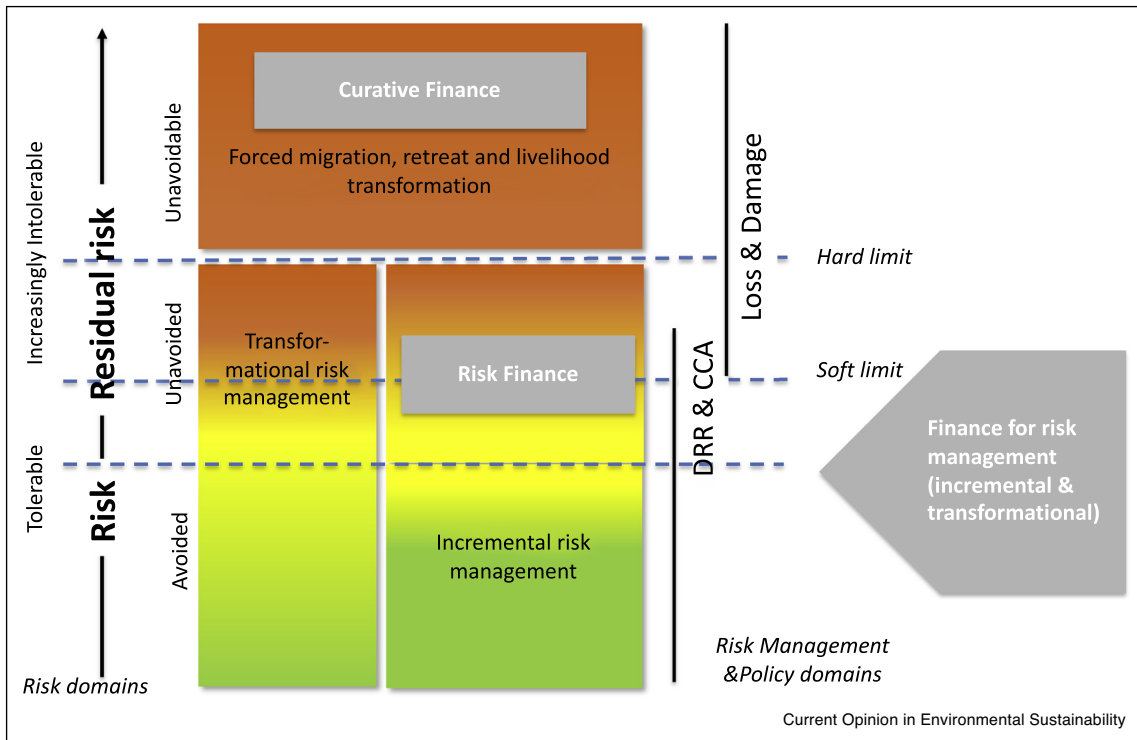
Financial sources and risk finance mechanisms relevant for Loss&Damage

Drawing on this risk layering approach, we may thus identify three pillars of DRR, CCA and L&D finance in one framework: finance for risk management to reduce climate-related risks, risk finance (risks that can and have not been reduced) and curative finance for unavaoidable loss of ecosystems and livelihoods. An important distinction to be made is between financing *sources* and risk financing *mechanisms*. While risk management identifies sources of finance for DRR and CCA, residual risk finance and curative finance are risk finance mechanisms (both sets of options can be supported by donor aid and lending). Financing sources provide funding for carrying out DRR and CCA (budgets, aid and assistance, resilience bonds as well as funds for ecosystem and livelihood restoration and rehabilitation). Risk finance and curative financing mechanisms support absorbing and compensating residual risks; they may be either pre-arranged (risk pooling and finance, social protection schemes, national and regional reserve/contingency funds and compensation mechanisms) or simply supported from budgets or aid when disasters strike.

What are key financing sources and risk financing options discussed as part of the Loss&Damage policy discourse and how do they link up to DRR&CCA policy and support? We proceed to populate the framework with finance options largely taken from Gewirtzman *et al.* [20], the UNFCCC technical paper [22,23], and Linnerooth-Bayer *et al.* [50] (see Table 2).

Finance for risk management constitutes an important element of a comprehensive finance architecture as a source for DRR, CCA and L&D (for transformation) interventions. Currently, national budgets and cost-sharing mechanisms, as well as grants and aid through official development assistance (ODA) are the two main sources for such investments into reducing risks, but evidence

Figure 2



Comprehensive climate risk layering approach and associated finance options and sources. Adapted from Mechler *et al.* [25].

suggests that available funding continues to fall short of the resources needed, particularly if additional needs for transformational measures (strategic retreat etc.) are considered as well [18,51,52]. Resilience-themed bonds and other innovative financing mechanisms such as community-based adaptation and risk reduction budgets offer additional pathways forward on this finance pillar [20,53].

Risk finance through market-based and sovereign risk transfer at local, national and regional scales constitutes a second important finance pillar for DRR&CCA, but also L&D for covering unavoidable residual risks in uninsured, vulnerable regions and countries. Risk finance reduces the volatility of risks, but does not (directly) reduce risks [50]. Risk transfer is particularly fit for enabling swift recovery from sudden-onset risks (to e.g. floods and storms) and also for some slower onset risks, such as drought (for crop insurance), but less viable for responding to very slow-onset risks, such as glacial retreat and desertification [36]. Risk finance has well documented down-sides, including ‘moral hazard,’ that is, reduced incentives to reduce risk after having attained (partial) financial cover [12]. Also for some slower onset risks, social protection schemes that work through social safety nets are seeing increasing attention as an opportunity for

addressing residual risk [54,55]. As a cross-cutting approach, risk finance schemes that build-in adaptation and risk reduction provisions, such as reduced insurance premiums following investments in risk reduction, are also receiving increasing attention [20,53]. Many countries utilize such additional ex-ante market-based disaster insurance system in lieu of ex-post loss compensation arrangements for responding to climate change related contingent liabilities [50,56]. Examples include Mexico’s Natural Disaster Fund (FONDEN), explicit cost-sharing arrangements or solidarity provisions for disaster recovery funded from reserves or budget shifts, as for example, in place in Canada, France, Japan and Peru [56]. Regional risk financing pools in the Caribbean and Pacific cover risks associated with sudden-onset windstorm (incl. flooding) and earthquake risks (see Ref. [50]). As to slower onset event risk, the key example is the Africa Risk Capacity (ARC) pool, a regional pool established in 2012 as a specialised agency of the African Union to help member states improve their preparedness and financial coping capacity for coping with drought in agriculture. Disbursements from the pool support participating governments’ drought relief efforts, with requirements on how these are used. While initial donor funding and ARC member annual premium payments capitalise the ARC,

Table 2

Building blocks of a finance framework for DRR&CCA and Loss and Damage

DRR&CCA and Loss and Damage Finance		
<i>Slow and sudden-onset risks becoming increasingly intolerable and irreversible</i>		
Avoidable but unavoids losses and damages		Unavoidable losses and damages
Risk Management Finance <i>Finance sources for supporting incremental and transformational risk assessments, risk reduction and risk financing measures</i>	Risk Finance <i>Risk financing mechanisms that transfer or retain residual risks</i>	Curative Finance <i>Finance for dealing with unavoidable risks</i>
<ul style="list-style-type: none"> National budgets International donor assistance and aid Resilience-themed bonds Ecosystem & livelihood restoration & rehabilitation funds 	National and regional risk pooling and financing (incl. catastrophe risk insurance) <ul style="list-style-type: none"> Catastrophe bonds Social protection schemes National and regional reserve/contingency funds 	National, regional and global loss distribution and compensation mechanisms
<ul style="list-style-type: none"> National contingency finance with risk reduction provisions, e.g. in contingency trust funds (revolving funds) National and regional risk pooling & risk transfer with built-in risk reduction incentives/requirements 		

Source: Classification by authors, informed by Gewirtzman *et al.* [20]. Note: a financing source is defined as providing (additional) finance for risk management and adaptation, risk finance and curative finance mechanism provide risk transfer and compensate residual risks (but do not necessarily provide additional funding).

the pool is currently deliberating the launch of an additional capitalization mechanism linked to a climate attribution trigger, the ARC Extreme Climate Facility [57].

Curative finance comes into play, where intolerable and irreversible residual risks lead to hard limits closing the adaptation space leading to forced migration and retreat, which will require financial support through loss distribution and compensation arrangements. As such, curative finance may constitute a critical (if currently contested) pillar of L&D finance [26,29,58]. Some countries are already starting to put in place national compensation mechanisms explicitly tailored to L&D from climate change, such as Bangladesh, where the national government is devising a national mechanism to address losses and damages from climate change [59]. A key open question for L&D is how to deal with slow-onset ‘beyond adaptation’ processes that have kicked-off and are threatening livelihoods already, such as through sea level rise and melting glaciers [35]. The ethical and policy

implications associated with curative finance remain subject to much debate, despite questions of liability having been explicitly excluded from the Paris Agreement ([42,43] paragraph 8). Yet, no matter the responsibility for impacts ‘beyond adaptation,’ a comprehensive approach that also addresses this component will be indispensable if the WIM is to deliver on its objective ‘to address loss and damage associated with climate change impacts in developing countries . . .’ ([60], decision 3/CP.18).

Application: risk management and finance options applied to key limit-prone systems at risk

The findings of IPCC’s SR1.5 report that projects irreversible impacts in a further warming world already beyond 1.5°C and 2°C [1] along with other recent scholarship on the materialising limits of adaptation (see for example, Refs. [44,61]) underpin the need for moving towards a comprehensive approach to L&D as well as

Table 3

Finance for minimising and addressing L&D for key vulnerable systems

Hazard/Process (type)	System (region)	Residual risks at 1.1°C/1.5°C/2°C	Risk management and adaptation		Curative L&D	Type of limit (system)	Finance		
			Incremental	Transformational			Risk management	Risk finance	Curative interventions
Ocean warming (slow-onset)	Coral reefs (tropics)	50%/70–90%/99% loss	Water clean-up	Artificial reefs, livelihood transformation	Forced livelihood transformation	Hard limit (natural)	Ecosystem and livelihood restoration and rehabilitation funds	na	Global and national loss distribution mechanisms (e.g. solidarity funds)
Global and local warming (slow-onset)	Terrestrial and wetland ecosystems (global)	Species ranges shifting (no estimate)/ 6% of insects, 8% of plants, 4% of vertebrates lose over 50%/18% of insects, 16% of plants and 8% of vertebrates with range losses of over 50%	Water and vegetation management, increased connectivity	na	na	Hard limit (natural)	Ecosystem and livelihood restoration and rehabilitation funds		<ul style="list-style-type: none"> • Livelihood restoration, • Global and national loss distribution mechanisms
Extreme heat (-slow - onset)	Human health (global, part. tropics)	No estimate/+350 million people exposed to deadly heatwaves in megacities by 2050/ annual occurrence of heat-waves similar to deadly 2015 heat-waves in India and Pakistan	Hydration, cooling zones, green roofs	Adjusted working hours and other systemic behavioural change	Forced livelihood transformation	Soft and hard limit (e.g. for outdoor work). (technological and socio-economic)	<ul style="list-style-type: none"> • National budgets • ODA L&D track • Resilience-themed bonds 	Adapted health insurance	<ul style="list-style-type: none"> • Global and national loss distribution mechanisms • Adapted social protection schemes
Sea level rise and increased wave run up, aridity and decreased freshwater availability (compound)	Coastal livelihoods (global, Asia, Pacific and Caribbean)	No estimate/31-69 million people at risk with several atoll islands made uninhabitable/32-79 million people at risk	Coastal defences, ecosystem-based adaptation, insurance, reef restoration	Managed retreat, livelihood transformation	Forced retreat and forced livelihood transformation	Soft and hard limit (technological, socio-economic)	<ul style="list-style-type: none"> • National budgets • ODA L&D track • Resilience-themed bonds • Ecosystem and livelihood restoration and rehabilitation funds 	<ul style="list-style-type: none"> • Risk pooling and financing (incl. c insurance) • Catastrophe and attribution bonds • Adapted social protection schemes • Reserve/ contingency funds 	<ul style="list-style-type: none"> • Global and national loss distribution mechanisms • Adapted social protection schemes

Source: Extended from Roy *et al.* [67] and Mechler *et al.* [62]. Note: 1.1°C is the current level of global warming induced by anthropogenic climate change, The SR 1.5°C report largely studied impacts and risks associated with 1.1, 1.5 and 2°C of warming.

CCA and DRR finance. Building on this evidence and a recent synthesis by Mechler *et al.* [62], we proceed to applying our suggested finance framework to four types of critical systems that are projected to experience soft or hard limits and thus as are in need of increasing efforts for managing climate related risks in a strongly warming world. Slow-onset hazards (incl. compounding hazards) are at the centre of attention. Table 3 presents the evidence and our framework for key residual risks at (current) 1.1°C, 1.5°C, and 2°C warming levels, the scope for incremental, transformational and curative adaptation actions as well as likely soft and hard limits to be encountered. This leads to identifying the types of finance options that may be needed for adaptation as well as absorbing any losses that cannot be further reduced.

Coral reefs are a key critical and increasingly well studied system that is fundamentally important as an ecosystem and ecosystem service provider. According to a 2004 study, more than 500 million people globally are dependent on coral reefs for coastal protection, nutrition and livelihoods, while this ecosystem is home to about a quarter of all fish species. Economic analysis estimated an ecosystem services value of around USD 10 trillion globally [63]. Furthermore regional-specific studies have been undertaken, including on the South Pacific [64] and ecosystem valuation has seen strong recognition, which may offer opportunities for careful consideration and integration into local to international decision-making across climate and biodiversity agendas [65]. The IPCC SR1.5C robustly projects irreversible loss of up to 90% of tropical coral reefs by mid-century under 1.5°C warming and nearly total loss under the 2°C scenario later in the century given current emission trajectories (thus constituting a hard limit) [66]. Adaptation potential is considered very limited: artificial reefs and water clean-up may be supported through risk management finance for ecosystem and livelihood restoration as well as through rehabilitation funds to be activated after warming episodes. However, as evidence increasingly indicates, the potential is very limited, and eventually coral reefs may be completely lost already at warming of 2°. Eventually, financial support from global and national loss distribution and compensation mechanisms will need to be activated to support those originally dependent on services from this precious ecosystem projected to be largely or completely lost due to global warming.

Addressing losses of terrestrial and wetland ecosystem species, which have been found to closely be tracking levels of gradual warming, poses a similar case. Deliberate adaptation potential (as in natural systems generally) also is considered very limited, leaving little room for harnessing water and vegetation management for adaptation. Nevertheless, increased connectivity may be supported by leveraging funds for ecosystem and livelihood restoration and rehabilitation finance. Given limited adaptation

potential, however, a hard limit is projected here as well over the next few decades, and global and national compensation may become necessary as livelihoods would be experiencing disruptions.

The SR1.5C identifies both soft and hard limit for heat-waves affecting tropical megacity dwellers' health; a soft limit is to occur where those affected are able to generally afford air conditioning, and a hard limit where outdoor work (farming, road construction and maintenance) becomes impossible. Here, all finance options and related actions may be considered feasible ranging from climate risk finance, for example, for installing cooling systems, to climate proofing, livelihood transformation, health insurance and social protection schemes both for the residual risk (health impact) as well as compensation in case of livelihood loss.

Climate change has been projected to strongly affect coastal and small islands' livelihoods through sea level rise combined with increasing aridity and decreased freshwater availability. What may be considered a soft limit if coastal defences, ecosystem-based adaptation and reef restoration may not work properly, consequently could become a hard limit if freshwater supply and coastal projection fail completely, eventually rendering some small islands uninhabitable. Also here, we suggest the whole set of finance and associated measures can be used to fund risk management, support risk finance pooling efforts for residual risks and consider compensation in case of a (perceived) need to abandon islands.

Conclusions

Finance has been a key element of the Loss and Damage discourse throughout and has recently moved to the centre of attention, yet without a very clear rationale how finance options may support actions that avert, minimise and address the increasingly systemic and irreversible risks linked to slow-and sudden onset hazards, what we consider the core remit of the L&D discourse.

Building on broad risk analytics our comprehensive finance taxonomy and framework systematically links finance sources and options to the policy space for L&D vis a vis DRR and CCA as made up of transformational risk management and risk finance for insurance-related options in vulnerable countries (*minimising*) as well as curative (*addressing*) policy options for forced relocation and migration after had limits beyond adaptation. This leads to three possible components of L&D finance: finance for transformational risk management for reducing risks and adapting to climate change (a source), risk finance for residual risks (a source and mechanism) as well as curative finance for unavoidable losses of ecosystems and livelihoods (a source and mechanism). There is considerable overlap with actions and support undertaken nationally and internationally through DRR and CCA. As

we, however, suggest the key defining feature of our generic taxonomy is to consider the increasingly systemic and irreversible climate-related slow and sudden-onset risks in line with the remit of the L&D discourse charged with finding solutions for averting, minimising and addressing risks ‘beyond adaptation’.

An application to key limit-prone systems, for which recent evidence suggests that these may be at risk of breaching soft and hard limits strongly driven by slow-onset climate change, serves to elucidate the differential roles to be played by finance to be extended from L&D and other policy domains. For at-risk natural systems (coral reefs, terrestrial ecosystems) and social systems (health, coastal livelihoods) we sketch out a systematic way forward for international and national policy to link deliberation on finance options to the scope and scale of risks identified in the literature — and thus the needs of those being affected today and in the future.

Our approach is generic and applied at regional levels so far, but it may further be taken forward to relevant decision-making scales in limit-prone systems and countries, and populated with empirical data, such as building on the UNFCCC [22] L&D finance review and other sources (see 68). In doing so, it may help to further systematically inform thinking about finance for L&D in combination with DRR and CCA policy domains as part of and outside of L&D deliberations.

Further deliberation appears indeed timely, as so far little finance has explicitly been made available for L&D, particularly for unavoidable risks that may lead into hard limits of adaptation. The brunt of finance has been extended to residual risk finance through risk pooling and risk transfer arrangements, such as through the G20 and V20 InsuResilience Global Partnership that has pledged to provide more than Euro 500 million to provide insurance cover to an additional 500 million uninsured people in developing countries by 2025 [7]. Along these lines, and in contrast to the language on L&D finance in the decision to establish the WIM, which gave a mandate for ‘enhancing’ and ‘mobilising’ finance, more recent ExCom documentation has shifted towards a central role for insurance and other market-based approaches as the primary approach for financing L&D (see Refs. [20,22,23]). Notions of curative finance, on the other hand, have garnered much less traction so far, while finance for adaptation and risk reduction remains predominantly addressed outside of L&D and attended to by the DRR and CCA policy domains, albeit not always in line with countries’ needs.

For impacts in natural systems, such as for slow-onset impacts on coral reefs, where there is currently strongest evidence that this system is at risk of complete loss already at 2°C of warming, very little finance has been

extended generally for minimising the risks and supporting those facing the aftermath of reaching a hard limit: According to some estimates less than 0.01% of global climate finance has been provided for supporting adaptation and maintenance of this ecosystem over the period of 2010–15, which is in stark contrast to its relevance as an ecosystem and the services it is providing [43].

The Loss and Damage discourse is scheduled to further proceed to discuss the role of finance with key bodies and institutions, such as UNFCCC’s Standing Committee on Finance. As well, while there is no explicit mandate for L&D (yet), the GCF, due to its general emphasis on approaches that lead to transformation and paradigm shifts, is a very relevant institution that may consider further support for this policy domain. In fact, already today about a quarter of GCF’s approved projects explicitly refer to L&D and 16% of project have links to L&D associated with their main project activities (Lempa *et al.*, 2021). For these and other bodies and institutions including the WIM ExCom, it seems thus very timely to work towards a more systematic approach to defining what role finance can play for the whole spectrum of critical risks associated with climate change.

Conflict of interest statement

Nothing declared

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