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Adaptation, Loss and Damage: The Case for Climate Justice

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Abstract

This paper discusses climate justice in the context of increasing climate costs triggered by anthropogenic climate change and provides a review of the literature to understand the scope of adaptation and Loss & Damage (L&D) costs, the methodologies to quantify them, and the debate around the mechanisms needed to finance them. The first section briefly explains that many countries heavily impacted by climate change are not commensurately responsible for it, yet the financial burden for adaptation and L&D still almost entirely falls on them. The second section clarifies the nature of climate costs and recalls the history of the L&D debate. The third section explores the steps needed to estimate adaptation and L&D costs and to allocate responsibilities for those costs. We review the literature on i) L&D and adaptation costs quantification, ii) the role of human-induced climate change versus natural variations (the attribution issue), iii) the contribution of individual countries to climate change and related costs. The fourth section examines potential financing mechanisms and shows that today, the financial support for L&D is insufficient, especially for countries that are vulnerable to extreme weather events and slow-onset processes, including rising sea level. The last section provides a pilot conceptual and methodological framework to assess adaptation and L&D costs and makes an initial attempt to frame a new dedicated Global Climate Impact Fund to share fairly and globally the burden of financing for human-induced adaptation and L&D costs among responsible countries.

We welcome comments and suggestions

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Table of content

List of Figures 3

List of Tables 3

List of abbreviations 4

I. Setting the scene: countries impacted by climate change are not the most responsible for it .. 5

II. The need for climate justice 7

A) A common definition of climate costs? 7

1. Taxonomy of climate costs 7

2. The concept of Climate Justice as Restorative Justice 10

3. History and state of the current debate around L&D 11

B) The global right to environment and reparative justice after disasters 13

1. The right to environment is now recognized as a universal human right........ 13

2. Historical responsibilities in climate change are unequivocal 14

3. There should be reparative justice for countries victims of the impacts of human-induced climate change 20

III. Who should pay for loss and damage caused by climate change? Reparative justice, climate attribution, and global versus national responsibility 20

A) How to quantify adaptation costs and loss and damage costs? 22

1. Quantifying losses and damages 22

2. Measuring adaptation costs and needs 27

B) How to assess the role of human activities on climate change, adaptation and L&D costs? ... 29

C) Sharing responsibility for disasters: how to measure countries' individual contributions to climate change?........ 33

IV. How to finance climate impact costs? Potential financial instruments and mechanisms..... 35

V. Ways forward for a new conceptual and methodological framework........ 42

Annexes........ 47

Annex 1. Cumulative CO_2 emissions in SIDS........ 47

References........ 48

List of Figures

Figure 1. The three pillars of climate-induced costs 7

Figure 2. From natural and anthropogenic climate change to climate-induced costs 9

Figure 3. Internal displacements in 2021 due to disasters and conflicts 10

Figure 4. Relative contributions of different GHG emissions to global warming 15

Figure 5. Cumulative production-based CO_2 emissions from fossil fuels, by country and region (% of global emissions) 16

Figure 6. Cumulative production-based CO_2 emissions from fossil fuels, by country and region (billion tons of CO_2) 17

Figure 7. Cumulative production-based CO_2 emissions from fossil fuels, by income group 18

Figure 8. Per capita cumulative production-based CO_2 emissions from fossil fuels, by income group 19

Figure 9. Three main streams of the L&D literature 22

Figure 10. Contributions to global mean surface temperature in 2012, by type of GHG and GHG origin 34

Figure 11. Coverage of Extreme Weather Events and Slow-Onset Processes by existing national financial instruments and mechanisms in CVF countries (%) 36

Figure 12. Coverage of Losses and Damages by existing national financial instruments and mechanisms in CVF countries (%) 36

Figure 13. Insured and uninsured share of climate-related extreme event losses by income group (2000-2019) 39

Figure 14. Preliminary integrated framework to assess third countries' contribution to L&D in vulnerable economies, including SIDS 44

List of Tables

Table 1. L&D quantification methodologies 24

Table 2. Overview of methodologies to measure adaptation needs 28

Table 3. Selected examples of attribution studies 30

Table 4. Selected examples of contribution studies 33

Table 5. Possible financing instruments for loss and damage: advantages and disadvantages 37

Table 6. Innovative financing instruments for addressing L&D: advantages and disadvantages 41

Table 7. Cumulative CO2 emissions from fossil fuels in SIDS (thousand tons of CO2) 47

List of abbreviations

AOSIS	Alliance of Small Island States
CO_2	Carbon dioxide
GCIF	Global Climate Impact Fund
GDP	Gross Domestic Product
GHG	Greenhouse gases
HIC	High-income countries
IDPs	Internally Displaced People
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
L&D	Loss and Damage
LIC	Low-income countries
LMIC	Lower-middle-income countries
OECD	Organisation for Economic Co-operation and Development
SDSN	Sustainable Development Solutions Network
SIDS	Small Islands Developing States
UE	European Union
UMIC	Upper-middle-income countries
UN	United Nations
UNDP	United Nations Development Program
UNDRR	United Nations Office for Disaster Risk Reduction
UNEP	United Nations Environment Program
UN ESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNFCCC	United Nations Framework Convention on Climate Change
UNHRC	United Nations Human Rights Council
V20	Vulnerable 20 Group

I. Setting the scene: countries impacted by climate change are not the most responsible for it

The climate system is currently undergoing changes of an unprecedented scale that will have long lasting effects on people's lives and the planet. There is an undeniable rise in the frequency and magnitude of extreme weather events such as floods, droughts and heatwaves, and a growing number of countries are affected by slow-onset processes, including increased surface temperatures and rising sea levels (IPCC, 2022; OECD, 2021). Scientists with the validation of the Intergovernmental Panel on Climate Change (IPCC) agree that a large share of the changes in climate is directly due to human activities (IPCC, 2022). The causal link between anthropogenic polluting emissions and the probability and intensity of extreme weather events has been investigated and proven by many studies, and evidence is particularly robust for hot extremes (Herring et al., 2018; Simon et al., 2018; Peterson et al., 2012; van Oldenborgh, 2007). While natural processes such as El Niño or la Niña still explain some climate variations, external factors (e.g. anthropogenic emissions, changes in land use, and human influence on the exposure to climate risk) are among the principal drivers of loss and damage (L&D) related to climate change (James et al., 2019). In addition, the Glasgow Climate Pact recognizes that climate change will increasingly cause economic, social, and environmental L&D (Wehner and Reed, 2022).

However, countries that are disproportionately impacted by climate change are not the same as the countries most responsible for it. Countries most affected by the devastating impacts of climate change and natural disasters are often low-income or vulnerable countries (including Small Island Developing States (SIDS)) that have only slighted contributed in per capita terms to global emissions and climate change, especially due to their low per capita levels of fossil-fuel use (Sachs, 2022; Sachs and Massa, 2021). On the other side, high-income countries and some emerging economies are historically the largest contributors per capita to greenhouse gas emissions, and therefore to climate change, but are often relatively less affected per person by the consequences (Skeie et al., 2017; Mace and Verheyen, 2016; Rocha et al., 2015, Frame et al., 2019). While some types of extreme events and the intensity of slow-onset processes are weaker in higher-income economies mainly thanks to their geographical location, these countries also benefit from greater resources to mitigate, adapt, and recover from natural disasters.

We should consider the impacts of climate change on a country both in per capita terms (e.g., the annual losses in international dollars per person) and as a share of national income (e.g. the annual losses relative to GDP). The latter is a measure of societal vulnerability. Suppose that both the US and Haiti incur US$ 500 loss per person from climate-related shocks. In the first case, the loss is a mere 0.7% of GDP per capita; in the latter case, the loss is 30% of GDP per capita, for a population living on the brink of destitution.

While the per capita contribution of the SIDS to historical emissions has been tiny, the burdens of climate impact are enormous (UNDP, 2022). SIDS score the highest on the SDSN's Pilot Multidimensional Vulnerability Index (Sachs et al., 2021) and record a particularly high vulnerability to environmental shocks, as they are highly affected by rising sea levels and hydrometeorological disasters. Among numerous examples, the capital of Tuvalu is expected to be 37% under water at the highest tide, and 97% under water by 2100 as stated by Tuvalu's Minister of Foreign Affairs at COP26 in Glasgow. Because it is located in the hurricane belt and rising global temperatures from anthropogenic emissions are making hurricanes more frequent and intense, Antigua and Barbuda is regularly affected by hurricanes, such as Irma that destroyed 95% of housing in 2017 (UNDP, 2022). While solutions exist to cover the costs and adapt to climate change, small countries like SIDS do not have the financial capacity to cover such costs through domestic resources alone.

As of today, the financial burden for adaptation and L&D still almost entirely falls on the affected nations and not systematically in any way on the countries that have been most responsible for climate change. Even if L&D are increasingly present on the international scene with the coming negotiations at COP27 in November 2022 in Egypt, few countries are willing to allocate funds to cover L&D in countries affected by climate change. Even in the case of the devastating floods in Pakistan in 2022, which affected 33 million people and reportedly killed nearly 1 700, pledges by the United States (US), Canada and few other countries will not exceed US$ 150 million and the UN humanitarian appeal (for which only one fourth is actually funded) reaches only US$ 472 million in total – just enough to cover around 1% of the total losses (Sachs, 2022; Walsh and Ormond-Skeaping, 2022). Likewise, funding for adaptation in vulnerable countries remains dramatically insufficient. Despite a recent increase of 53% on average annually between 2017 and 2020, funding dedicated to adaptation programs only represent 7% of total climate finance (Buchner et al., 2021), which still mainly target mitigation and green transitioning actions. The under-financing L&D and adaptation in poor or vulnerable countries often leads them to subscribe to new loans from the IMF to recover from the disasters they are inflicted with. Such new loans increase the burden of debt and reduce the capacity of the countries to recover. A new dedicated L&D financing mechanism that would not be based on loans but rather on insurance or grants would provide adequate and timely support to affected countries while avoiding to increase the burden of debt (Walsh and Ormond-Skeaping, 2022) and related long-term consequences on development, resilience and economic growth.

The costs of adaptation and losses and damages inflicted by climate change on vulnerable countries are massive and cannot be covered by domestic resources only. In the Caribbean, for example, climate change is estimated to provoke L&D amounting to more than US$ 12.6 billion every year (Akiwumi, 2022), or more than 12% of the GDP of the Caribbean Community. The climate-related L&D that countries face depends fundamentally on the severity of the impacts of climate change, and the degree of adaptation and prevention countries were able to put in place to prevent damages. When domestic financial resources are limited, countries struggle more to implement efficient adaptation programs, and therefore they face heavier losses and damages. The support of the international community to pay the costs from both adaptation and L&D imposed by anthropogenic climate change in vulnerable countries and especially in SIDS is therefore essential for these small islands to survive. With already small tax bases and domestic resources that have shrunken due to the COVID-19 pandemic, foreign resources in SIDS are more necessary than ever to build climate resilience.

Countries that are historically more responsible for climate change should bear a fair share of the global costs of adaptation and losses & damages. This paper stresses the need for climate justice at the international level, building on the fact that support must be provided for adaptation in countries most affected by climate change, as well as to help these countries recover from their L&D. It also details some of the methodologies used by scientists to quantify L&D and underlines some of the limitations they are facing for example to assess the non-economic costs of climate-related disasters or the costs of slow-onset processes. This paper also gives an overview of the attribution and contribution research that measures the impact of humans and specific countries on climate change. A comparative review of potential financing mechanisms for addressing climate-related L&D is also included. While data availability on climate and impact indicators still represents a significant obstacle for an assessment of L&D in SIDS, this paper proposes an integrated framework to advance the discussions on how to quantify and finance adaptation and L&D costs in small islands and vulnerable countries.

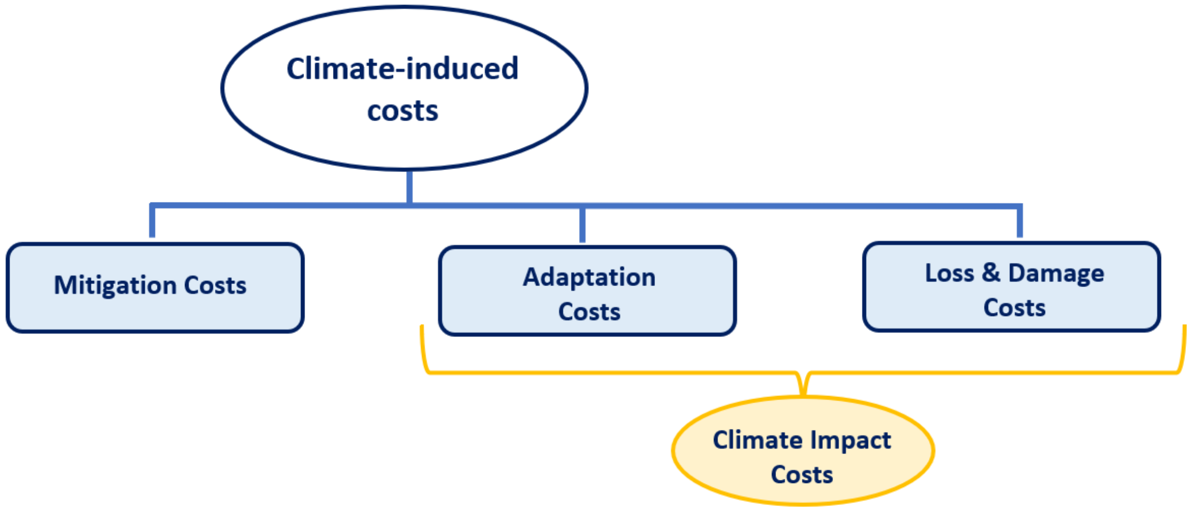
II. The need for climate justice

A) A common definition of climate costs?

1. Taxonomy of climate costs

There are three types of investments needed for climate safety: mitigation, adaptation and loss and damage (Figure 1).

Figure 1. The three pillars of climate-induced costs



Source: Authors' elaboration.

Mitigation costs refer to costs related to "*human intervention to reduce the sources or enhance the sinks of greenhouse gases*" (IPCC, 2001). So, they are borne to address the root causes of climate change. Some examples are the costs for replacing greenhouse gas-emitting fossil fuels (e.g. coal, oil, and natural gas) with clean and renewable energies (e.g. solar, wind, and geothermal), making old buildings more energy efficient, replacing traditional internal-combustion vehicles with electric options, or for planting trees and preserving forests to absorb and store more carbon dioxide from the atmosphere.

Adaptation costs are costs related to the "*adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects*" (IPCC, 2001). Therefore, they address the impacts of climate change. Adaptation costs include expenses for redesigning housing, building sea walls, elevating infrastructure, and promoting drought-tolerant crops, among many others. UNEP (2022) estimates that annual adaptation needs inflation adjusted are in the range of US$ 160-340 billion by 2030 and US$ 315-565 billion by 2050. In 2009 at COP15 in Copenhagen, rich countries promised to channel US$100 billion a year to poor economies by 2020 for climate adaptation (and mitigation), but that promise was broken (Timperley, 2021). Out of the US$ 100 billion fund pledged to developing countries, only US$ 28.6 billion have been mobilized for developing countries and SIDS only had access to US$ 1.5 billion (Akiwumi, 2022). Moreover, most of the finance went to mitigation interventions rather than to adaptation projects.

In addition to their different objectives, mitigation and adaptation costs differ also in terms of spatial and time scale and concerned economic sectors (Tol, 2005). On one hand, mitigation costs are borne to respond to an *international* issue in the long-term, targeting sectors such as energy, transportation, industry, and waste management. On the other hand, adaptation costs are costs paid in response to *local* issues to get benefits in the short-term, mainly in the water and health sectors, as well as in coastal and low-lying areas.

We will henceforth group the three types of climate costs into two categories, by combining Adaptation and Losses and Damages into a single category we term Climate Impact Costs. Thus, we will speak of Total Climate Costs as the sum of Climate Mitigation Costs and Climate Impact Costs, with the latter category including both the Adaptation and Loss & Damage categories. In this typology, we regard reparative (or restitutive) justice as applying to Climate Impact Costs. These are, after all, the costs faced by each country as the result of the global historical greenhouse gases (GHG) emissions. The Climate Mitigation Costs are costs borne by each country for cutting emissions in order to avoid damaging the global climate. Each country, in principle, has the ethical responsibility to avoid creating harm to other countries through its energy system.

Although a common definition of L&D still does not exist, L&D costs can be defined as costs related to the residual impacts of climate change which are not prevented or avoided by optimum adaptation and mitigation efforts[6]. In other words, they are incremental costs incurred because of climate related disasters, that can be reduced (but not eliminated) through adaptation and that persist even after optimal mitigation and adaptation (Shawoo et al., 2021; European Parliament, 2022). L&D costs can be the consequence of severe weather events (e.g. cyclones, hurricanes, tornadoes, droughts, heatwaves) or slow onset events (e.g. sea level rise, ocean acidification and salinization, land degradation, desertification or glacial retreat).

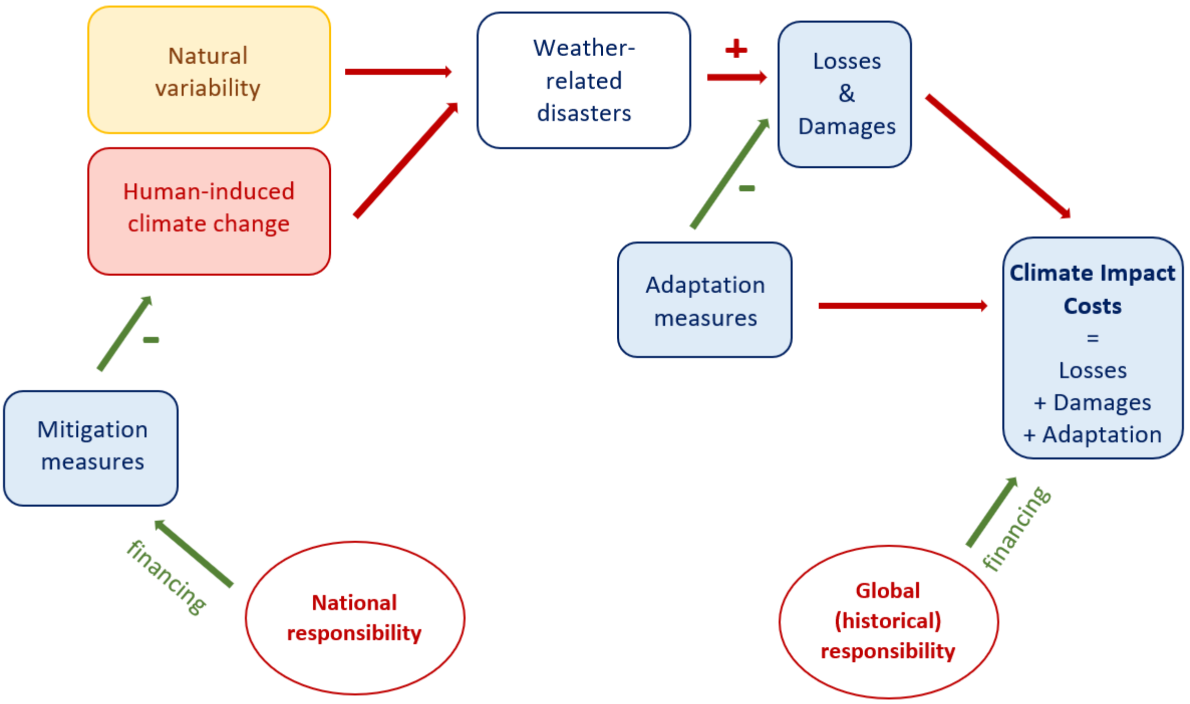
According to the IPCC WGII Sixth Assessment Report (AR6) (IPCC, 2022), losses and damages represent the irreversible impacts caused by anthropogenic climate change, distinct from the 'Loss and Damage' discussion point under the UNFCCC, which is to "address loss and damage associated with impacts of climate change, including extreme events and slow-onset events, in developing countries that are particularly vulnerable to the adverse effects of climate change". As per definitions introduced by AR6, adaptation in human systems is the process of adjustment to actual or expected climate and its effects, in order to moderate harm or to take advantage of beneficial opportunities. In natural systems, adaptation is the process of adjustment to actual climate and its effects, that can be facilitated by human intervention.

As adaptation needed to build resilience to climate change-related impacts on livelihoods and the planet is severely underfunded, L&D is growing at an unprecedented scale with dramatic consequences for most vulnerable countries such as SIDS. As shown in Figure *2*, both adaptation and L&D are costs largely induced by human actions and for which financing should be shared among polluting countries according to their historical responsibility in climate change (see Section III C.). Adapting to climate change helps reduce the amount of damages inflicted but represents substantial investment costs that add to the climate impact costs. As explained further in the paper (see for

[6] Throughout the paper, this definition of L&D is preferred over the broader one stating that L&D refer to all negative consequences of climate change.

instance Section II A 2), a climate justice regime would share the costs of adaptation and L&D but would require that each country is responsible for cleaning its energy system by funding its own mitigation measures.

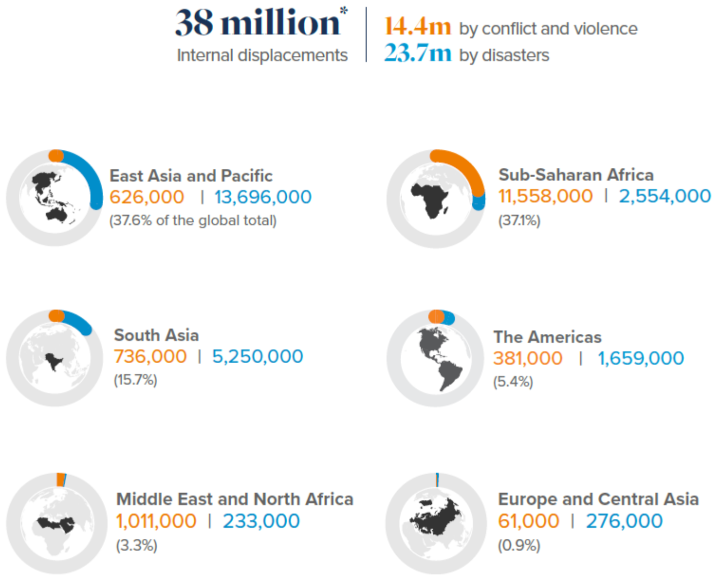
Figure 2. From natural and anthropogenic climate change to climate-induced costs



Source: Authors' elaboration.

When talking about L&D, a distinction is made between economic and non-economic costs (Thomas et al., 2018). *Economic* L&D costs are direct physical costs due to the negative impacts of climate change on resources, goods and services traded in markets. They can be easily quantified. Examples are costs related to damages to infrastructure, decreases in agriculture production or in services such as tourism, disruption of economic activities, etc. *Non-economic* L&D costs, instead, are indirect costs which are difficult to quantify and refer to climate-induced impacts such as loss of life, biodiversity, social cohesion, and cultural heritage or displacement and migration of communities. Beside their direct and permanent consequences on people's lives, well-being, and health, non-economic L&D also have substantial impacts on economic growth and development. For instance, out of the total 59.1 million internally displaced people (IDPs) accounted at the end of 2021, around 38 million were displaced in the sole year 2021, and 23.7 million of them were displaced because of natural disasters (IDMC, 2022). More than half of the internally displaced people by disasters in 2021 were in the East Asia and the Pacific region (Figure *3*). At an estimated average cost of US$ 390 per displaced individual annually, the total cost of the climate IDPs amounts to close to US$ 10 billion per year. This estimated cost mainly refers to housing and schooling expenses and does not include the economic impact of displacement on host communities or IDPs in the process of returning, nor does it account for investments made by governments or development stakeholders to address the longer-term economic consequences of displacement such as unemployment and mental health issues.

Figure 3. Internal displacements in 2021 due to disasters and conflicts



Source: IDMC (2022)

2. The concept of Climate Justice as Restorative Justice

As a result of a newly adopted United Nations (UN) General Assembly Resolution (A/RES/76/300), each person and country have the *right to a safe climate* (See Section II. B. 1). Therefore, each person and each country are both a rights holder and a duty bearer. Persons and nations that undermine that right through their GHG emissions are ultimately imposing an unfair loss on other people and countries. That loss should be compensated as part of restorative justice. This is the same principle of compensation in return for a tort damage, such as when one neighbor harms another by polluting their land. The aggrieved party may sue the polluter for restitution.

The costs of adaptation plus losses & damages caused by human-induced climate change are the climate costs that require restorative justice. Since no country has a right to create climate change, no country can demand restorative justice to cover the costs of mitigation. Each country should be mitigating its own emissions in order to avoid imposing costs on other countries.

How much should be due to each country? Each country should pay restorative justice funds in proportion to the share of its historical emissions, relative to their size (and considering the effect of past emissions on current GHG concentrations based on climate modeling). These national payments should be aggregated in a Global Climate Impact Fund (GCIF). Each country should receive from the same GCIF a level of restorative payments equal to the country's costs of adaptation plus losses and damages resulting from global human-induced climate change. If a country's share of historical emissions equals its share of global climate impact costs, then it receives no net payments from the GCIF (as it pays out the same that it receives). If its share of historical emissions is greater than its share of climate damages (as will be true for most High-Income Countries, or HICs), then the country will pay more to the GCIF than it will receive from the GCIF. If its share of historical emissions is less than its share of climate damages (as will be true of most SIDS and most of the Low-Income Countries – LICs – and Lower-Middle-Income Countries - LMICs), then it will receive more from the GCIF than it will pay to the GCIF. In other words, those countries will be restituted for their climate impact costs.

3. History and state of the current debate around L&D

The concept of L&D appeared for the first time in 1991 thanks to the Alliance of Small Island States (AOSIS) which highlighted the need of creating a ***separate*** international insurance pool to compensate the most vulnerable and low-lying coastal developing countries from the consequences of sea level rise (INC, 1991). At that time, it was suggested to create a fund through contributions defined considering the role played by each country to increase global CO_2 emissions and their relative share of global gross national product (GNP).

In 2007, the Bali Action Plan called for "*disaster reduction strategies and means to address loss and damage associated with climate change impacts* *in developing countries that are particularly vulnerable to the adverse effects of climate change"* (United Nations, 2007). In 2008 the AOSIS put forward a proposal for the creation of a multi-window mechanism to address climate-induced loss and damage, including an insurance, compensatory, and risk management component (AOSIS, 2008).

It was only in 2013, at COP19 in Warsaw, that a functional mechanism for addressing climate-induced loss and damage was established: the Warsaw International Mechanism for Loss and Damage (WIM) aiming at (i) enhancing knowledge and understanding, (ii) strengthening dialogue, coordination, and synergies among stakeholders, and (iii) enhancing action and support, including finance and technical assistance (United Nations, 2013). In the spirit of promoting solidarity and collaboration, parties to the negotiations of the WIM decided not to establish responsibilities and attribution in addressing losses and damages that countries experience because of climate change. Both developed and developing countries occupy 10 seats each in the Executive Committee of the WIM (ExCom) – a structure of governance that tends to slow the decision-making process and may prevent the WIM from successfully establishing a financing mechanism for L&D. As for now, the WIM has not unlocked progress on the discussions around L&D financing but has mainly improved knowledge-sharing and coordination among some countries.

In 2015, at COP21, a second milestone was achieved with the adoption of the Paris Agreement where a standalone Article 8 recognized "*the importance of averting, minimizing, and addressing loss and damage*" and acknowledges the WIM as the main instrument under the United Nations Framework Convention on Climate Change (UNFCCC) to address L&D (United Nations, 2015; European Parliament, 2022). L&D costs were recognized as a separate category from mitigation and adaptation costs, and approaches to address L&D as a standalone pillar of international climate change law. Thanks to Article 8, L&D received more solid political legitimacy, and it became harder for rich countries to push against the creation of a new L&D financing mechanism by claiming that L&D costs should be included into adaptation costs.

Nevertheless, the Paris Agreement failed in establishing a legal basis for the financing of L&D costs. Indeed, in paragraph 51 of Article 8 in the Paris Agreement, it was stated "that Article 8 of the Agreement does not involve or provide a basis for any liability or compensation" (United Nations, 2015).

COP23 launched in 2017 the InsuResilience Global Partnership (IGP) to increase local capacities in adaptation and resilience. The partnership brings together governments of the G20 and V20 groups[7],

[7] The Group of 20 (G20) is a strategic multilateral platform connecting the world's major developed and emerging economies. The Vulnerable 20 (V20) is Group of Ministers of Finance of the Climate Vulnerable Forum is a cooperation initiative that gathers the twenty economies most vulnerable to climate change.

actors of the private sector, civil society and international organizations and operates through direct or indirect climate risk insurance schemes. Contrary to other proposed solutions in climate and disaster risk financing and insurance, the IGP provides premium and capital support to improve the affordability of the insurance scheme and reach more vulnerable countries (Hirsch, 2022).

In 2019, at COP25 in Madrid it was decided to create the Santiago Network on Loss and Damage (SNLD) with the objective of catalyzing technical assistance to vulnerable developing countries through relevant organizations, bodies, networks, and experts to implement required approaches to address L&D. The governance aspects of the SNLD are currently raising debate across countries of the UNFCCC. Developing countries advocate for the SNLD to have its own executive committee (on an equal footing than the ExCom of the WIM), whereas developed countries demand that it operates under the supervision of the WIM. Although the purpose of the SNLD is not to establish a L&D financing mechanism, it might be able to provide useful funding in some developing countries for capacity building and assistance, on the basis of individual projects (Hirsch, 2022).

At COP26 in Glasgow, all developing countries under the Group of 77, accompanied by China and AOSIS, proposed the adoption of a Loss and Damage Finance Facility (LDFF) – a suggestion that was rejected by developed countries. Besides the reluctance of industrialized countries to recognize the need for a specific mechanism to finance L&D costs, the LDFF has not been at the center of the climate negotiations because the proposition still lacks clarity (and consensus among developing countries) on the exact form and modalities the LDFF should follow. Only small progress towards the financing of L&D was made at COP26 but the discussion led to the agreement on the Glasgow Dialogue on L&D, which opens the door to pursue the negotiations on L&D financing. The issue on LDFF is therefore expected to become central in discussions at COP27 in Sharm El Sheikh, where a consensus on L&D financing might be reached. The main arguments advanced by developing and vulnerable countries relate to international solidarity (if not moral obligation) and the strong economic case for a LDFF that would ensure the continuity of international supply chains (European Parliament, 2022).

Because of the failure to reach an international agreement on the creation of a L&D financing facility, funding allocated to L&D are still insufficient and much less than money allocated to mitigation and adaptation. While financing for clean energy in poorer nations is about USD$100 billion a year and the funding for adaptation is at almost USD$20 billion a year and expected to double by 2025, the money allocated to L&D are just few millions offered by few countries (notably Scotland and Denmark) or philanthropic organizations (Carrington, 2021). These small funds are in contrast with the several billions of L&D costs that poorer countries bear every year.

The divide between industrialized countries on one side and developing and vulnerable countries on the other is deeply linked to their different interpretation of what L&D are (European Parliament, 2022). Developed countries tend to perceive L&D as an issue of uncertainty and volatility in climate risk and therefore advocate their role is to provide technical support to affected countries, which should be responsible for their own vulnerability and adaptation. The position of the European Union in the latest climate negotiations at COP26 was clear: the EU recognizes that developing countries face large financing needs in terms of climate and that climate risk insurance could be a way to support them, but states that no separate and specific L&D mechanism is needed for that purpose. On the other hand, vulnerable countries view L&D as the result of industrialized countries' adverse externalities over the past centuries (in the form of GHG emissions) and advocate that polluters have a moral obligation to pay for L&D they directly caused. Here again, the perception of who the polluters are differ across countries. While for developing countries the polluters are both national governments and private entities, industrialized economies tend to support that only large polluting private companies should compensate for L&D (Pill, 2022). Because developed countries believe L&D are already covered by adaptation and mitigation programs, they suggest that L&D financing should be integrated in existing financing mechanisms, such as the Adaptation Fund or the Green Climate Fund. Although such mechanisms might cover part of the task to "advert and minimize L&D", they are not addressing the actual L&D. Therefore, vulnerable and developing countries call for the creation of a new and specific financing mechanism for L&D.

Experts state that it is essential for vulnerable and developing countries to discuss L&D financing in other policy forums, such as the G7, G20, and IGP, to overcome the limitations of the WIM. Since no significant progress has been achieved under the UNFCCC to advance on L&D financing, countries started to organize outside the Forum to create alternative financing mechanisms. The V20, for example, will soon test its own LDFF and solicits financial contributions from countries of the G7 and G20, and from philanthropies. Earlier in 2007, the Caribbean Development Bank launched the first multi-country risk pool insurance scheme – the Caribbean Catastrophe Risk Insurance Facility (CCRIF) – to provide financial support to countries affected by hurricanes or earthquakes (European Commission, 2022). The G7 will also establish a Global Protection Shield against climate risks – with a first pledge by Germany that should amount to EUR1 billion – that could represent a significant complement to the LDFF under the UNFCCC if ever adopted.

B) The global right to environment and reparative justice after disasters

1. The right to environment is now recognized as a universal human right

The right to healthy environment is now recognized as a universal human right. Through a resolution adopted in October 2021, the UN Human Rights Council (HRC) officially declared the right to a "clean, healthy, and sustainable environment" to be a universal human right, therefore indivisible from the right to life, mental health, adequate food, housing, water, and cultural life, among others (UN, 2021a). Building on the HRC decision, the UN General Assembly adopted the resolution A/RES/76/300, recognizing the right to a clean, healthy, and sustainable environment as a human right. The resolution calls upon States, international organizations, business enterprises and other relevant stakeholders as duty bearers to adopt policies, enhance international cooperation, strengthen capacity-building, and continue to share good practices in order to scale up efforts to ensure a clean, healthy and sustainable environment for all.

Pollution, climate change, and the loss in biodiversity pose an enormous threat on human rights for today's and future generations, as they increasingly challenge access to food and healthcare, are responsible for the displacement and migration of millions of people each year (IDMC, 2022), and disproportionally impact the most vulnerable and poorest communities. The mere existence of some countries and communities such as those living in SIDS is threatened by the consequences of climate change, raising the unbearable question of how to keep these populations alive, along with their cultural heritage (Sachs and Massa, 2021). Mainly through GHG emissions that impact global temperatures and sea levels, anthropogenic climate change is altering coastal habitats and populations living in low-lying atolls such as Kiribati, the Maldives, Marshall Islands, Tuvalu and Tokelau will have to leave their islands if sea levels were to rise by one more meter (Akiwumi, 2022). Although the UN resolution is not legally binding for the UN member states, the UN General Assembly urges the international community – countries but also businesses and international organizations – to increase efforts for climate change adaptation. More than 150 countries already committed to protect this universal right to environment, but a concrete alignment of national institutions is still missing. To enhance progress on climate justice, the right to a clean, healthy, and sustainable environment could for instance be inserted in national constitutions and regional treaties (UNEP, 2021b).

For many decades, human actions have violated the right to a clean environment. Through their practices, rich countries have generated polluted, hazardous, and unhealthy living environments for populations around the planet, disregarding the transboundary and inter-temporal consequences of their emissions. Entire countries and populations – with the SIDS at the frontline – are suffering from climate-related disasters which are the responsibility of other nations. Today, these affected countries call for help from the international community to better adapt to the changing climate they did not create, and they ask for reparations.

Limited technological progress to enable a full energy transition everywhere, reduce pollution and limit global warming is also the result of insufficient financing for clean energy research towards effective and sustainable mitigation solutions. Public financing in clean energy research declined by 23% in 2019 and continued shrinking throughout the COVID-19 pandemic (UN, 2022).

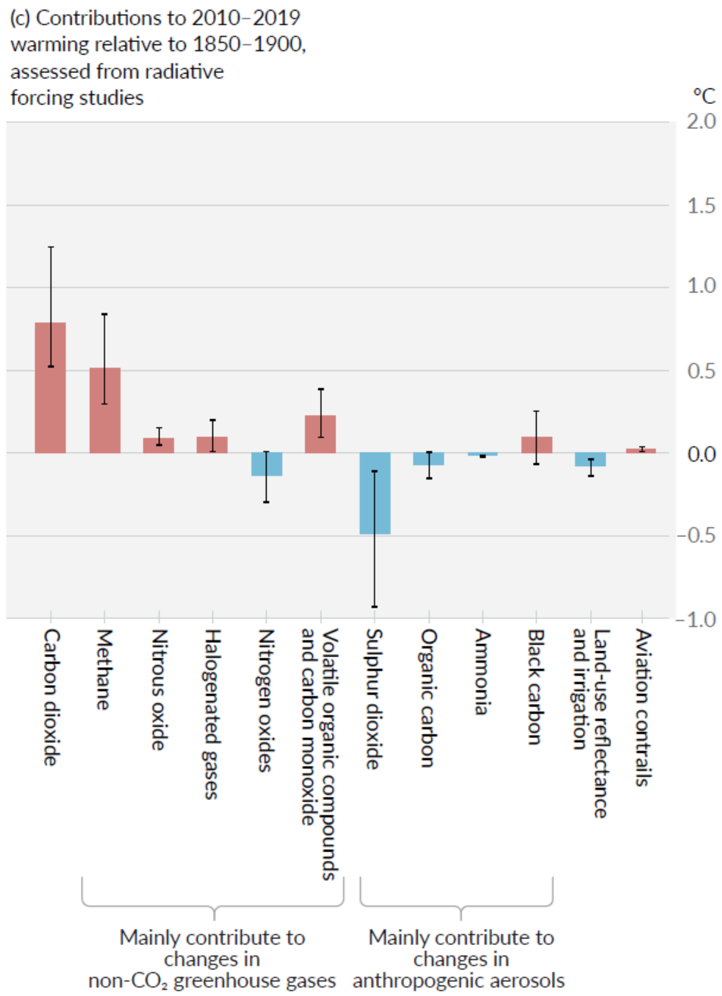
2. Historical responsibilities in climate change are unequivocal

The human influence on climate change is unequivocal, as human activities since the industrialized era have warmed the atmosphere, the surface of the Earth and the oceans. While natural forces contributed to changes in global mean air and surface temperatures between -0.1°C and 0.1°C in the 2010-2019 period compared to the 1850-1900 period, human activities directly increased temperatures between 0.8°C and 1.3°C. Human-induced climate change is also the main responsible for the intensification of extreme weather events all over the world, such as heatwaves and floods (IPCC, 2021).

GHG emissions are the largest sources of anthropogenic climate change. Among other phenomena, GHG emissions are the main causes for the increase in air temperatures (they are responsible for a rise by 1°C to 2°C), the intensification of heavy precipitations across the world, the ice loss in the Arctic Sea, and the rise in observed global sea levels. The scientific community also shows that other human drivers such as aerosol emissions contributed to cooling temperatures, while the impact of natural drivers (between -0.1°C and 0.1°C) and internal variability (between -0.2°C and 0.2°C) were weaker. Therefore, the observed warming in global climate is mainly driven by GHG emissions from human activities, which are partly dissimulated by aerosol emissions (IPCC, 2021).

Among GHG emissions, the largest contributor to anthropogenic climate change is the increase in atmospheric concentrations of carbon dioxide (Figure *4*). CO_2 emissions are principally resulting from the combustion of fossil fuels (i.e. coal, oil, natural gas) and land use changes (e.g. deforestation). Since 1850, humans released more than 2 500 Gt of CO_2 in the atmosphere (Evans, 2021). The IPCC (2021) warns that the atmospheric concentrations of CO_2 are continuously increasing, and that in 2019, they reached their highest levels in more than two million years. While fossil fuel CO_2 emissions decreased in 2020 during the first waves of the COVID-19 pandemic, they are climbing again, mainly due to a bump in economic activity in China and India (Friedlingstein et al., 2022).

Figure 4. Relative contributions of different GHG emissions to global warming



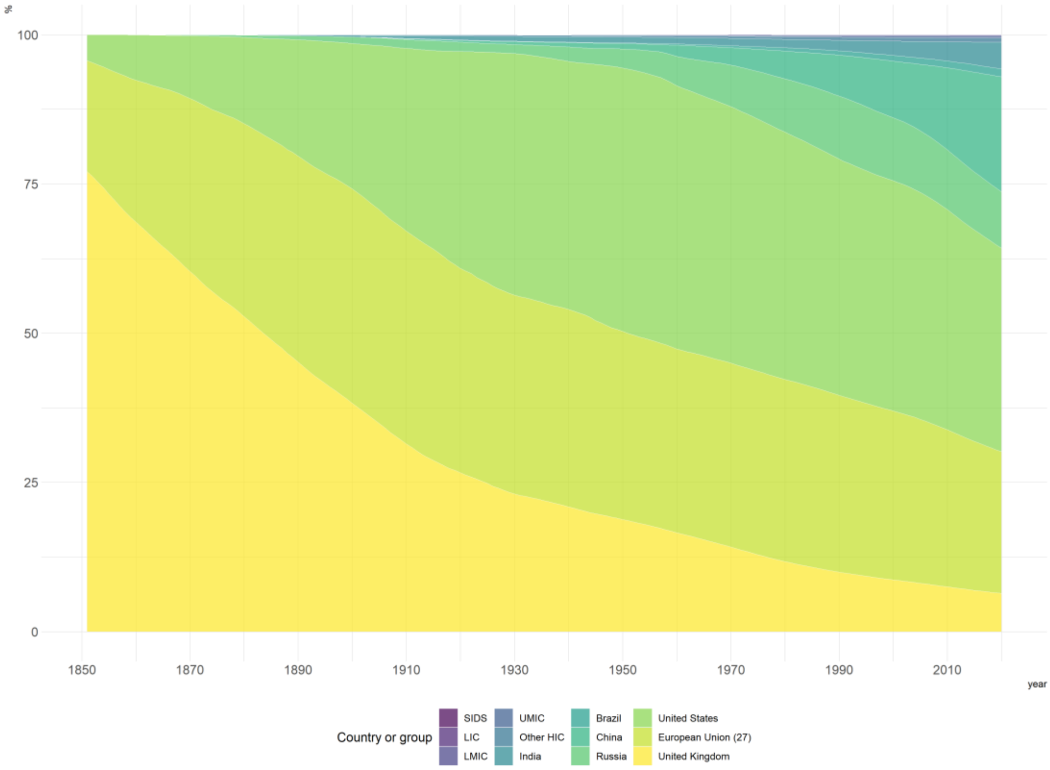
Source: IPCC (2021).

Tracing historical trends in CO_2 emissions is essential to understand which country (or sector) contributed most to current climate change, as emissions have long-term impacts on the climate. Overall, CO_2 emissions from fossil fuel combustion doubled over the last 30 years and were multiplied by more than 12 over the last century. Emissions originating from land use represent a third of total historical emissions. Since 1850, humans emitted around 2 500 billion tons of CO_2 (i.e. 2 500 Gt CO_2). The IPCC estimates that each 1 000 Gt of CO_2 released in the atmosphere translates into an increase in global mean temperature by +0.45°C. This gradient defines the "carbon budget", which is the maximum amount of CO_2 that can still be emitted if we want to limit global warming to +1.5°C (as specified in the Paris Agreement). Today, 86% of the carbon budget has already been used by humans, and it is expected to be fully reached by 2030 – meaning that after this date, it will be too late to limit global warming below +1.5°C (Evans, 2021).

On average, since the beginning of the industrialization period, high-income countries have generated the largest share of global CO_2 emissions, while the contribution to total CO_2 of poorer countries heavily affected by climate change has been and remains marginal (Figure 5). Over the period 1850-2019, SIDS were responsible for 0.02% of all CO_2 emissions from fossil fuels, while the United States (US) alone accounted for more than 34% of emissions, the European Union (EU) for almost 24%, and China for nearly 19% (Figure 5). Puerto Rico and Tuvalu are the SIDS with the lowest cumulative CO_2 emissions, with emissions rounding at 210 and 270 thousand tons during the 1850-

2019 period, respectively. By contrast, Singapore is the SIDS that emitted the largest quantities of CO_2 over the period, with 2 billion tons released into in the atmosphere. Cuba and Trinidad and Tobago are the two other SIDS that emitted more than 1 Gt of CO_2 in the same period (with around 1.5 billion tons of emissions). SIDS' cumulative CO_2 emissions data are available in Annex 1. Cumulative CO_2 emissions in SIDS

Figure 5. Cumulative production-based CO_2 emissions from fossil fuels, by country and region
(% of global emissions)

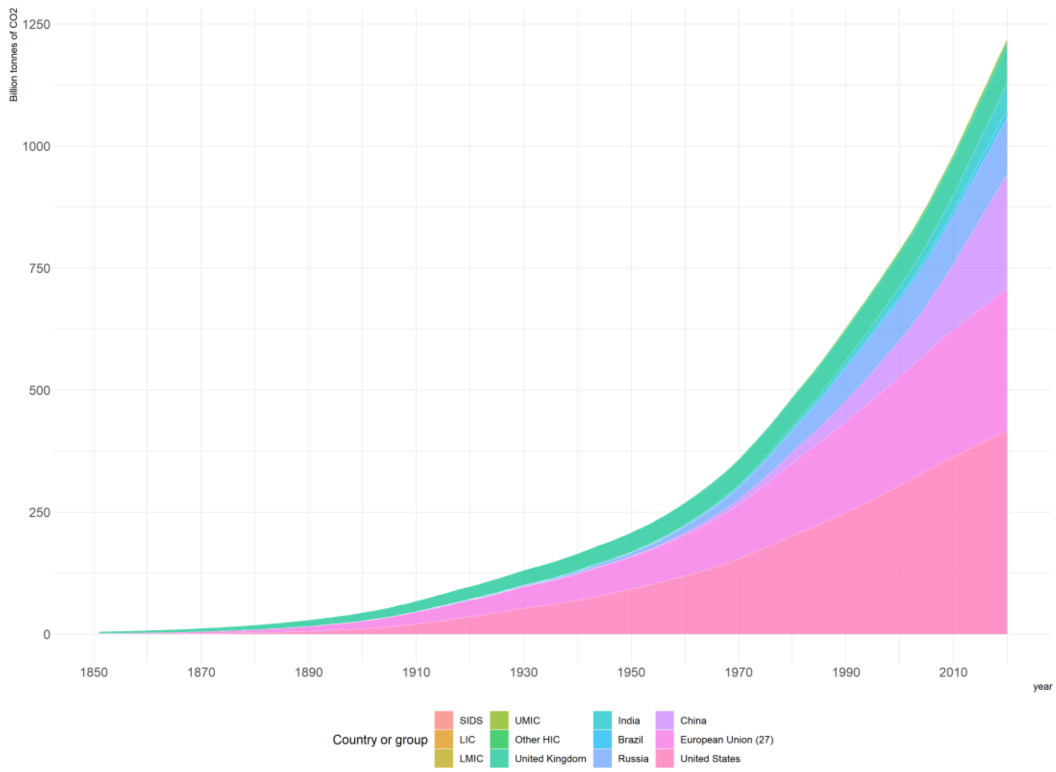


Note: Production-based CO_2 emissions only. *Sources*: Authors' elaboration based on The Global Carbon Project (2020) and Our World in Data (2021).

Over the period from 1850 to 2020, the US have been the largest historical emitters of CO_2 from fossil fuels, followed by the EU (27 members), the United Kingdom (UK), China, and Russia (Figure 6). In the 19th century, most CO_2 emissions were originating from land use changes due to the expansion of agriculture in countries such as the US. Near the end of the 19th century and the worldwide takeoff of the industrial revolution, emissions from fossil fuels started to become the main components of global CO_2 emissions (Evans, 2021), and European countries such as the UK, France and Germany began to be at the top of CO_2 emitters. In the second half of the 20th and then the 21st century, emerging economies such as China, Brazil and India significantly increased their share in global emissions.

High-income countries (HIC) are the countries emitting the largest quantity of CO_2 per inhabitant. Since 1850, HIC have emitted on average more than 750 tons of CO_2 per inhabitant – a result above upper-middle-income countries (UMIC) that emitted just below 250 tons per capita over the same period (Figure 8, panel b). China is for instance the largest emitter of CO_2 in the world in aggregate terms but not in per capita terms. Over the 1850-2020 period, HIC have been responsible for more than 75% of all CO_2 emissions per capita (Figure 8, panel a). In more recent years, the relative share of emerging economies and UMIC in cumulative per capita CO_2 emissions has progressively increased to reach more than 30% of total per capita emissions since 1850, while the contribution of HIC started to slightly decrease. These numbers are nevertheless hiding a significant increase in emissions coming from consumption in HIC, so that overall, richer countries remain the largest source of CO_2 emissions in the world (Sachs et al., 2022).

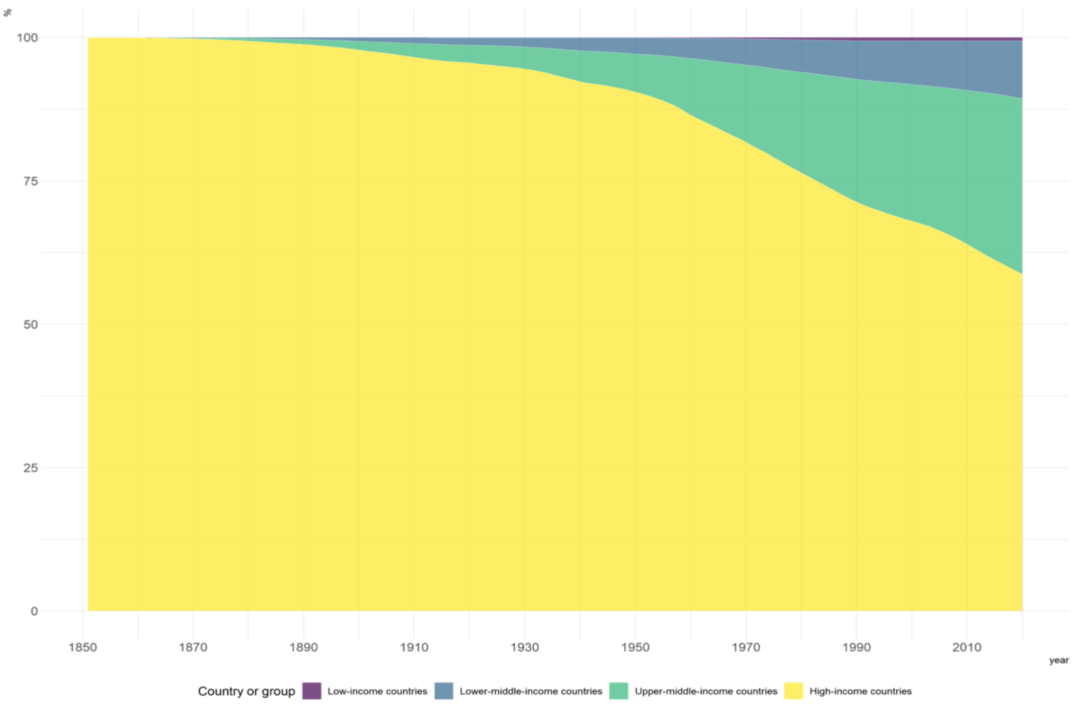
Figure 6. Cumulative production-based CO_2 emissions from fossil fuels, by country and region (billion tons of CO_2)



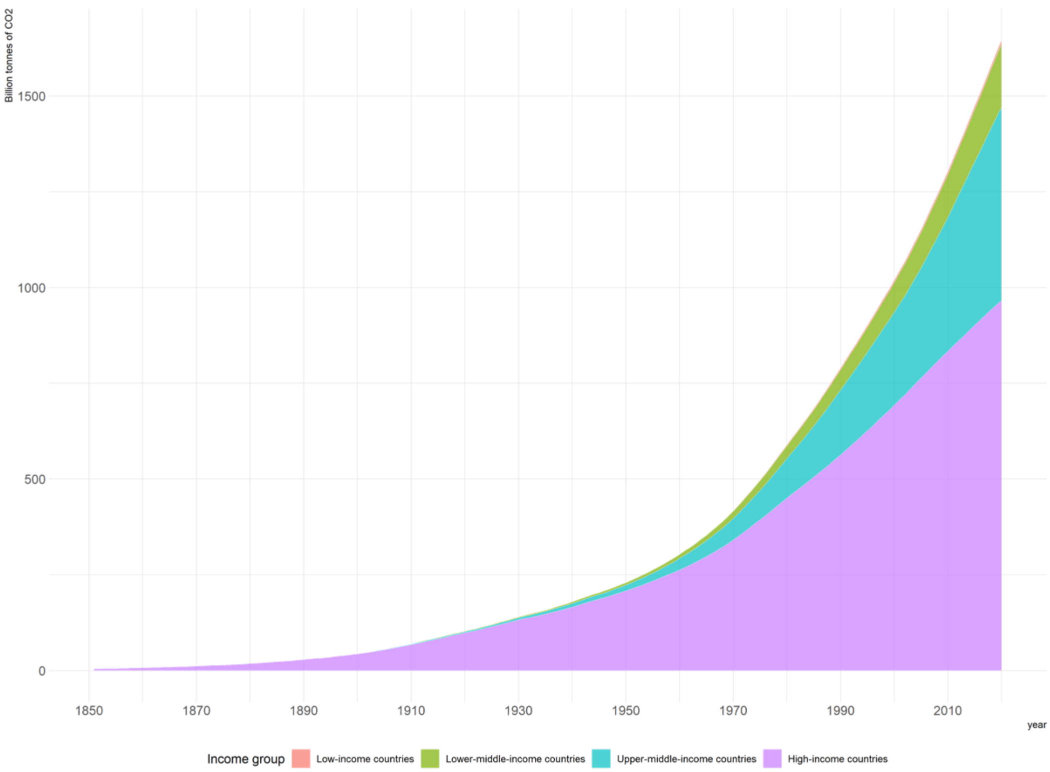
Note: Production-based CO_2 emissions only.
Sources: Authors' elaboration based on The Global Carbon Project (2020) and Our World in Data (2021).

Figure 7. Cumulative production-based CO_2 emissions from fossil fuels, by income group

Panel (a) - % of global emissions



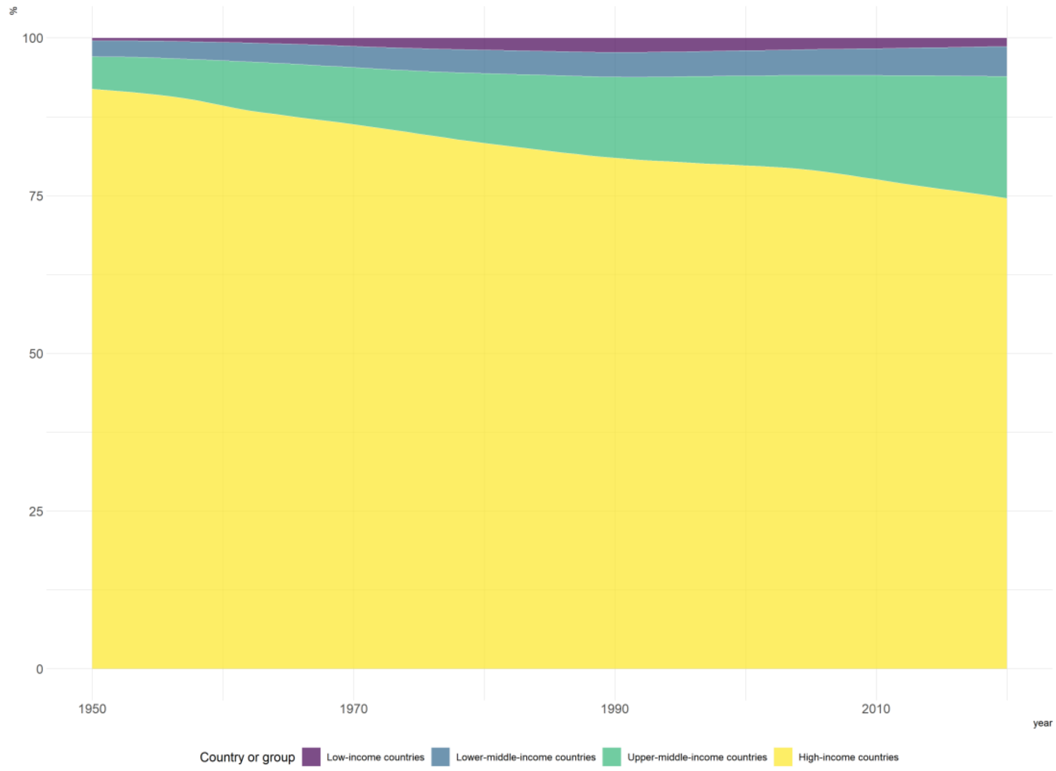
Panel (b) - billion tons of CO2



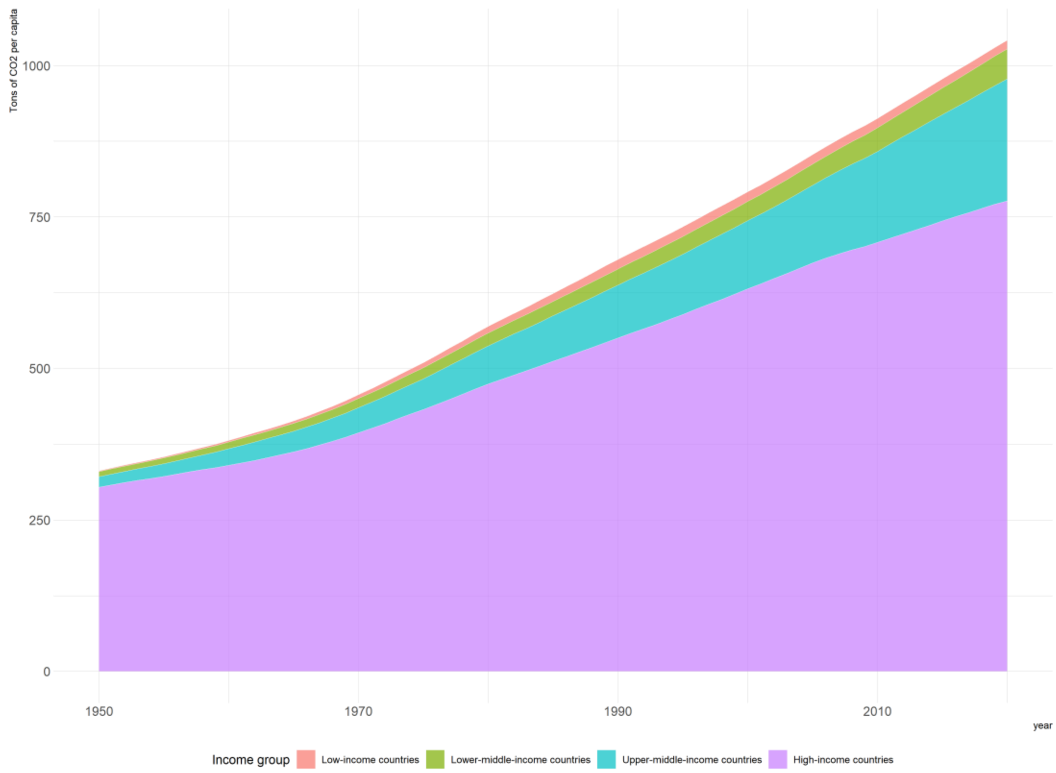
Note: Production-based CO_2 emissions only.
Sources: Authors' elaboration based on The Global Carbon Project (2020) and Our World in Data (2021).

Figure 8. Per capita cumulative production-based CO_2 emissions from fossil fuels, by income group

Panel (a) - % of global emissions per capita



Panel (b) – Tons of CO_2 per capita



Note: Production-based CO_2 emissions only.
Sources: Authors' elaboration based on The Global Carbon Project (2020) and Our World in Data (2021).

3. There should be reparative justice for countries victims of the impacts of human-induced climate change

As noted earlier, the concept of climate justice and the search for reparations are intrinsically linked with historical responsibility in GHG emissions and climate change. The international community of countries would come closer to climate justice if the high-income countries and emerging economies that contributed most to global emissions were the ones bearing most of the financial costs of climate adaptation and L&D globally.

Yet, higher-income economies still refuse to officially recognize their historical responsibility in climate change and in the burden of L&D that remain on vulnerable countries such as SIDS. Although through the creation of the UNFCCC in 1992 all countries agreed on the principle of "common but differentiated responsibilities" and "distributive fairness", little has been done on the international scene (e.g. a global climate justice court does not exist yet), and only small progress has been made towards the financing of L&D at the latest COP meetings, since leading economies are reluctant to agree on the creation of a specific financing mechanism for L&D and climate reparations. There are infinite divergences in the way countries interpret the UNFCCC principle, which all mirror countries' own interests and go beyond the divide between the economic South and North (Calliari et al 2020).

III. Who should pay for loss and damage caused by climate change? Reparative justice, climate attribution, and global versus national responsibility

The first most important step to help countries and communities recover after disasters is to correctly measure or predict both adaptation costs and climate-attributable L&D (see Section III A). Quantifying both categories of costs is very challenging due to the multidimensional nature of these costs – economic and non-economic, short- and long-term – that challenges both the collection and the analysis of adaptation and L&D data. There are three stages in the calculation of the adaptation and L&D costs:

- The first is to assess the optimal adaptation costs. As a general rule, adaptation outlays should be made to the point where the marginal cost of adaptation equals the marginal reduction in expected losses and damages. That is, optimum adaptation does not reduce L&D to zero, because that would incur excessively high adaptation costs. Optimum adaptation proceeds only to the point where the marginal benefit of adaptation (in terms of reduced L&D) equals the marginal cost.
- The second is to measure the share of the optimal adaptation costs that should be covered in the GCIF. Some optimal adaptation (e.g., flood control) should be undertaken even in the absence of human-induced climate change. The part of adaptation covered by global reparative justice is only the portion of optimum adaptation outlays incurred as the result of human-induced global climate change.
- The third is to calculate the share of L&D that should be covered by the GCIF. Like adaption costs, L&D have three distinct components. The first is the L&D incurred because the country has failed to undertake optimum adaptation. Such L&D are the responsibility of the country,

not of reparative justice, provided that they had the means including financial resources to adapt. The second is L&D resulting from weather-related shocks unrelated to human-induced global climate change. Such L&D also are not covered by global reparative justice. The third is L&D that result from global human-induced climate change in the presence of optimum adaptation – and that should be covered by the GCIF.

This leads to the next important step in climate justice, which is to understand the share of climate impact costs due to global human-induced climate change, and therefore the share that is subject to reparative justice. When a natural weather-related disaster hits, it is typically impossible to assert that the given shock was due to long-term human-induced climate change versus natural weather variability. Instead, climate scientists say that as a result of human-induced climate change, the frequency of such a shock was increased by long-term climate change (see Section III B). This means that the attribution to human-induced climate change is probabilistic. For example, if human-induced climate change has raised the frequency of a category 5 hurricane in a given country from 1 per century to 5 per century, we can say that 80% of category 5 hurricanes hitting the country are attributable to human-induced climate change, and 20% to natural variability.

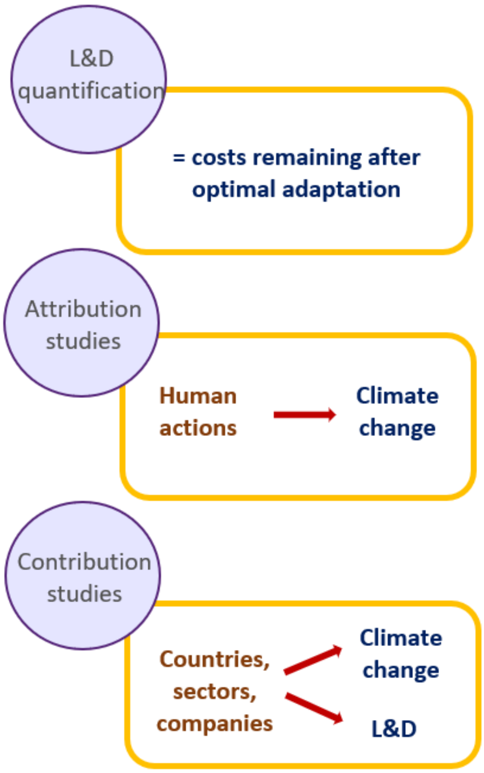
Determining who should pay for L&D caused by climate change is a complex exercise that mobilizes cross-disciplinary skills and knowledge. The idea around the attribution debate is that human-induced costs following climate-related disasters should be shared among polluting countries, according proportionally to their respective historical responsibility in climate change that can be proxied by their historical share in global CO_2 emissions. Several methodological issues arise from this. For example, should we start counting responsibility from the beginning of the industrialization period, or from the creation of the UNFCCC that marks the moment where countries and stakeholders started to be conscious about the consequences of their pollution patterns? While polluting countries should cover both the adaptation and insurance costs against L&D originating from anthropogenic climate change, should natural-induced costs be shared equally among all countries – including the less polluting ones – as a tool to ensure enough incentive to plan for greater resilience to climate change in affected regions or countries?

Overall, research on L&D is organized around three pivotal fields with the objective of quantifying L&D and assessing who should pay for it. Figure 9 summarizes the different challenges that L&D quantification, attribution, and contribution studies are exploring:

- The first challenge is L&D costing: to correctly *quantify* the total amount of L&D costs[8] that need to be covered for allowing countries and communities to recover from climate-related disasters, noting that L&D resulting from inadequate adaptation would not receive reparative compensation.
- The second challenge is related to the *attribution* of climate change, i.e. to identify the respective role of human actions and natural variability in climate change, in the probability of climate disasters, and in the resulting L&D.
- The third challenge is to identify who (e.g. countries, and/or economic sectors) *contributed* to the human-induced climate change and the resulting L&D, i.e. to assess countries' respective share in global greenhouse gases emissions and the resulting consequences on the climate.

[8] The unavoidable economic, but also social, human, and cultural costs of disasters, that occur after a climate event or during a slow-onset process (see Section II).

Figure 9. Three main streams of the L&D literature



Source: Authors' elaboration based on James et al. (2019).

A) How to quantify adaptation costs and loss and damage costs?

The first step towards the design and development of a global fund to share the financing of climate impact costs imposed to countries by human-induced climate change is to correctly measure both adaptation and L&D costs. Through extensive review of the literature, this section presents the different methodologies adopted by academics, international organizations, or governments to 1) quantify the total amount of losses and damages and 2) measure the financial needs for climate adaptation.

1. Quantifying losses and damages

Measuring adaptation and L&D costs is paramount to recover from climate change impacts and enhance resilience to future climate events. Although the international community is making efforts to increase funding for mitigation and adaptation to climate change[9], natural disasters are intensifying in magnitude and frequency, and L&D costs are rising (Doktycz and Abkowitz, 2019). In this context, quantifying L&D costs is key for two main reasons. First and foremost, because L&D are the costs that affected countries and communities are facing after a climate-related disaster (extreme event or slow-onset process) and need to address if they want to recover and enhance their resilience to future climate events. Secondly, assessing L&D costs is paramount to inform climate regulations on the international scene and to design more efficient and fairer climate policies (Auffhammer, 2018).

[9] Multilateral Development Banks have now surpassed their objectives for climate finance in low- and middle-income countries, that reached US$ 51 billion in 2021 (ADB, 2022).

Researchers have developed various models to quantify L&D costs. Thomas et al. (2018) provide a comprehensive review of the literature on frameworks to measure L&D. The authors identify four different groups of modelling techniques (see (i-iv) below). The growing literature on L&D attribution adds a fifth type of model to quantify L&D (see (v) below), since event attribution techniques have now the potential to be used also to measure total L&D costs (Wehner and Reed, 2022; OECD, 2021).

Following the classification suggested by Thomas et al. (2018), models that measure L&D costs can be classified into the following five groups (Table 1):

i. Needs assessment models
ii. Risk assessment models
iii. Catastrophe risk models
iv. Economic models
v. Event attribution models

All types of models are data intensive. They mobilize a significant amount of granular, timely and relatively high-frequency data (e.g. local level, sectoral level) regarding the type of event, the scale and characteristics of the meteorological hazard, the exposure and preparedness of the populations (James et al., 2019), and the indicators of the processes, entities or dimensions on which the impact is measured (e.g. economic production by sector, household income, demographics, etc.). These data are difficult to gather, especially for the type and scale of disasters occurring in vulnerable countries such as SIDS (e.g. hurricanes affecting entire countries), and where fewer categories of assets are insured. Sources such as EM-DAT, DesInventar and Sigma Explorer provide useful data on economic losses and fatalities, but suffer a number of limitations, including the lack of accountability for non-economic L&D.

The L&D models differ on their methodologies, timing of application (i.e. *ex-ante* or *ex-post*), nature of costs they are able to estimate (i.e. economic and non-economic), and type of disasters covered. While needs assessment models and economic models are generally able to provide L&D costs estimates after the occurrence of a disaster, risk assessment models can also be used *ex-ante* to predict future L&D costs. Table 1 provides a summary of the different L&D quantification models.

Most of the L&D quantification models focus on the economic dimension of L&D, whereas little has been done in the literature to measure non-economic L&D. Models generally consider economic losses coming from the destruction of physical infrastructure and other assets, the reduction in production capacities, the drop in income and economic growth, and the increase in financial risks. For instance, it is estimated that if climate policies do not improve, the GDP in most vulnerable countries (including SIDS) will drop by 19.6% in 2050 and almost 65% by 2100. Among SIDS, the GDP of Guyana is expected to be among the most affected by climate change, with a drop of more than 72% by 2100 (Andrijevic and Ware, 2021). Today, SIDS lose on average 2.1% of their GDP annually in L&D, and in the aftermath of a disaster, usually experience an increase in their public debt by 9% (Slany, 2020). While some models measure the amount of expenditure or investment needed to rebuild infrastructure and productive assets (needs assessment models), others compare the costs and benefits of different insurance strategies to reduce future risks of disasters or to catch-up with pre-disaster economic growth rates or debt levels (risk assessment models) (Thomas et al., 2018).

Table 1. L&D quantification methodologies

	Overview	Type of estimates	Timing of model	Type of L&D cost	Type of disaster
Needs assessment models	Estimate the expenditure needed to rebuild and recover after disasters (e.g. DaLA model; PDNA model)	Country-specific Sector-specific	Post-disaster	Economic costs Social costs	Slow-onset processes Numerous extreme weather events
Risk assessment models	Cost-benefit analyses of climate risk reduction strategies (e.g. Hazus-MH, CATSIM)	Regional Country-specific	Pre-disaster Post-disaster	Economic costs	Some extreme weather events
Catastrophe risk assessment models	Predict L&D based on the analysis of past disasters and insurable goods (mostly used by insurance companies)	Country-specific	Pre-disaster Post-disaster	Economic costs	Some extreme weather events
Economic models	Econometric studies using damage functions or input-output models	Country-specific Sector-specific	Post-disaster	Economic costs	Slow-onset processes Numerous extreme weather events
Attribution models	Identify human influence on probability and magnitude of climate events, extrapolated to measure the magnitude of social, economic, and environmental impacts	Regional Country-specific	Post-disaster	Economic costs Social costs Environmental costs	Slow-onset processes Numerous extreme weather events

Sources: Authors' elaboration based on the classification and examples provided by Thomas et al. (2018), Doktycz and Abkowitz (2019), Wehner and Reed (2022), and Auffhammer (2018).

Climate-related L&D affect many aspects of people's lives, including their well-being, physical and mental health (James et al., 2019; Serdeczny, 2016). Costing the damages inflicted on non-market goods (i.e. non-economic L&D) is particularly challenging due to the lack of baseline market pricing for these entities. Research on the measurement of non-economic L&D has therefore mainly focused on one non-economic dimension – the loss of lives caused by disasters (Auffhammer, 2018). SIDS are the countries most vulnerable to natural disasters, and annually record fatalities linked to storms, hurricanes, floods, or earthquakes. In 2010, Haiti experienced the most damaging earthquake, during which the country lost more than 200 thousand people (Slany, 2020). In the Pacific, disasters that occurred between 2000 and 2016 provoked more than 2 300 fatalities in total, and affected more than 5 million people, often through loss of housing (ESCAP, 2018). A few models also evaluate the consequences of climate change and extreme weather events on social costs, including health and education costs (e.g. the Damage and Loss Assessment (DaLa) model), and assess the human resources necessary to recover (e.g. the Post-Disaster Needs Assessment (PDNA) model). However, these models usually try to translate these non-economic costs into monetary terms, to sum them up with economic L&D. Although there is no consensus on the correct ethical methodology to price human lives, some of these models rely on average life expectancy and use, for example, the loss of income that someone would have been able to generate through his/her lifetime (Doktycz and Abkowitz, 2019).

Needs and risk assessment models are commonly used in the literature to estimate the impacts of climate change. Doktycz and Abkowitz (2019) identify four specific models among the methodologies quoted above that seem to be more widely used by international organizations and researchers to measure L&D costs – two needs assessment models (DaLA model, and PDNA model), and two risk assessment models (HAZUS-MH model, and CATSIM model). The DaLA model is one of the only models able to assess L&D from both extreme weather events and slow-onset processes, and to provide estimates of both economic and social costs (e.g. on housing, water and sanitation, culture, transportation, tourism) (ECLAC, 2014). The PDNA model extends the scope of the DaLA model to incorporate estimates of the needs in human resources to allow recovery in the economy, government activities and institutions, and social sector (GFDRR, 2008). The Hazus-MH Assessment model is mostly used after the occurrence of a disaster as it is also a useful tool for emergency response. It uses Geographic Information Systems (GIS) and satellite imagery to identify physical damage (e.g. destruction of schools) and economic losses (e.g. business interruptions, loss of jobs) (FEMA, 2022).

Econometric models are also a valuable tool to quantify L&D as they are simpler models that also allow for the quantification of indirect L&D and macroeconomic effects over time. Auffhammer (2018) highlights how L&D can be measured by relying on Integrated Assessment Models, such as the Dynamic Integrated Climate Economy DICE model (Nordhaus, 1992), Climate Framework for Uncertainty Negotiation and Distribution FUND model (e.g. Waldhof, 2014) and Policy Analysis of the Greenhouse Effect PAGE model (Hope, 1993). These models predict different climate scenarios and impute the resulting climate variables in damage functions to estimate L&D costs[10]. The paper by Burke and Emerick (2016) is a good example of the use of econometrics in L&D measurement. The authors exploit the heterogeneity of temperature and precipitation across US counties and their long-term growth trends to identify the impacts of climate change on the amount of L&D in the US agricultural sector.

Catastrophe risks models are mainly used by insurance companies to assess the actual losses inflicted to countries after a specific extreme event, or to predict potential future losses. They have the advantage to be able to provide detailed estimates of L&D at the country or regional levels (Craeynest, 2010) and to model past disasters. Nevertheless, since they focus only on insurable goods and assets, their applicability in developing and vulnerable countries is low. Data produced by these models are not usually publicly available.

The rapid and recent developments in the science of event attribution make now possible to measure the total amount of L&D also using extreme event attribution techniques (OECD, 2021). Such methods are publicly available and can be applied on data from multiple databases. They utilize novel statistical and computational tools to provide a fast and precise measure of L&D, with the advantage of giving additional information on the drivers of L&D (Wehner and Reed, 2022). In the case of Pakistan in 2022, scientists mobilized attribution models to quickly estimate L&D using the relationship between the floods and climate change (Otto et al., 2022). Useful examples of attribution studies that measure the impact of anthropogenic climate change on a series of economic or social variables are provided in James et al. (2019). They include the following: Schaller et al. (2016) on the monetary losses after floods in the UK in 2013 and 2014; Mitchell et al. (2016) on the number of deaths caused by GHG emissions during the heatwave in Europe in 2003.

[10] For more detailed explanations, we refer the reader to the paper by Auffhammer (2018).

The results of the L&D quantification assessments are used to feed various open-source disasters databases, such as EM-DAT[11], DesInventar[12], and Sigma Explorer[13]. Other databases owned by reinsurance companies also provide data on disasters and their estimated impacts in terms of L&D, but access to these data is usually restricted. Although the various open-source disasters databases are extremely useful to convey further analyses on disasters and their consequences, they only provide information on monetary losses (e.g. infrastructure, insured losses) and fatalities, thus leaving aside other non-economic variables. It is worth noting that the major disasters databases tend to overrepresent the L&D generated by extreme rainfall and flooding – because floods affect relatively more certain types of physical assets and infrastructure for which measuring the damages is easier (e.g. the damage caused by floods on roads is immediately quantifiable, limited in space and easy to monetize) (OECD, 2021; Tschumi and Zscheischler, 2019).

Although many studies using L&D quantification models have significantly contributed to highlight the importance of taking L&D into account, the baseline models for measuring L&D costs still face some limitations. First, the low data availability is one of the main limitations of current L&D quantification models. The different methodologies require data on either the climate characteristics of the natural disaster (e.g. level of precipitations), or the preparedness and exposure of economic systems and communities to the hazard (e.g. number of people living in floodplain, houses built with resistant methods and material). The process of data collection itself can be difficult in a post-disaster context, where human and technical capacities are likely to be harmed and reduced. Longer-term data on economic and non-economic L&D are also challenging to obtain, as they require resources for regular updates or follow-up of people affected by the disasters several years after the event. When models rely on analysis of past climate events, the main challenge is the level of territorial disaggregation of the data. These constraints on data availability result in a larger number of studies performed for disasters in developed countries than in developing or vulnerable countries, where assessing L&D costs is most needed.

Secondly, most L&D studies tend to overlook the welfare impacts of climate change and to leave aside essential non-economic costs, such as the impacts of disasters on psychological health and morbidity, education, and the effects on cultural losses and on biodiversity and species that require a more qualitative approach (Thomas et al., 2018; Stone et al., 2013). Consequently, models based on econometric analyses could have the potential to expand the type of L&D costs taken into account, as using these methodologies makes it easier to cover many sectors, places and times. Generally speaking, rigorously quantifying the amount of L&D is complex in itself because the consequences of anthropogenic climate change are not limited in space or time (e.g. GHG emissions by a specific country will have devastating consequences around the planet for many generations) (Auffhammer, 2018).

Thirdly, although most vulnerable countries are under the threat of slow-onset processes, few of the L&D assessment models are able to quantify L&D costs associated with these types of disasters. The DaLA and PDNA models are some of the exceptions, as they have the capacity to evaluate some L&D costs caused by slow evolving disasters.

Finally, the fact that institutions and researchers use different models to quantify L&D makes it difficult to compare results across studies and cases (Doktycz and Abkowitz, 2019). L&D quantification

[11] EM-DAT, The International Disaster Database developed by the Centre for Research on the Epidemiology of Disasters – CRED, is accessible at: https://www.emdat.be/database.
[12] DesInventar, the software hosted by UNDRR, is accessible at: https://www.desinventar.net/.
[13] Sigma Explorer, database created by Swiss Re Institute, is accessible at: https://www.sigma-explorer.com/.

studies would benefit for more cross-disciplinary studies, exploiting the synergies between economics and climate modelling science. The costs of assessing L&D should not fall only on the affected countries. A specific international institution could oversee the measurement of L&D, as well as the attribution of these costs among responsible countries.

2. Measuring adaptation costs and needs

With slow progress on mitigation engagement and results worldwide, adaptation measures have progressively gained momentum, and with them, the need for measurement assessments of adaptation needs and costs. Although the literature focused on the measurement of adaptation needs appeared earlier than studies on L&D, the measurement of adaptation costs remains a complex issue mainly because adaptation is needed in a large array of sectors – both economic and non-economic. Investments in adaptation were long jeopardized by uncertainties in climate forecasting, but progress on the measurement of climate change impacts should help reduce the level of risk. Nevertheless, adaptation measures tend to still be taken in a reactive manner rather than being anticipatory (Massetti and Mendelsohn, 2018). Besides, adaptation needs highly depend on countries' and sectors' specificities which are often non observable (Leiter and Pringle, 2018).

Measuring adaptation needs is a key step to gauge the financing needs in countries affected by the adverse effects of climate-induced climate change and help share responsibilities between the public and private sector. While with the right incentives (e.g. subsidies on insurance against natural disasters) the private sector has a role to play in implementing (and funding) adaptation measures, most of the burden to finance adaptation falls on governments – especially for adaptation in non-marketable sectors (e.g. education, biodiversity).

Several empirical methods have been developed in the literature to measure adaptation needs (Table 2). Among the most predominant methodologies are i) Cross-sectional studies, ii) Simulation studies, iii) Panel weather studies, and iv) other intermediate studies such as the unified approach by Bento et al. (2021). All these methodologies use different types of datasets and rely on different assumptions.

Policymakers more generally rely on adaptation indicators frameworks to measure adaptation needs. The main limit of the empirical models presented above is their lack of capacity to assess adaptation needs in non-economic sectors (e.g. coastal protection, health). Because there is no consensus on a common approach to measure adaptation needs across countries, such empirical models are also rarely used by policymakers. Instead, policymakers more easily rely on another type of methodology to measure adaptation needs, by using different sets of adaptation outcome indicators. Adaptation metrics are used to set targets for adaptation programs and track progress over time but can also be used to identify the needs (both in terms of outcomes and money) and to allocate resources across sectors and countries (Leiter and Pringle, 2018). Notwithstanding the usefulness of this approach at the local or national level, there is no consensus on the choice of adaptation indicators at the global level, which represents the main limitation of this approach to measure adaptation needs, as estimate might differ significantly across countries and regions depending on the indicators that compose the framework. Examples of adaptation indicators that can be used are: "improve access to drinking water", "ensure earthquake-proof buildings", "increase the amount of irrigated agricultural land", "increase the share protected areas", etc. Using these adaptation indicators frameworks, vulnerability assessments can then assess the current state of progress on the indicators regarding the targets, and by deducting the resources available for adaptation in each country, they can provide estimates on the adaptation financing needs at the scale of the country, for a variety of timeframes and sectors.

Table 2. Overview of methodologies to measure adaptation needs

	Overview	Type of climate change	Type of estimates	Advantages	Drawbacks
Cross-sectional studies	Evaluate how decisions by economic actors (e.g. farmers) vary depending on the climate conditions they experience	Slow-onset processes	Long-term	Can estimate long-term needs in adaptation	Sector-specific estimates Event-specific estimates (one source of climate change) Omitted variable bias No evaluation of adaptation in non-market sectors Limited use by policymakers
Simulation studies	Forecast various adaptation paths, by maximizing objective functions under constraints (e.g. climate change)	Slow-onset processes	Long-term	Can identify most efficient adaptation strategies (costs-benefits) Address omitted variable bias by adopting a partial equilibrium approach	Sector-specific estimates (no measurement on entire economy) Event-specific estimates (one source of climate change) No evaluation of adaptation in non-market sectors Limited use by policymakers
Panel weather studies	Exploit unanticipated climate shocks to analyze the response of economic actors	Extreme weather events	Short term	Address omitted variable bias	No evaluation of adaptation in non-market sectors Limited use by policymakers
Other empirical approaches	The unified approach to measure impact on the economy by Bento et al. (2021)	Slow-onset processes Extreme weather events	Short- and long-term	Simultaneously exploits variations in weather shocks and in climate variables to identify both short-and long-term adaptation needs	No evaluation of adaptation in non-market sectors Limited use by policymakers
Adaption indicators frameworks	Outcome indicators used to measure adaptation gap and related financing	Slow-onset processes Extreme weather events	Short- and long-term	Easier to use by policymakers	No harmonized commonly agreed set of indicators across countries

Sources: Authors' elaboration based on Massetti and Mendelsohn (2018) published in The Review of Environmental Economics and Policy; Leiter and Pringle (2018) published in partnership with UNEP; and Bento et al. (2021) published as a NBER working paper.

B) How to assess the role of human activities on climate change, adaptation and L&D costs?

While measuring the total L&D costs is essential to improve recovery plans, identifying what is causing climate change and what are the drivers of the worsening in disasters' impacts is essential to increase future resilience to climate events. Disasters caused by climate change will keep increasing – both in frequency and magnitude – and their resulting L&D will continue to grow (IPCC, 2021; OECD, 2021). Identifying what is responsible for climate change is crucial to assess the evolution of climate risks and prioritize actions to reduce them, and is also key to decide how to finance L&D.

The purpose of "attribution science" is to identify the drivers of climate change, and more specifically, to disentangle the respective roles of humans and nature in climate change and disasters (Wehner and Reed, 2022; OECD, 2021). By assessing the individual influence of humans' activities and natural processes in climate change, the objective of attribution studies is also to determine whether anthropogenic climate change is responsible for the current worsening in climate disasters' impacts and L&D.

Attribution science is divided into two major streams of work: one assessing the impact of human activities on climate change, and the other focusing on the impact of anthropogenic activities on L&D. A large share of the attribution literature seeks to assess how human activities influence climate change. The objective of researchers is to quantify the role of anthropogenic GHG and aerosol emissions, human practices in land use, and human influence on assets and populations' exposure to climate risks, on climate variables (e.g. global temperatures, precipitations, sea level). The other and smaller part of the attribution literature tries to identify how human actions (versus other drivers including natural processes) influence L&D from climate disasters. Evaluating the proportion of L&D costs generated by anthropogenic climate change is even more complex than identifying the role of human activities in climate change only. One of the main reason lies in the fact that this part of the literature also evaluates costs that are very diverse in nature. Studies in this field therefore go beyond climate science and require inputs from economics, social science, human development, and environmental science (James et al., 2019; Stone et al., 2013). Isolating the specific influence of anthropogenic climate change on specific L&D is particularly difficult as L&D result from the interaction of many other drivers, including natural processes, and the increasing exposure of assets and populations to climate risks. Table 3 reviews some representative examples of attribution studies, giving an overview of the nature of climate variables the literature tends to focus on.

Table 3. Selected examples of attribution studies

Category	Authors	Type of climate event (and type of L&D cost)	Scope and Main results
Role of human activities on climate change	Tett et al. (1999)	Global warming	Solar irradiance is the major driver of the rise in temperatures observed during the first half of the 20th century. Yet, natural processes are not sufficient to explain the rise in global temperatures after 1950, which can be rather explained by the increase in anthropogenic GHG and sulfate aerosols emissions.
	Stott et al. (2000)	Global warming	More than 80% of the rise in global temperatures is due to anthropogenic factors.
	Bindoff et al. (2013) in 5th IPCC report	Global warming	Anthropogenic GHG generated increases in global mean surface temperatures between 0.5°C and 1.3°C between 1951 and 2010, while the contribution of natural drivers to global warming is between -0.1°C and 0.1°C.
	Pershing et al. (2022)	Global warming	Research in attribution science is currently undergoing important progress. New tools (e.g. the Climate Shift Index created by the Climate Central scientific group) are now able to estimate how climate change impacts global temperature, on a daily basis.
	Zhang et al. (2013)	Precipitations	Human activities intensified the magnitude of maximum daily precipitations in the Northern Hemisphere by more than 3% between 1951 and 2005.
Role of human activities on the probability and magnitude of extreme weather events	Herring et al. (2018)	Mainly heat-related events	First study to find out that several extreme weather events (mostly heat-related events) that occurred in 2016 would not have been possible in the pre-industrial world – meaning that anthropogenic activities are the key drivers of these disasters. Attribution studies tend to be more conclusive for heat-related events since the consequences of human activities on global temperatures are more flagrant.
	Simon et al. (2018)	Wildfires	Human actions alone multiplied by five the risk of wildfires that occurred in 2015 and 2016 in Western North America and by two in the extratropical region of Australia.
	Peterson et al. (2012)	Floods, droughts	Focus on six extreme weather events that occurred in 2011. While floods in Thailand are mainly explained by natural climate variability, the heavy droughts in the Horn of Africa experienced in the same year were directly caused by the rise in temperatures in the Pacific Indian Ocean due to anthropogenic factors.
	Van Oldenborgh (2007)	Heatwave	The warm autumn of 2006 in Europe was due to both natural trends and anthropogenic global warming. Studies relying on single climate models tend to underestimate the role of human induced climate change.
	Otto et al. (2012)	Heatwave	While the magnitude of the Russian heat wave in 2010 was mostly explained by internal factors, external (i.e. anthropogenic) factors were the main drivers of its probability to occur.
Role of human activities on L&D	Schaller et al. (2016)	Floods (Economic costs)	One of the first "end-to-end" attributions studies to estimate the role of anthropogenic climate change in i) the probability and magnitude of flood risks in southern England in 2013/2014 and ii) in the damages that these floods generated. Even if human activities played a limited role in increasing the risk of floods for this specific event, they generated significant monetary losses.
	Callahan and Mankin (2022)	Heatwaves (Economic costs)	The economic impact of human-induced heatwaves is heavier in poor tropical countries than in more developed countries. Annually, developing countries have been losing 6.7% of their

		GDP per capita to extreme heat, while richer economies have lost 1.5% of their GDP annually for the same reason.
Mitchell et al. (2016)	Heatwave (Fatalities)	Use multiple regional climate models to quantify the impact of human activities on heat-related fatalities during the 2003 European heatwave.
Brainard et al. (2018)	Global warming (Environmental costs)	Reveal that human-induced climate change had a direct influence on the disruption of coral reef and seabird communities in the central equatorial Pacific region during El Niño in 2015/2016.

Historically, the first attribution studies developed models to evaluate the role of human activities on climate change, and more particularly on slow-onset processes (e.g. global warming, rising sea levels). These "trends attribution models" usually utilize a combination of climate models to compare the respective influence of anthropogenic emissions and natural drivers (e.g. El Niño, La Niña, solar variations, volcanic emissions) on global temperatures. They simulate different scenarios of temperatures by adding and removing specific drivers (e.g. what would be the current temperatures if humans never emitted GHG), and compare these trends to current observed temperatures.

Rather than measuring the influence of human activities on slow-onset processes, the most recent attribution studies focus on measuring the impact of human activities on the probability and magnitude of specific extreme weather events such as floods or hurricanes (James et al., 2019). Methodologies such as the probabilistic event attribution approach (Massey et al., 2014) rely on a combination of climate and statistical models to estimate the causal impact of anthropogenic GHG emissions on the probability that a specific climate event happens. Models usually single out the effect of anthropogenic emissions by comparing the probability of occurrence of the studied event in the current climate (i.e. considering natural and anthropogenic drivers) with the probability of occurrence of the same event in alternative climate scenarios where the anthropogenic drivers of climate change are removed (i.e. where the event is only influenced by natural and internal drivers). The accuracy of the estimates mainly depends on the capacity of the climate models to simulate hypothetical climate scenarios where anthropogenic factors are removed one by one. The World Weather Attribution initiative[14] and the American Meteorological Society (AMS) are among the most important providers of extreme weather attribution studies today.

The part of the literature focusing on the direct influence of human activities on L&D caused by climate change and climate disasters is dominated by impact attribution studies. These utilize the outputs of global climate models (i.e. the changes in temperatures, precipitations and sea levels) to estimate the impact of human activities on different sectors of the economy and society, including on environmental aspects (OECD, 2021). Such models require baseline past data on the various economic, social, or environmental costs they seek to explain, as well as detailed data at the local level on various climatic variables. While most studies focus on economic L&D, some authors also investigate the role of anthropogenic activities on non-economic L&D, including the number of deaths after a disaster, or on environmental L&D.

Overall, attribution science reveals that human activities are playing a significant role in increasing the probability and intensity of heatwaves, as well as the magnitude of extreme rainfall events (Fischer and Knutti, 2015), and therefore in increasing L&D resulting from climate change. The literature also highlights that through their pollutant GHG emissions, but also through their choices to increasingly locate assets, wealth, and populations in places particularly exposed to climate risks, humans have a significant role to play in increasing L&D (Visser et al., 2014). More political attention

[14] World Weather Attribution' studies are available at: https://www.worldweatherattribution.org/.

needs to be directed on attribution research, as it represents a critical tool to improve mitigation and adaptation planning.

Nevertheless, attribution studies are subject to several limitations that make their application more difficult in developing or vulnerable countries than in richer regions of the world (OECD, 2021; James et al., 2019). Most of the current issues in attribution investigations are linked to their requirements in quantitative data, and to their high reliance on climate models simulations. Because the collection of climate and impact data is more complex in highly vulnerable countries such as SIDS, the attribution literature tends to focus more on disasters for which more and better-quality data is available, i.e. disasters taking place in higher income regions (e.g. Europe, North America). Attribution science requires long-term data on climate trends and various climate variables, as well as disaggregated data on economic assets and other social or environmental variables to estimate the impacts of anthropogenic climate change on L&D at the local level. Partly due to weaker statistical capacity and lower funding capacity for monitoring systems and sustainable development, the availability of (or access to) such long term and disaggregated data is more limited in developing countries. Moreover, current climate models are scarcely effective to predict the types of extreme events occurring in developing regions (and more particularly in the tropics), since the latter tend to be more influenced by global physical phenomena than in other parts of the world, and therefore more uncertain. Also, insurance coverage is weaker in developing countries, and it is common that many assets that are usually destroyed or damaged after disasters do not benefit from insurance (OECD, 2021). Since the monitoring of L&D is often possible through data on insured goods and assets, tracing the impacts of climate change on L&D in developing countries is often more difficult, as it requires additional skills and technical capacities to use alternative measurement methods (e.g. GIS analysis).

The limited availability of data in developing and vulnerable countries and regions call for the harmonization of disaster databases and increased international funding for attribution studies. Because of the disparities in the capacity of countries across the world to collect historical, timely, and accurate climate and impact data, caution is needed in the use and interpretation of the data provided in the existing global and national disaster databases (e.g. EM-DAT, SHELDUS). Gall et al. (2009) provide a comparative review of four open-source disaster databases, and argue that international effort must be provided to implement a harmonized and comparable collection of climate and impact data at the international level. While more funding in the context of L&D (and adaptation) should be allocated to the improvement of disasters monitoring systems in vulnerable countries to expand the coverage of natural disasters, more institutional and international funding should also be directed to attribution studies in general. Currently, attribution investigations are usually funded by national governments or national meteorological offices and therefore tend to focus only on climate events that occurred in the country providing the funds (OECD, 2021). It is just when more robust data on disasters and their economic, social and environmental impacts will be available, that attribution studies will be used on the diplomatic scene to help decide how to share the financing of L&D among countries responsible for them (Hoegh-Guldberg et al. 2011).

C) Sharing responsibility for disasters: how to measure countries' individual contributions to climate change?

Contribution studies are used to measure countries' (or regions, cities, sectors, companies) historical responsibility in climate change. While the attribution studies described in the previous sub-section quantify the impact of human activities on climate change and L&D, they do not provide information on individual countries' responsibility. The search for historical responsibility in climate change is key to the question of climate justice and to the debate on how to finance L&D (Otto et al., 2017), especially for SIDS which are the first victims of climate change but did not significantly contribute to it.

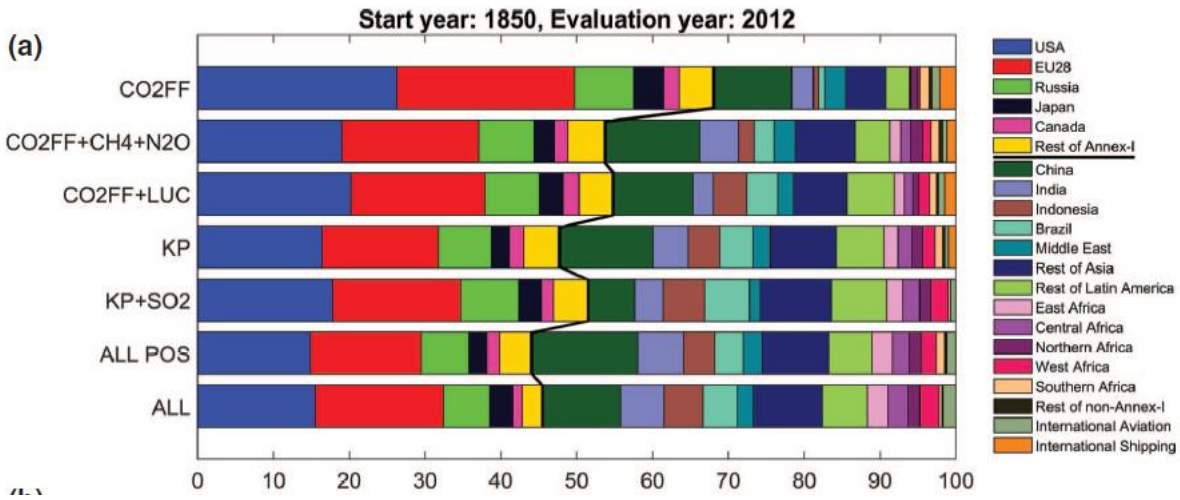
Historical contributions to climate change are not only evaluated through the share of each country in global emissions, but rather by looking at the proportion of climate change each country is responsible for (through its emissions). Models that investigate countries' contributions to climate change typically measure the impact of each countries' polluting emissions on climate variables, mainly global temperatures (Skeie et al., 2017; Mace and Verheyen, 2016; Rocha et al., 2015; Frame et al., 2019), but also, in some cases, on the probability of extreme weather events (Otto et al., 2017). Researchers test the influence of individual countries' quantities of emissions on the changes in climate, using a counterfactual methodology which allows to identify to which extent certain modifications in the climate would have occurred if countries' emissions would not have existed (James et al., 2019). Table 4 summarizes key results from a selection of contribution studies.

Table 4. Selected examples of contribution studies

Responsibility focus	Authors	Type of climate variable	Results
Countries	Skeie et al. (2017)	Global surface temperatures	The 43 countries of the Annex-I countries of the UNFCCC contribute to 68% of total warming through their production-based emissions of CO_2, and 54% of global warming when considering other GHG such as methane and nitrous oxide.
	Mace and Verheyen (2016)	Global surface temperatures	The US, the EU, China, Russia, India, and Brazil are the countries most responsible for the expected increase in global temperatures by 1°C by 2100, as the rest of the world would only contribute by 34% to this rise in temperature.
	Rocha et al. (2015)	Global surface temperatures	Cumulative GHG emissions between 1850 and 2012 by the US, the EU, and China contributed to around 50% of global warming, and more specifically to a rise by 0.5°C in 2100. Inside the EU, Germany and the former member Great Britain are the main contributors.
	Frame et al. (2019)	Global surface temperatures	Using a novel index, authors show that the higher their GDP per capita, the more countries tend to contribute to climate change, but the less they are likely to be affected by it.
	Otto et al. (2017)	Extreme weather events	Emissions by the US and the EU directly contributed to make several extreme disaster events more likely, such as the heatwave in Argentina whose probability increased between 20% and 60%.
Private sector	Fuglestvedt et al. (2008)	Global surface temperatures	The transport sector (mainly road transport) has been contributing to around 15% of all anthropogenic global warming originating from human-induced CO_2 emissions.
	Heede (2014)	Focus on CO_2 emissions	The 90 largest producer companies of oil, natural gas, coal and cement represent 63% of all cumulative global CO_2 emissions. The largest contributors are Chevron, ExxonMobil, SaudiAramco, BP, and Gazprom.

Overall, contribution studies highlight that high-income countries and emerging economies are the most responsible for climate change. They demonstrate that high income countries (including the US and the European Union) are responsible for more than half of the rise in temperatures today (Skeie et al., 2017), and that together with emerging economies (including China, Brazil and Russia), they will be responsible for more than two thirds of global warming by 2100 (Mace and Verheyen, 2016). The 43 countries of the Annex-I countries of the UNFCCC (i.e. the EU, and other industrialized or emerging countries) contribute to 68% of total warming through their production-based emissions of CO_2, and 54% of global warming when considering other GHG such as methane and nitrous oxide (Figure 10).

Figure 10. Contributions to global mean surface temperature in 2012, by type of GHG and GHG origin



Notes: CO2FF = CO_2 from fossil-fuel combustion and cement production; CH4 = methane; N2O = nitrous dioxide; LUC = CO_2 emissions from land use changes; KP = Kyoto Protocol gases; SO2 = sulfur dioxide.
Source: Skeie et al. (2017)

While some authors focus on the role of countries in climate change, others prefer to highlight the responsibilities of productive sectors and private companies. In the search of climate justice, analyzing the private sector's contribution to global emissions and climate change is also a key element that could unlock progress on diplomatic debates at COP27. Scientific studies reveal a significant role of private companies in global emissions.

Results of individual contribution studies are sensitive to a series of methodological choices(see Skeie et al., 2017), and to the sensitivity and accuracy of the emissions data (Solazzo et al., 2021). The following aspects are essential when estimating countries' respective contributions to climate change:

1) **The climate variable on which the impact of pollutant emissions is measured.** Most studies focus on the impact of emissions on global temperatures, but other variables can be considered (e.g. precipitations, sea level) depending on the objective of the study.
2) **The year from which we start accounting for emissions.** While emissions from high-income countries started in the early 20th century, the increase of emissions from emerging economies rather happened in the 21st century. Therefore, when using later starting years (e.g. 2000), the relative contribution of the US and the EU decreases, while China becomes the largest contributor to climate change. Is it fair using industrialization dates rather than the exact dates on which countries began to agree to reduce their emissions (e.g. creation of the IPCCC)?

3) **The year in which the impacts on climate are measured.** While analyzing the impact of past emissions on the current climate is key, it is important to measure their effect on future deregulations of the climate, as emissions have long-lasting impacts (Mace and Verheyen, 2016).
4) **The components of pollutant emissions which are considered (i.e. all GHG and aerosols or a sub-selection).** When estimating CO_2 emissions only, the relative contribution of richer economies to climate change is larger than if we consider other types of GHG. In addition, which origin of emissions should be considered (i.e. production-based, consumption-based, extraction-based)?
5) **Measurement of emissions in absolute or per capita terms.** While what matters for the Earth system and the consequences on global L&D is the absolute amount of emissions, measuring the contribution to climate change in per capita terms could be useful in the context of historical responsibility and to unlock financing solutions. For instance, the contribution of China to climate change is high in absolute terms but decreases when expressed in per capita terms.

IV. How to finance climate impact costs? Potential financial instruments and mechanisms

Although the estimated magnitude of L&D finance needs is significant, existing financial support to address L&D is still insufficient. There is no official and commonly accepted estimate of L&D finance needs, but the numbers projected by researchers are considerable. Baarsch et al. (2015) estimate economic L&D costs to be US$ 400 billion in 2030 and US$ 1–1.8 trillion by 2050. In another study, Markandya and González-Eguino (2018) project L&D costs of at least US$ 290-580 billion by 2030 for developing countries alone. Notwithstanding this, existing financial support to address L&D is insufficient (Schäfer et al., 2021a), with most climate finance addressing mitigation costs rather than adaptation and L&D costs (Buchner et al., 2021). There are also important differences of L&D financial support across countries and types of L&D costs.

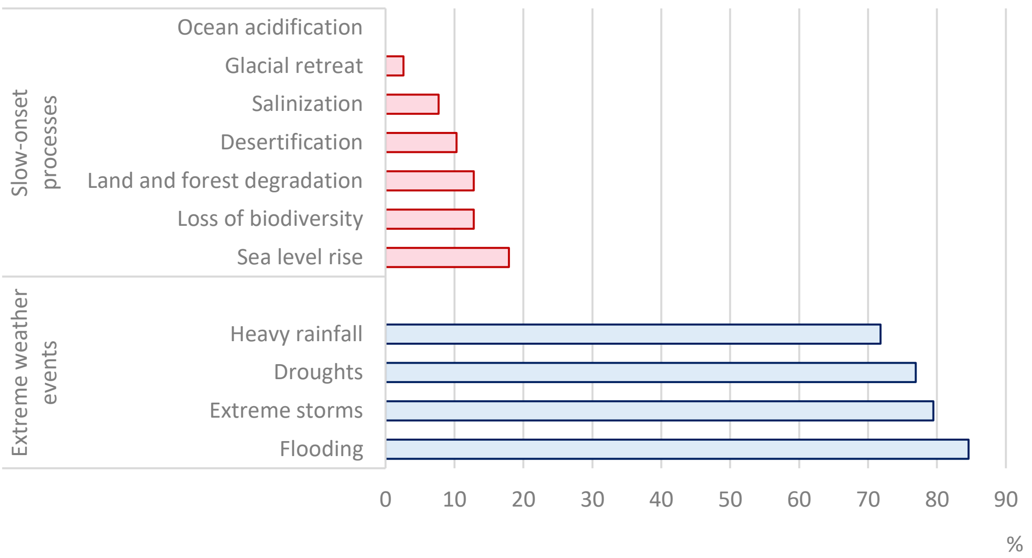
Financial support is lacking especially for vulnerable countries such as SIDS which are the most exposed to climate-induced L&D due to their geographical locations and physical characteristics and have limited national financial resources to address L&D costs. The OECD (2021) reports that while in high-income countries, over half of economic L&D from climate-related extreme events are covered by insurance, in other countries just a tenth are insured.

Across the different types of L&D costs, financial support is particularly scarce for L&D costs due to slow-onset processes and for non-economic L&D costs. Notably, these costs are significant in SIDS where sea level rise is responsible of several losses and damages such as coastal flooding, coastal erosion and loss of land, loss of ecosystems, which enhances coastal flooding and erosion, and loss of freshwater resources. Looking at Climate Vulnerable Forum (CVF) countries[15], Künzel and Schäfer (2021) find that financial support for L&D costs due to slow-onset processes is largely insufficient and much more limited than financing for L&D costs due to extreme weather events. As shown by Figure

[15] Climate Vulnerable Forum countries consist of 48 countries (including 17 SIDS) from the African, Asian-Pacific and Latin American and Caribbean region facing severe threats due to climate impacts. For a list of CVF countries, see: https://thecvf.org/members/

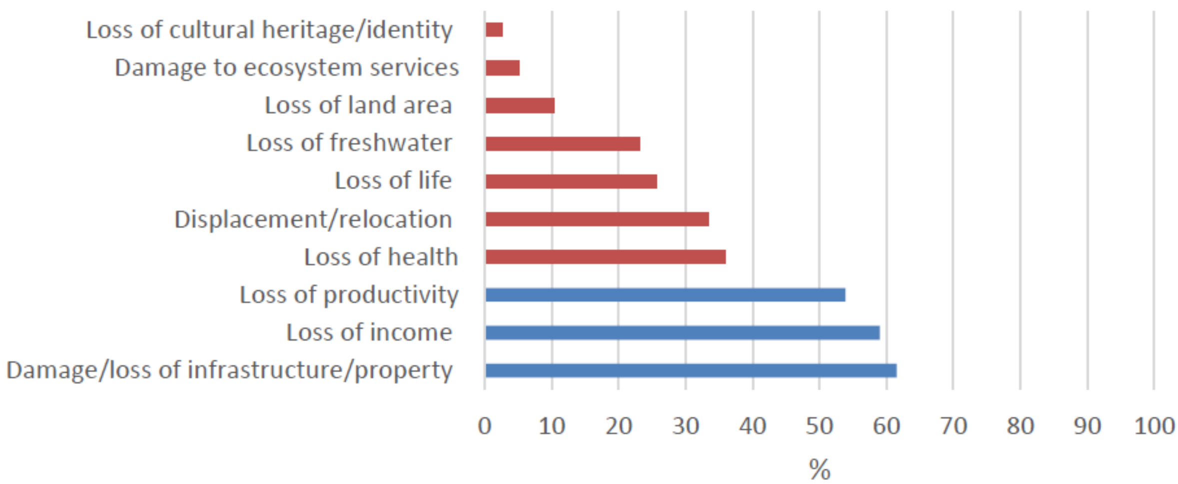
11, while about 80% of CVF countries have financing mechanisms in place to respond to flooding and extreme storms, only 18% of CVF countries have mechanisms addressing sea level rise. And an even smaller share of CVF countries have put in place financing instruments to address salinization and glacial retreat (8% and 3%, respectively). Lack of and/or insufficient data and knowledge on slow-onset processes is, among others, one reason for the gap in financial support for L&D due to slow-onset processes. Major gaps also exist in CVF countries regarding financing mechanisms addressing non-economic L&D costs compared to economic L&D costs (Figure *12*). Against 60% of CVF countries having in place instruments to cover damage/loss in infrastructure/property and loss in income, only 10% and 2.5% of CVF countries have financing instruments addressing loss of land area and loss of cultural heritage/identity respectively.

Figure 11. Coverage of Extreme Weather Events and Slow-Onset Processes by existing national financial instruments and mechanisms in CVF countries (%)



Source: Künzel and Schäfer (2021).

Figure 12. Coverage of Losses and Damages by existing national financial instruments and mechanisms in CVF countries (%)



Source: Künzel and Schäfer (2021).

To address L&D costs, both financing mechanisms and financing sources are needed (Schäfer et al., 2021b). On one hand, financing instruments are needed to guarantee adequate financial capacity of governments or other stakeholders to cope with L&D costs. On the other hand, financing sources - which could be either national or international - should provide the necessary funds to set up and implement financing mechanisms to address L&D costs.

The traditional financing mechanisms that could be used to prevent and deal with L&D costs can be classified into three categories: (i) instruments for risk reduction; (ii) instruments for risk retention; and (iii) instruments for risk transfer (Table 5). Risk reduction mechanisms refer mainly to social protection and humanitarian assistance, while several mechanisms for risk retention and risk transfer are outlined in UNFCCC texts, and include savings, debt, and insurance instruments with or without an element of risk transfer (UNFCCC Secretariat, 2014).

Table 5. Possible financing instruments for loss and damage: advantages and disadvantages

	Financing Instruments	Pros	Cons
Risk Reduction	Social protection Humanitarian assistance	Can be used in case of both extreme weather events and slow onset processes	Slow to mobilize
Risk Retention	Contingency finance (savings, funds, borrowing)	Can be rapidly disbursed	Divert funds away from other key spending needs Cannot be used for slow onset processes Can worsen a country's fiscal burden
Risk Transfer	Catastrophe risk insurance Risk pools Catastrophe bonds	Can provide rapid payouts after disasters	Cannot be used for high-frequency events and slow onset processes Can create moral hazard effects by reducing incentives for risk reduction

Source: Authors' elaboration on several sources.

Financing mechanisms for risk reduction such as social protection and humanitarian assistance are key for providing *ex post* financial support for climate-induced losses as well as *ex ante* financial support for prevention of L&D costs. Social protection can be used for responding to economic costs due to climate change impacts incurred by households, businesses or subnational governments such as loss of income, or damages to private (e.g. homes) or public (e.g. schools, hospitals, etc.) infrastructure, among others. In the form of adaptive social protection, it can also provide finance for enhancing the capacity of societies to prepare, cope and adapt to the impacts of climate change. In a similar way, humanitarian assistance can provide post-disaster relief but in the form of forecast-based financing it can enable humanitarian action in advance of a potential disaster, by releasing funds according to scientific forecasts of extreme weather.

Risk reduction instruments can be used to respond to L&D from any type of natural hazards but are slow to mobilize. The advantage of social protection and humanitarian assistance is that they can be used in case of both extreme weather events and slow-onset processes. However, the main challenge is that the timing and volume of such financial support can be unpredictable and slow to mobilize.

Financing instruments for risk retention refer to contingency finance which consists of funds set aside to finance contingency plans in case of climate-related disasters. Disaster relief funds, restoration funds with preferential interest rate, contingent credit, and microcredit are some examples of contingency finance instruments that can be used.

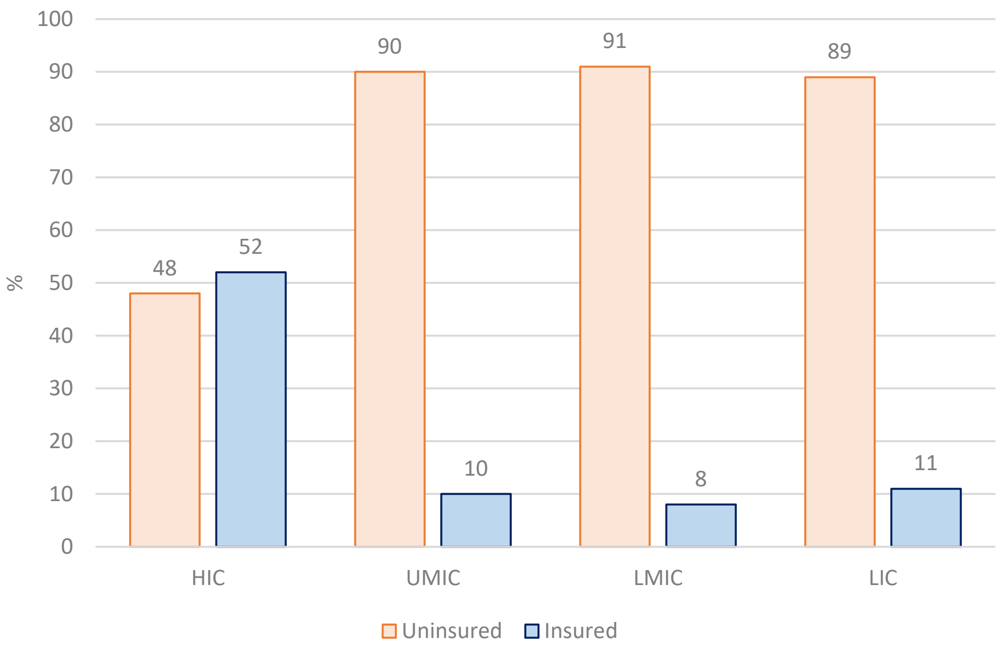
The main advantage of contingency funds is that they can be rapidly disbursed in the wake of a disaster, but they leave the burden of L&D with affected countries and may divert funds away from other spending needs. On one hand, in case of natural disaster contingency finance allows governments to act fast to help victims and provide relief. However, an important drawback is that setting aside funds for an uncertain future impede governments to allocate funds to other key development projects such as building roads, or setting up health or education programs, among others. Moreover, since contingency finance instruments do not transfer the risk, the onus of L&D remains on affected countries and therefore these mechanisms can be used just for natural hazards with high/medium frequency but low/medium severity in order not to become too costly and unaffordable, especially for heavily indebted countries. There is always also a risk that the costs for disaster emergency response and recovery exceed contingency funds. In this case, a government may be forced to raise additional funds through new loans, thus adding to the country's fiscal burden.

Financing instruments for risk transfer such as catastrophe risk insurance and risk pools are mechanisms that allow to transfer risk from the initial risk holder to the insurer, in exchange for a premium. Catastrophe bonds also belong to this category. There is evidence that insurance mechanisms can be effective in reducing the economic L&D costs due to climate change. A study by Cambridge Centre for Risk Studies and AXA XL (2020) shows that countries with higher insurance penetration recover on average within 12 months, while countries with lower penetration face average recovery periods of four years. A similar positive result is found by OECD (2018) with respect to the use of international property catastrophe reinsurance.

So far insurance mechanisms have played a limited role in addressing L&D costs and while their use is rather widespread in developed countries, it is still very scarce in developing economies. OECD (2021) reports that over the period 2000-19, only 40% of all reported climate-induced economic losses were insured (Figure 13). Moreover, high-income countries insured more than 50% of the reported economic losses, while developing countries less than 10%. For some vulnerable countries the percentage of insured reported economic losses can be as low as 1-3% (Sheehan, 2021; Hoeppe, 2016). The main reason for such a limited use of insurance instruments in developing countries is governments' lack of knowledge and understanding of insurance products.

While risk transfer mechanisms can provide rapid payouts after disasters, they have several important drawbacks ranging from being unaffordable due to high premiums or high interest rates to causing moral hazard effects by reducing incentives for risk reduction. Insurance instruments and catastrophe bonds are difficult to use to cover L&D costs from high-frequency or low-frequency and high impact events such as slow onset disasters since the high frequency or high severity of the events force insurance companies and investors to increase respectively their premiums and interest rates thus making insurance products unaffordable, especially for developing countries and poor households. Moreover, insurance mechanisms may cause a moral hazard effect since being covered, the insured party has less incentives to take preventive actions to reduce risks (Hudson et al., 2014). This sheds light on the importance for risk reduction investments in adaptation to maintain the insurability of climate-related risks by decreasing exposures and vulnerabilities.

Figure 13. Insured and uninsured share of climate-related extreme event losses by income group (2000-2019)



Source: OECD (2021).

Next to the above traditional financing mechanisms, a number of innovative finance tools have been proposed over the last decade to address L&D costs[16] (Table 6). These include:

- **International Financial Transaction Taxes (FTT)**: this levies on specific types of financial transactions have the advantage of being able to raise predictable and substantial funds to address the funding needs of L&D in case of climate change-related events. For example, AGF (2010) reports that the UN High-Level Advisory Group on Climate Change Financing expects that an FTT could raise about US$ 2–27 billion in revenue globally. If the levies are applied in developed countries that contribute the most to climate change, FTT can be an **equitable** financial solution to address L&D costs and more **politically acceptable** since conceptually they are not linked to L&D. However, they can be **difficult to apply** if some countries are unwilling to impose it or are not logistically prepared to administer the tax.

- **Air travel levies (International Airline Passenger Levy, Solidarity Levy)**: these international and domestic levies paid while purchasing airline tickets are feasible financing mechanisms to address L&D costs and have the advantage of having a **clear link to L&D**. Nevertheless, they have a number of drawbacks. First, they can be **difficult to implement** if some countries are unwilling to introduce them. Second, they bring the **risk of reducing a country's competitiveness**. Third, such modest levies (in some cases even voluntary like the solidarity levy) can **lead to insufficient funds** to finance L&D response efforts.

- **Taxes on airplane and ship fuels (Bunker Fuels Levy)**: these fuel taxes have a **clear link with L&D** since international aviation and maritime transport are responsible of a big share of emissions causing climate change. Moreover, they are considered potentially **promising for**

[16] For a detailed description of innovative financing mechanisms, we refer the reader to Durand et al. (2016).

raising substantial amounts for addressing L&D costs (Farid et al., 2016). However, fuel taxes can be **difficult to apply due to political resistance** and can become **ineffective if they lead firms to attempt to purchase fuels in places without taxation**. They can also increase the costs of exports of a country and threaten the tourism sector, which in SIDS is a crucial source of income for disaster risk reduction.

- **Carbon taxes (Fossil Fuel Majors Carbon Levy, Global Carbon Tax, Carbon Pricing Schemes)**: these financing instruments target large oil, coal, and gas producers as well as industries consuming carbon. Therefore, they direct to the most responsible of gas emissions and hence of climate change and L&D costs. In this way, they have the advantage of being **in line with the principle of compensatory justice**. Carbon taxes can also be a **significant source of funding**. According to Richards and Boom (2014), a fossil fuel majors levy of US$ 2 per ton of CO_2 could yield US$ 50 billion per year. The main drawback of these mechanisms is that **many countries may resist to their introduction.** Although these mechanisms are in line with the principle of climate justice, it would be important to reach an agreement and a compromise among countries on the start date from which GHG emissions should start to be accounted. Carbon pricing instruments have also the disadvantage that they are based on current emissions rather than historical responsibility, and therefore they can be highly controversial among developing countries. The recent IMF's proposal of carbon price floors differentiated by level of development allows to improve the fairness of burden sharing across countries (Parry et al. 2021; Chateau et al., 2022).

- **Debt for loss and damage swaps**: these instruments can support countries experiencing climate-induced L&D costs by **providing debt relief** following disasters. However, debt for loss and damage swaps can create **disincentives to reduce** risks and **cannot provide additional resources to respond to immediate needs** stemming from the impacts of natural hazards (Massa et al., 2022). Debt-for-climate swaps have already been used in the context of adaptation. For instance, Belize negotiated a US$8.5 million debt forgiveness swap for a climate adaptation program related to the conservation and expansion of protected areas in the rainforest (Akiwumi, 2022).

- **Issuance of additional Special Drawing Rights (SDRs)**: there are proposals of reallocating the estimated US$ 500 - US$ 650 billion as SDRs available from the IMF from developed to developing countries more vulnerable to climate-induced events. Persaud (2021) suggests that the world's strongest economies lend the new SDR allocation to an IMF-administered global disaster mechanism, which in turn will provide immediate, unconditional liquidity to countries suffering loss and damage greater than 5% of GDP on the independent declaration that a climate or natural disaster event has occurred.

Table 6. Innovative financing instruments for addressing L&D: advantages and disadvantages

	Pros	Cons
International Financial Transaction Taxes	Equitable Politically acceptable since conceptually not linked to L&D	Difficult to apply if countries are unwilling to impose it
Air travel levies	Have a clear link to L&D	Difficult to apply if countries are unwilling to impose it Can bring the risk of reducing a country's competitiveness Can lead to insufficient funds to finance L&D
Taxes on airplane and ship fuels	Have a clear link to L&D Can raise substantial amounts for addressing L&D costs	Difficult to apply due to political resistance Can become ineffective if they lead firms to attempt to purchase fuels in places without taxation Can threaten the tourism sector and increase the costs of exports
Carbon taxes	In line with the principle of compensatory justice Can raise significant funds	Difficult to apply in case of countries' resistance
Debt for loss and damage swaps	Can provide debt relief in the wake of disasters	Can create disincentives to reduce risks Cannot provide additional resources to respond to immediate needs in the wake of disasters
Issuance of additional Special Drawing Rights (SDRs)	Can provide to affected countries significant funds for addressing L&D costs	

Source: Authors' elaboration on several sources.

Moving to the financing sources that could provide the necessary funds to set up and implement financing mechanisms to address L&D costs, very few multilateral sources can currently be identified within the UNFCCC. Indeed, within the UNFCCC, the only current multilateral source is the Green Climate Fund since the Santiago Network on Loss and Damage provides only technical assistance for L&D. However, only less than 25% of all approved GCF projects refer to L&D (Bhandari et al., 2022).

At COP26, G77 and China asked to establish, within the UNFCCC, the Glasgow Loss and Damage Finance Facility (LDFF), a new source of financing focusing exclusively on economic and non-economic L&D suffered by developing countries and affected communities and people. According to proposals, the LDFF should have two funding windows: one for responding to L&D from rapid-onset events in the aftermath of climate disasters, and one for addressing the impacts of slow-onset events. It should also be designed in line with a climate justice-oriented approach and mobilize L&D finance according to six key principles: 1. International cooperation and solidarity, historical responsibility and the polluter pays principle; 2. New and additional; 3. Needs-based, adequate, predictable and precautionary; 4. Locally driven with subsidiarity – enveloping gender responsiveness and equitable representation; 5. Public and grant-based; 6. Balanced and comprehensive (Sharma-Khushal et al., 2022).

Outside the UNFCCC, there are instead several different multilateral sources, including the Global Facility for Disaster Reduction and Recovery (GFDRR), the Global Risk Financing Facility (GRiF), and multilateral development banks. The Climate Vulnerable Forum (CVF) and the Vulnerable Twenty Group (V20) – of which a third of the members are SIDS – have also set up the CVF-V20 Multi-donor Trust Fund, which is the first funding window to work explicitly and exclusively on climate-related L&D and could be used as a prototype for the Glasgow Loss and Damage Facility. More recently, the G7 in partnership with the V20 agree to launch at COP27 the Global Shield against Climate Risks, which aims at providing and facilitating more and better pre-arranged finance, insurance, and social protection mechanisms to address climate-related L&D (V20 and G7, 2022). Official Development Assistance (ODA) could also be an important source of financing for L&D costs, although currently disaster risk reduction still makes up a small fraction of overall investments in development aid (11% in the period 2010-19) (UNDRR, 2021).

Other important financing sources are national funds, the private sector, philanthropies, and country governments. At COP26, five philanthropies pledged US$3 million to address loss and damage (CIFF, 2021). The governments of Scotland and of the Belgian region of Wallonia committed approximately US$ 2.5 million and US$ 1 million, respectively (The Brussels Time, 2021). More recently, the government of Denmark pledged US$ 13 million funds to developing countries specifically for loss and damage (Osborne, 2022).

V. Ways forward for a new conceptual and methodological framework

The coming assembly of COP27 in November 2022 is expected to be a turning point in L&D and climate justice negotiations. The world needs a consensus on what L&D are and on how financing them. Large-scale international funding for L&D is critical for the survival of many populations and communities, especially in vulnerable countries such as SIDS which risk to disappear under water if no resources are allocated to support adaptation programs and cover the remaining L&D costs. The urgent need to unlock access to funding for L&D is not new for vulnerable countries, but today the consequences of climate change are not anymore a potential risk in the future neither for developed economies, which are also beginning to suffer directly from the negative impacts of climate change. While this might contribute to raise consciousness within the international community on the fact that more support and finance for climate-related L&D (and climate adaptation) is urgently needed, this might as well progressively close the window of opportunity to reach an agreement on L&D. Since in times of crisis higher-income countries tend to prioritize their own economies (e.g. COVID-19 vaccines hoarding, see UN (2021b) and McAdams et al. (2020)), the increase of climate change impacts on their territories might further disincentivize them to commit to any L&D facility.

L&D are not only a matter of disaster-response, but rather the direct consequence of our incapacity to fully mitigate and adapt to climate change, and the failure of polluting countries to compensate for the costs they inflict on others. Together with adaptation, L&D represents the burden of climate change that polluting countries have been imposing on vulnerable countries, including SIDS. The question of how to finance L&D is therefore directly linked with the willingness of countries to cooperate and fight against the current and long-term consequences of climate change that materializes through global warming, sea level rise, dysregulation in regional precipitations, or more frequent and intense extreme weather events. To finance adaptation and L&D, we need to adopt a harmonized methodology to first quantify adaptation and L&D costs (including non-economic aspects), and then to fairly split the burden of the costs among countries. This costs-sharing approach should be, for the most important part, based on countries' historical responsibility in climate change (e.g. assessing countries' individual contributions to GHG emissions, relative to their size).

This section presents a preliminary integrated framework that could be applied by researchers and international organizations to assess issues around L&D financing in SIDS and other vulnerable countries. Partly building on OECD (2021), the preliminary framework for the assessment of adaptation and L&D, as well as specific countries' contributions to climate change should address five main issues (summarized by Figure 14):

1) **Assess total adaptation and L&D costs (from both slow-onset processes and extreme weather events).**
    a. How? By using adaptation measurement studies and national budgets (for adaptation) and by making use of L&D quantification models (for L&D), such as DaLA or PDNA, that can estimate total L&D from both slow-onset processes and extreme weather events.
    b. Possible data sources? For adaptation costs, the COFOG IMF database may be used. For L&D costs, some initiatives such as the UNDP-Bangkok Regional Hub effort to develop a taxonomy on disaster L&D in 19 countries in the Asia Pacific Region, 9 countries in Africa, 3 in Arab States and 4 in Europe and CIS could lead to the creation of important data sources on L&D. Digital technology could also be exploited more to gather data on L&D.
    c. Current limitations for SIDS? The main obstacles for such investigation are the lack of robust data on both current and historic climatic variables, as well as the imperfect collection of data for economic impacts, and the lack of measurements of non-economic impacts. Weak data governance and underdeveloped digital technology are also key obstacles for data gathering and sharing at the national, regional, and global level.

2) **Estimate to which extent climate change (slow-onset process or extreme event) was intensified by anthropogenic activities.**
    a. How? By using the methodologies of attribution studies that usually use a combination of climate models to compare observed trends in specific climate variables (e.g. temperatures) with simulated trends of the same variables in alternative scenarios where anthropogenic drivers (e.g. GHG or aerosol emissions) are excluded.
    b. Possible data sources? Database reporting data on CO_2 (e.g. Global Carbon Project (2020)), methane and nitrous oxide releases and changing land use patterns.
    c. Current limitations for SIDS? The main obstacles for such investigation are the lack of robust data on both current and historic climatic variables, and the lack of technical knowledge of climate models.

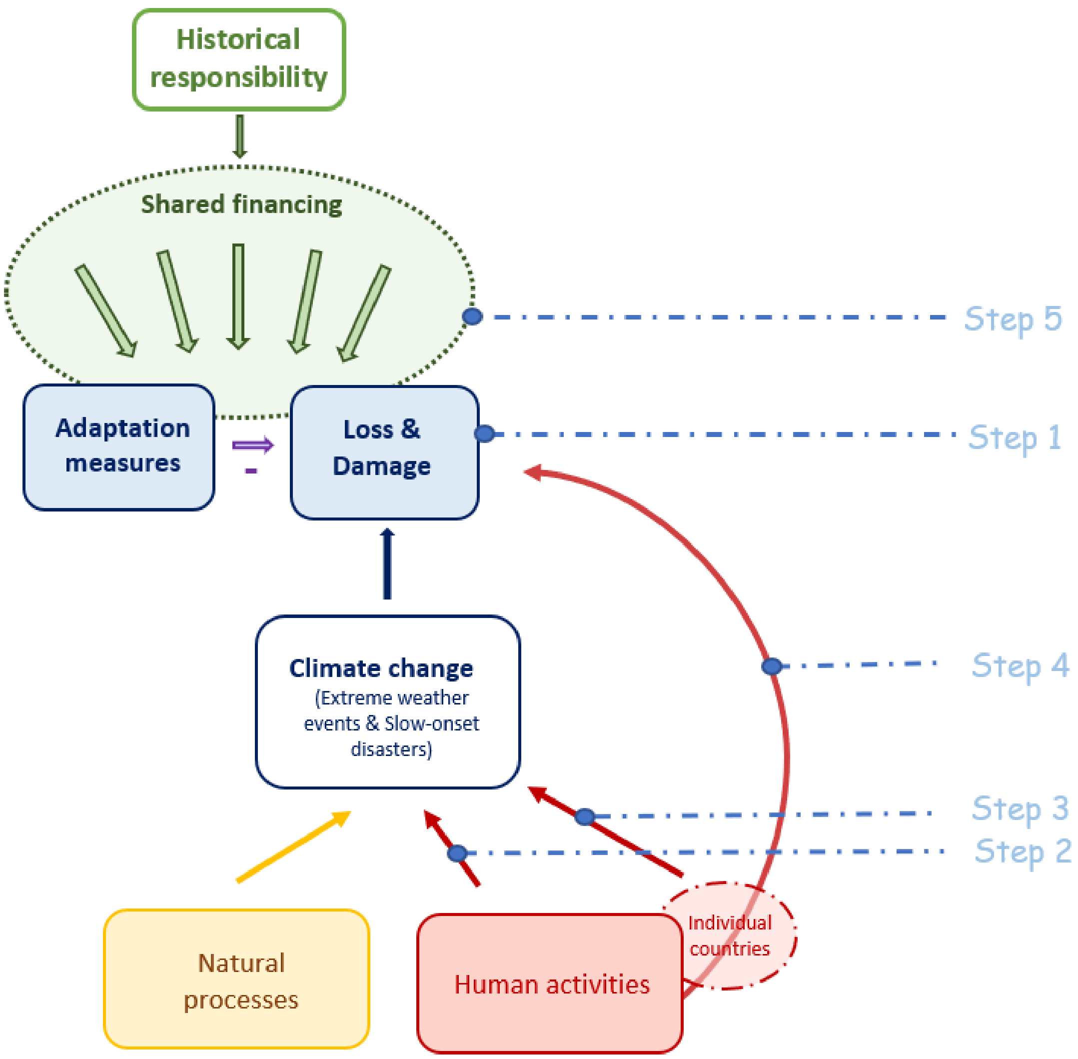
3) **Measure third countries' individual contributions to climate events suffered by a given country.**
    a. How? By using the results of Step 2 and methodologies of the contribution studies that rely on simple climate models and statistical methods to quantify the share of specific countries in GHG and aerosols emissions time trends, and estimate their respective consequences on climate variables (e.g. temperature, probability of event).
    b. Possible data sources? Global Carbon Project (2020) database on historical CO_2 emissions, by country and year.

c. Current limitations for SIDS? The main obstacles for such investigation are the lack of robust data on both current and historic climatic variables.

4) **Identify the proportion of adaptation and L&D costs that was caused by anthropogenic climate change and specific countries.**
   a. How? By combining the results of Step 1 to the results of Step 3 and predicting the share of each country in total L&D, based on their contributions to climate change.
   b. Possible data sources? Same as Step 1 and Step 3.
   c. Current limitations for SIDS? The main obstacles for such investigation are the lack of robust data on both current and historic climatic variables, and the fact that there is no background methodology for this step of the framework.

5) **Propose a financing mechanism for adaptation and L&D costs, based on the results of Step 4**. The framework is the starting point to design a new dedicated Global Climate Impact Fund to share on the global scale the financing of adaptation and L&D costs generated by human-induced climate change (see Box 1).

Figure 14. Preliminary integrated framework to assess third countries' contribution to L&D in vulnerable economies, including SIDS



Source: Authors' elaboration.

Box 1. Details on the proposed GCIF to finance incremental adaptation and L&D caused by human-induced climate change

Which costs should be under shared financing?

To align with the concept of reparative justice, the GCIF should cover both adaptation and L&D costs that are caused by human-induced climate change. Should be considered costs that emerge after sudden extreme weather events but also during the process of slow-onset disasters. While total climate-related costs linked to anthropogenic activities should be shared among polluting countries only (proportionally to their contribution to GHG emissions and the consequent change in climate), the remaining costs caused by natural variability and inadequate adaptation could be shared among all countries, including those non responsible of, but affected by, climate change. This could provide the right incentive to affected countries to continue investing in their efforts to adapt to climate change. More precisely, the GCIF could cover:

- A share of adaptation costs. Human-induced climate change raises the level of optimum adaptation outlays in affected countries. The global share of adaptation costs that should be financed through the fund therefore depends on this *increment* of optimum adaptation spending caused by human-induced climate change. Adaptation expenditure necessary to cover for climate change caused by natural variability should not be covered by the GCIF.

- And a share of L&D costs. The global fund should not finance L&D that are caused by natural variability in climate and inadequate adaptation measures in affected countries. The costs that should be financed are the total L&D to which we deduct the share caused by nature and the share due to inadequate adaptation.

How to calculate the total outlays needed by the GCIF?

Since the GCIF should fund a share of adaptation and L&D costs that are caused by human-induced climate change as describe above, the total outlays needed by the GCIF could be calculated as below:

$$total\ GCCF\ outlays = \sum_{country=1}^{N} (incremental\ adaptation\ + L\&D\ from\ human\ activities)$$

Where $L\&D\ from\ human\ activities$
$$= (Total\ L\&D\ costs - L\&D\ caused\ by\ inadequate\ adaptation) * share\ due\ to\ human\ activity$$

The GCIF would gather funds to cover the costs of incremental adaptation and L&D generated by human-induced climate change, that are inflicted to all countries by all types of disasters (i.e. both extreme events and slow-onset processes).

What should be the sharing rule to assign countries' financing contributions to the GCIF?

Contributions to the fund should be based on the principle of historical responsibility in climate change and cover all types of climate-related costs that countries are responsible to create. Half of the amount covered by polluting countries should be based on their current GHG emissions and the other half based on their cumulative historical GHG emissions. A price could be assigned to each ton of CO_2 emitted based on total outlays needed and the volume of emissions emitted.

What would be the institutional arrangements and functioning of the GCIF?

Rather than being a post-disaster recovery scheme based on a disaster-by-disaster compensation approach that would leave aside most L&D costs inflicted by slow-onset processes (to which SIDS are disproportionately vulnerable), the GCIF should be a **global insurance mechanism**, where the premia would be paid according to polluting countries' historical and current responsibilities in CO_2 emissions. In order to reduce the moral hazard issue typically associated with insurance schemes, the GCIF should ensure that beneficiary countries do take adaptation and prevention measures, for example by including a precondition to enter the insurance scheme based on countries' efforts to prevent damages (e.g. to prohibit new constructions in floodplains). The fact that the share of L&D caused by natural processes is planned to be shared among all countries (not only polluting countries) is an additional guarantee to reduce the moral hazard issue.

The GCIF could channel funds to the major multilateral development banks (MDBs) (e.g. the World Bank, the IMF, or regional MDBs) that would, on their side, be in charge to manage the disbursements to affected countries. The MDBs would also oversee the spending of the funds and make sure beneficiary countries comply with the requirements on adaptation spending to avoid moral hazard of the insurance payments.

The GCIF would be a dedicated instrument to finance incremental adaptation and L&D caused by human-induced climate change and would prevent countries to be obliged to contract new loans (e.g. with the IMF) that increase their burden of debt and jeopardize their capacity to recover and build resilience to climate change (Walsh and Ormond-Skeaping, 2022).

Annexes

Annex 1. Cumulative CO_2 emissions in SIDS

CO_2 emissions data are available for all 38 SIDS UN members (Table 7). For SIDS non-UN members, only 8 out of 20 have available data.

Table 7. Cumulative CO2 emissions from fossil fuels in SIDS (thousand tons of CO2)

iso3	Country	2019	2020
ATG	Antigua and Barbuda	21096	21527
ABW	Aruba	75168	75921
BHS	Bahamas	167181	169519
BHR	Bahrain	891343	926303
BRB	Barbados	53788	54875
BLZ	Belize	18480	19063
BMU	Bermuda	28581	29205
CPV	Cape Verde	12737	13287
COM	Comoros	5043	5302
CUB	Cuba	1594097	1614249
DMA	Dominica	4668	4807
DOM	Dominican Republic	719948	747717
FJI	Fiji	48035	49429
PYF	French Polynesia	27955	28784
GRD	Grenada	7968	8263
GLP	Guadeloupe	81256	83818
GNB	Guinea-Bissau	9807	10094
GUY	Guyana	98378	100590
HTI	Haiti	73296	76215
JAM	Jamaica	445426	452856
KIR	Kiribati	2017	2085
MDV	Maldives	23115	24911
MHL	Marshall Islands	3265	3417
MTQ	Martinique	85925	88274
MUS	Mauritius	111777	115757
FSM	Micronesia (country)	3566	3713
NRU	Nauru	4802	4858
NCL	New Caledonia	148315	157007
PLW	Palau	10343	10562
PNG	Papua New Guinea	162847	169499
PRI	Puerto Rico	209	209
KNA	Saint Kitts and Nevis	6128	6340
LCA	Saint Lucia	13926	14366
VCT	Saint Vincent and the Grenadines	6758	6967
WSM	Samoa	6537	6782
STP	Sao Tome and Principe	3248	3361
SYC	Seychelles	12888	13380
SGP	Singapore	2111524	2157028
SLB	Solomon Islands	10136	10435
SUR	Suriname	112979	115203
TLS	Timor	6017	6543
TON	Tonga	4240	4384
TTO	Trinidad and Tobago	1534052	1569561
TUV	Tuvalu	271	279
VUT	Vanuatu	4571	4752

Sources: Global Carbon Project (2020) and Our World in Data (2021).

References

ADB (2022), "MDBs' Climate Finance in Low and Middle-Income Countries Reaches $51 Billion in 2021", Asian Development Bank News Release, October 14th 2022, available at: https://www.adb.org/news/mdbs-climate-finance-low-and-middle-income-countries-reaches-51-billion-2021.

AGF (United Nations High-Level Advisory Group on Climate Change Financing) (2010), Report of the Secretary-General's High-level Advisory Group on climate change financing. New York: United Nations. Retrieved from http://www.un.org/wcm/webdav/site/climatechange/shared/Documents/AGF_reports/AGF_Final_Report.pdf

Andrijevic, M. and Ware, J. (2021), "Lost & Damaged: A study of the economic impact of climate change on vulnerable countries", Christian Aid publication, available at: https://mediacentre.christianaid.org.uk/climate-change-could-cause-64-gdp-hit-to-worlds-vulnerable-countries/.

Akiwumi, P. (2022), "Climate finance for SIDS is shockingly low: Why this needs to change", UNCTAD News, May 24th 2022, available at: https://unctad.org/news/climate-finance-sids-shockingly-low-why-needs-change.

AOSIS (2008), Alliance of Small Island States (AOSIS) – Proposal to the AWG-LCA. Multi-Window Mechanism to Address Loss and Damage from Climate Change Impacts. AOSIS: Alliance of Small Island States. Available at: http://unfccc.int/files/kyoto_protocol/application/pdf/aosisinsurance061208.pdf

Auffhammer, M. (2018), « Quantifying Economic Damages from Climate Change", *Journal of Economic Perspectives*, Vol. 32, n°4, p. 33-52, available at: DOI: 10.1257/jep.32.4.33.

Baarsch, F., de Bruin, K., Granadillos, J., Hare, B., Lissner, T., Perrette, M., Schaeffer, M., and C.-F., Schleussner (2015), Impacts of low aggregate INDCs ambition: research commissioned by Oxfam. http://policy-practice.oxfam.org.uk/publications/impacts-of-low-aggregate-indcs-ambition-research-commissioned-by-oxfam-582427

Bento, A., Miller, N., Mookerjee, M., Severnini, E. (2021), "A unifying approach to measuring climate change impacts and adaptation", *NBER Working Paper Series*, n°27247, NBER Cambridge, http://www.nber.org/papers/w27247.

Bhandari, P., Warszawski, N., and C., Thangata (2022), The Current State of Play on Financing Loss and Damage. Available at: https://www.wri.org/insights/current-state-play-financing-loss-and-damage

Bindoff, N.L., et al. (2013), "Detection and Attribution of Climate Change: from Global to Regional", In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Brainard, R., et al. (2018), Ecological impacts of the 2015/16 El Niño in the central equatorial Pacific", In: Explaining Extreme Events of 2016 from a Climate Perspective, *Bull. Amer. Meteor. Soc*., Vol. 99, Issue 1, S21–S26, available at: doi:10.1175/10.1175/BAMS-D-17-0128.1.

Buchner, B., Naran, B., Fernandes, P., Padmanabhi, R., Rosane, P., Solomon, M., Stout, S., Strinati, C., Tolentino, R., Wakaba, G., Zhu, Y., Meattle, C., and S., Guzmán (2021), Global Landscape of Climate Finance 2021. Available at: https://www.climatepolicyinitiative.org/wp-content/uploads/2021/10/Full-report-Global-Landscape-of-Climate-Finance-2021.pdf

Burke, M. and Emerick, K. (2016), “"Adaptation to Climate Change: Evidence from US Agriculture." *American Economic Journal: Economic Policy*, Vol. 8, Issue 3, p. 106-140, available at: DOI: 10.1257/pol.20130025.

Callahan, C.W. and Mankin, J.S. (2022), “Globally unequal effect of extreme heat on economic growth”, *Science Advances*, Vol. 8, Issue 43, available at: DOI: 10.1126/sciadv.add3726.

Calliari, E., Serdeczny, O. and Vanhala, L. (2020), “Making sense of the politics in the climate change loss & damage debate”, *Global Environmental Change*, Vol. 64, available at: https://doi.org/10.1016/j.gloenvcha.2020.102133.

Cambridge Centre for Risk Studies and AXA XL (2020), Optimising Disaster Recovery: The Role of Insurance Capital in Improving Economic Resilience, Cambridge Centre for Risk Studies at the University of Cambridge Judge Business School, https://axaxl.com/-/media/axaxl/files/optimizing-disaster-recovery.pdf

Carrington, D. (2021), What is ‘loss and damage’ and why is it critical for success at Cop26?, The Guardian, 13 November 2021.

Chateau, J., Jaumotte, F. and G., Schwerhoff (2022), Economic and Environmental Benefits from International Cooperation on Climate Policies, Departmental Paper DP/2022/007, International Monetary Fund, Washington, DC. Available at: https://www.imf.org/en/Publications/Departmental-Papers-Policy-Papers/Issues/2022/03/16/Economic-and-Environmental-Benefits-from-International-Cooperation-on-Climate-Policies-511562.

CIFF (2021), Philanthropies offer kick-start funds for prospective Glasgow Loss & Damage Facility to support vulnerable countries suffering from climate change. CIFF: The Children’s Investment Fund Foundation. Available at: https://ciff.org/news/philanthropies-offer-kick-start-funds-for-prospective-glasgow-loss-damage-facility-to-support-vulnerable-countries-suffering-from-climate-change/

Craeynest, L. (2010), “Loss and damage from climate change: the cost for poor people in developing countries”, Action Aid Discussion Paper, The Hague, Netherlands.

Doktycz C. and Abkowitz M. (2019), “Loss and Damage Estimation for Extreme Weather Events: State of the Practice”, *Sustainability*, Vol. 11, Issue 15, p. 4243, available at: https://doi.org/10.3390/su11154243.

Durand, A., Hoffmeister, V., Weikmans, R., Natson, S., Huq, S., and Timmons Roberts, J. (2016), Financing Options for Loss and Damage: a Review and Roadmap, d.i.e. Discussion Paper 21/2016. Available at:

https://www.researchgate.net/publication/309479325_Financing_options_for_loss_and_damage_a_review_and_roadmap

ECLAC (2014), "Handbook for Disaster Assessment", available at: https://www.cepal.org/en/publications/36823-handbook-disaster-assessment.

ESCAP (2018), "Ocean Accounting for Disaster Resilience in the Pacific SIDS: A brief note for policymakers", From Risks to Resilience Series, available at: https://www.preventionweb.net/files/62203_oceanaccounts30oct2018lowres.pdf.

European Parliament (2022), "Understanding Loss and Damage. Addressing the unavoidable impacts of climate change", European Parliament Briefing - Towards climate neutrality, available at: https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/733598/EPRS_BRI(2022)733598_EN.pdf.

Evans, S. (2021), "Analysis: Which countries are historically responsible for climate change?", Carbon Brief, October 5th 2021, available at: https://www.carbonbrief.org/analysis-which-countries-are-historically-responsible-for-climate-change/.

Farid, M., Keen, M., Papaioannou, M., Parry, I., Pattillo, C., & Ter-Martirosyan, A. (2016), After Paris: Fiscal, macroeconomic, and financial implications of climate change (IMF Staff Discussion Note SDN/16/01). Washington, DC: International Monetary Fund. Retrieved from https://www.imf.org/external/pubs/ft/sdn/2016/sdn1601.pdf

FEMA (2022), "Hazus", available at: https://www.fema.gov/flood-maps/products-tools/hazus.

Fischer, E. and Knutti, R. (2015), "Anthropogenic contribution to global occurrence of heavy-precipitation and high-temperature extremes", *Nature Clim Change*, Vol. 5, p. 560–564, available at: https://doi.org/10.1038/nclimate2617.

Frame, D.F. et al. (2019), "Emissions and emergence: a new index comparing relative contributions to climate change with relative climatic consequences", *Environmental Research Letters*, Vol. 14, n°8, available at: https://iopscience.iop.org/article/10.1088/1748-9326/ab27fc.

Friedlingstein et al. (2022), "Global Carbon Budget 2021", *Earth System Science Data*, Vol. 14, Issue 4, p. 1917-2005, available at: https://doi.org/10.5194/essd-14-1917-2022.

Fuglestvedt, J. et al. (2008), "Climate forcing from the transport sectors", PNAS, Vol. 105, n°2, p. 454-458, available at: https://doi.org/10.1073/pnas.0702958104.

Gall, M., Borden, K.A. and Cuttter, S.L. (2009), "When do Losses Count? Six Fallacies of Natural Hazards Loss Data", *American Meteorological Society*, available at: DOLIO.I I75/2008BAMS272I.I.

Global Carbon Project (2020), "Supplemental data of Global Carbon Budget 2020 (Version 1.0) [Data set]", Global Carbon Project, available at: https://doi.org/10.18160/gcp-2020.

GFDRR (2008), "Post-Disaster Needs Assessments Guidelines Volume A (2013)", available at: https://www.gfdrr.org/en/publication/post-disaster-needs-assessments-guidelines-volume-2013.

Heede, R. (2014), "Tracing anthropogenic carbon dioxide and methane emissions to fossil fuel and cement producers, 1854–2010", *Climatic Change*, Vol. 122, p. 229–241, available at: https://doi.org/10.1007/s10584-013-0986-y.

Herring et al. (2018), "Explaining Extreme Events of 2016 from a Climate Perspective", *Bulletin of the American Meteorological Society*, Vol. 99, Issue 1, S1–S157, available at: https://doi.org/10.1175/BAMS-ExplainingExtremeEvents2016.1.

Hirsch, T. (2022), "Outside the Box: Rethinking the Climate and Disaster Finance Agenda", MCII Discussion Paper Series June 2022, available at: https://climate-insurance.org/wp-content/uploads/2022/06/Climate_Disaster_Finance_Agenda_MCII_June2022_final.pdf#page=17.

Hoegh-Guldberg, O., Hegerl, G., Root, T. et al. (2011), "Difficult but not impossible", *Nature Climate Change*, Vol. 1, Issue 72, available at: https://doi.org/10.1038/nclimate1107.

Hoeppe, P. (2016), Climate risk insurance for the poor and vulnerable. Presentation, MCII Side Event: Insurance and Comprehensive Climate Risk Management. Bonn, Germany.

Hope, C., Anderson, J. and Wenman, P. (1993), "Policy analysis of the greenhouse effect: An application of the PAGE model", *Energy Policy*, Vol. 21, Issue 3, March, p. 327-338, available at: https://doi.org/10.1016/0301-4215(93)90253-C.

Hudson, P., Botzen, W. J. W., Czajkowski, J., & Kreibich, H. (2014). Risk selection and moral hazard in natural disaster insurance markets: Empirical evidence from Germany and the United States. Philadelphia, PA: Risk Management and Decision Processes Center.

IDMC (2022), "Global Report on Internal Displacements. Children and youth in internal displacement", Internal Displacement Monitoring Centre and Norwegian Refugee Council, available at: https://www.internal-displacement.org/global-report/grid2022/.

INC (1991), Negotiation of a Framework Convention on Climate Change, 17 December 1991. INC: Intergovernmental Negotiating Committee for a Framework Convention on Climate Change.

IPCC (2022), "Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change" [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844, available at: https://report.ipcc.ch/ar6/wg2/IPCC_AR6_WGII_FullReport.pdf

IPCC (2001), Climate change 2001: Synthesis Report. Cambridge University Press. Cambridge, UK. Available at: https://www.ipcc.ch/report/ar3/syr/

James, R.A. et al. (2019), "Chapter 5. Attribution : How is It Relevant for Loss and Damage Policy and Practice?", in Mechler, R. et al. (eds.), Loss and Damage from Climate Change, Climate Risk Management, Policy and Governance, https://doi.org/10.1007/978-3-319-72026-5_5.

Künzel, V. and Schäfer, L. (2021), National Financial Instruments and Mechanisms to Manage Climate Risks and Impacts. Germanwatch. Available at: https://germanwatch.org/en/20399

La Rovere et al., (2002), "The Brazilian Proposal on Relative Responsibility for Global Warming", In: Baumert et al. (eds). Building on the Kyoto Protocol: Options for Protecting the Climate, available at: https://www.researchgate.net/publication/245589583_Building_on_the_Kyoto_Protocol_Options_for_Protecting_the_Climate.

Leiter, T. and Pringle, P. (2018), "Pitfalls and potential of measuring climate change adaptation through adaptation metrics", In: *Adaptation metrics: Perspectives on measuring, aggregating and comparing adaptation results*, UNEP Partnership, available at: https://tech-action.unepccc.org/wp-content/uploads/2018/03/udp-perspectives-adaptation-metrics-web-1.pdf#page=31.

Mace, M. and Verheyen, R. (2016), "Loss, Damage and Responsibility after COP21: All Options Open for the Paris Agreement", *Review of European, Comparative & International Environmental Law*, Vol. 25, p. 197-214, available at: DOI:10.1111/reel.12172.

Markandya, A. & González-Eguino, M. 2018: Integrated Assessment for Identifying Climate Finance Needs for Loss and Damage: A Critical Review. In: Mechler R. et. al. (eds.): Loss and damage from climate change. Concepts, methods and policy options. Springer, 343-362.

Massa, I., Lafortune, G. and Marinescu, S. (2022), "Who's willing to pay for sustainability in the Pacific?", 360info, July 11th 2022, available at: https://360info.org/whos-willing-to-pay-for-sustainability-in-the-pacific/.

Massetti, E. and Mendelsohn, R. (2018), "Measuring Climate Adaptation: Methods and Evidence", *Review of Environmental Economics and Policy*, Vol. 12, Issue 2, Summer 2018, p. 324-341, available at: doi: 10.1093/reep/rey007.

Massey et al., (2014), "weather@home – development and validation of a very large ensemble modelling system for probabilistic event attribution", Quarterly Journal of the Royal Meteorological Society, Vol. 141, p. 1528-1545, July, available at: https://doi.org/10.1002/qj.2455.

McAdams D., McDade K.K., Ogbuoji O., et al. (2020), "Incentivising wealthy nations to participate in the COVID-19 Vaccine Global Access Facility (COVAX): a game theory perspective", *BMJ Global Health*, available at: https://gh.bmj.com/content/5/11/e003627.

Mitchell D., Heaviside C., Vardoulakis S. et al. (2016), "Attributing human mortality during extreme heat waves to anthropogenic climate change", *Environmental Research Letters*, 11:74006, available at: https://doi.org/10.1088/1748-9326/11/7/074006.

Nordhaus, W. D., (1992), "The 'Dice' Model: Background and Structure of a Dynamic Integrated Climate-Economy Model of the Economics of Global Warming", Cowles Foundation Discussion Papers. 1252; available at: https://elischolar.library.yale.edu/cowles-discussion-paper-series/1252/.

OECD (2018), The Contribution of Reinsurance Markets to Managing Catastrophe Risk, http://www.oecd.org/finance/the-contribution-of-reinsurance-markets-to-managingcatastrophe-risk.pdf

OECD (2021), "Managing Climate Risks, Facing up to Losses and Damages", *OECD Publishing*, Paris, https://doi.org/10.1787/55ea1cc9-en.

van Oldenborgh, G. J (2007), "How unusual was autumn 2006 in Europe?", *Clim Past*, Vol. 3, p.659–668, available at: https://doi.org/10.5194/cp-3-659-2007.

Osborne, M. (2022), Denmark Will Pay 'Loss and Damage' to Developing Countries for Climate Change Impacts, 21 September 2022. Available at: https://www.smithsonianmag.com/smart-news/denmark-will-pay-loss-and-damage-to-developing-countries-for-climate-change-impacts-180980812/

Otto et al. (2022), "Climate change likely increased extreme monsoon rainfall, flooding highly vulnerable communities in Pakistan", World Weather Attribution, available at: https://www.worldweatherattribution.org/climate-change-likely-increased-extreme-monsoon-rainfall-flooding-highly-vulnerable-communities-in-pakistan/.

Otto et al. (2017), "Assigning historic responsibility for extreme weather events", *Nature Climate Change*, Vol. 7, p. 757-759, November, available at: https://doi.org/10.1038/nclimate3419.

Otto et al. (2012), "Reconciling two approaches to attribution of the 2010 Russian heat wave", *Geophysical Research Letters*, Vol. 39, Issue 4, February, available at: https://doi.org/10.1029/2011GL050422.

Our World in Data (2021), "Cumulative CO_2 emissions by world region" [database]", available at: https://ourworldindata.org/grapher/cumulative-co2-emissions-region?time=1850..latest.

Parry, I., Black, S. and J., Roaf (2021), Proposal for an International Carbon Price Floor among Large Emitters, IMF Staff Climate Note 2021/001, International Monetary Fund, Washington, DC. Available at : https://www.imf.org/en/Publications/staff-climate-notes/Issues/2021/06/15/Proposal-for-an-International-Carbon-Price-Floor-Among-Large-Emitters-460468

Persaud, A. (2021), Debt, natural disasters, and special drawing rights: A modest proposal, 17 March 2021. Available at: https://cepr.org/voxeu/columns/debt-natural-disasters-and-special-drawing-rights-modest-proposal

Pershing, A., Gilford, D.M. and Giguere, J. (2022), "Climate Central Temperature Attribution System Methods", Climate Central, available at: https://assets.ctfassets.net/cxgxgstp8r5d/4PyuClhY6ZT5LEGyfq01rc/9b81e5f911baad59575550e4dd549f57/Climate_Central_Methods_Temperature_Attribution_System_June-2022.pdf.

Peterson et al. (2012), "Explaining Extreme Events of 2011 from a Climate Perspective", *Bulletin of the American Meteorological Society*, July

Pill, M. (2022), "Towards a funding mechanism for loss and damage from climate change impacts", *Climate Risk Management*, Vol. 35, available at: https://doi.org/10.1016/j.crm.2021.100391.

Richards, J.-A., & Boom, K. (2014), Carbon majors funding loss and damage. Berlin: Heinrich Boell Foundation. Retrieved from https://www.boell.de/en/2014/06/05/carbon-majors-funding-loss-anddamage

Rocha, M. et al. (2015) , "Historical Responsibility for Climate Change – from countries emissions to contributions to temperature increase", Climate Analytics and the Potsdam Institute for Climate

Research, available at:
https://climateanalytics.org/media/historical_responsibility_report_nov_2015.pdf.

Sachs (2022), "Pakistan and the Fight for Climate Justice", Project Syndicate, September 13th 2022, available at: https://www.project-syndicate.org/commentary/pakistan-flooding-climate-justice-rich-countries-should-bear-cost-by-jeffrey-d-sachs-2022-09.

Sachs, J. and Massa, I. (2021), "The Rich World's Debt to Island States", Project Syndicate, July 15th 2021, available at: https://www.project-syndicate.org/commentary/climate-threat-to-small-island-developing-states-by-jeffrey-d-sachs-and-isabella-massa-2021-07.

Sachs, J., Lafortune, G., Kroll, C., Fuller, G. and Woelm, F. (2022), "From Crisis to Sustainable Development: the SDGs as Roadmap to 2030 and Beyond. Sustainable Development Report 2022.", Cambridge University Press, available at: https://dashboards.sdgindex.org/.

Sachs, J., Massa, I., Marinescu, S. and Lafortune, G. (2021), "The Decade of Action and Small Island Developing States: Measuring and addressing SIDS' vulnerabilities to accelerate SDG progress", SDSN Working Paper, available at: https://resources.unsdsn.org/the-decade-of-action-and-small-island-developing-states.

Schäfer, L., Jorks, P., Seck, E., Koulibaly, O., and A. Diouf (2021a), National and international approaches to address loss and damage from slow-onset processes – Status quo, challenges and gaps. Available at: https://germanwatch.org/de/20127

Schäfer, L., Jorks, P., and E. Seck (2021b), Financing Instruments and Sources to Address Loss and Damage from Slow-onset Processes, November 2021. Available at:
https://www.germanwatch.org/en/21067

Schaller, N., Kay, A., Lamb, R. et al. (2016), "Human influence on climate in the 2014 southern England winter floods and their impacts", Nature Climate Change, Vol. 6, p.627–634, available at: https://doi.org/10.1038/nclimate2927.

Serdeczny, O., Waters, E. and Chan, S. (2016), "Non-Economic Loss and Damage in the Context of Climate Change. Understanding the Challenges", German Development Institute Discussion Paper 3/2016, available at: https://www.idos-research.de/uploads/media/DP_3.2016.pdf.

Sharma-Khushal, S., Schalatek, L., Singh, H., and H. White (2022), The Loss and Damage Finance Facility Why and How. Available at: https://us.boell.org/en/2022/05/31/loss-and-damage-finance-facility-why-and-how

Shawoo, Z., Maltais, A., Bakhtaoui, I. and Kartha, S. (2021), "Designing a fair and feasible loss and damage finance mechanism", Stockholm Environment Institute Briefing Paper, October 2021, available at: https://cdn.sei.org/wp-content/uploads/2021/10/211025c-davis-shawoo-loss-and-damage-finance-pr-2110l.pdf#page=5.

Sheehan, M. (2021), Weathering climate risk: V20 Group and the IDF call for joint collaboration and international support to strengthen global physical climate risk management capabilities, 20 September, Reinsurance News, https://www.insdevforum.org/weathering-climate-risk-v20-group-and-the-idf-call-for-joint-collaboration-and-international-support-to-strengthen-globalphysical-climate-risk-management-capabilities/

Simon et al. (2018), "Anthropogenic Forcings and Associated Changes in Fire Risk in Western North America and Australia during 2015/16", In: Explaining Extreme Events of 2016 from a Climate Perspective, *Bull. Amer. Meteor. Soc.,* Vol. 99, Issue 1, S21–S26, available at: doi:10.1175/10.1175/BAMS-D-17-0128.1.

Skeie et al. (2017), "Perspective has a strong effect on the calculation of historical contributions to global warming", *Environmental Research Letters*, Vol. 12, n°2, February, available at: https://iopscience.iop.org/article/10.1088/1748-9326/aa5b0a.

Slany, A. (2020), "Multiple disasters and debt sustainability in Small Island Developing States", UNCTAD Research Paper No. 55, available at: https://unctad.org/system/files/official-document/ser-rp-2020d14_en.pdf.

Solazzo, E. et al. (2021), "Uncertainties in the Emissions Database for Global Atmospheric Research (EDGAR) emission inventory of greenhouse gases", *Atmos. Chem. Phys*., Vol. 21, p. 5655–5683, available at: https://doi.org/10.5194/acp-21-5655-2021.

Stone, D., Auffhammer, M., Carey, M. et al. (2013), "The challenge to detect and attribute effects of climate change on human and natural systems", *Climatic Change*, Vol. 121, p. 381–395, available at: https://doi.org/10.1007/s10584-013-0873-6.

Stott, P., Tett, S., Allen, M.R., Mitchell, J.F.B. and Jenkins, G.J. (2000), "External Control of 20th Century Temperature by Natural and Anthropogenic Forcings", *Science*, Vol. 290, Issue 5499, p. 2133-2137, available at: DOI: 10.1126/science.290.5499.2133.

Tett, S., Stott, P., Allen, M. et al. (1999), "Causes of twentieth-century temperature change near the Earth's surface", *Nature*, Vol.399, p.569–572, available at: https://doi.org/10.1038/21164.

Timperley, J. (2021), The broken $100-billion promise of climate finance — and how to fix it, Available at: https://www.nature.com/articles/d41586-021-02846-3#ref-CR6.

The Brussels Time (2021), COP26: Wallonia earmarks one million euros for loss and damages. 14 November 2021. Available at: https://www.brusselstimes.com/193568/cop26-wallonia-earmarks-one-million-euros-for-loss-and-damages

Thomas, A., Menke, I. and O. Serdeczny (2018), Loss and Damage Costing and Financing Mechanisms: Caribbean Outlook. Available at: https://climateanalytics.org/publications/2018/loss-and-damage-costing-and-financing-mechanisms-caribbean-outlook/

Tol, R.S.J. (2005), Adaptation and mitigation: trade-offs in substance and methods. Environmental Science and Policy 8(6): 572-578. Available at: https://www.sciencedirect.com/science/article/abs/pii/S1462901105001061

Tschumi, E. and J. Zscheischler (2019), "Countrywide climate features during recorded climate related disasters", *Climatic Change*, Vol. 158/3-4, pp. 593-609, available at: http://dx.doi.org/10.1007/s10584-019-02556-w.

United Nations (2007): Report of the Conference of the Parties on its thirteenth session, held in Bali from 3 to 15 December 2007. Available at: https://unfccc.int/resource/docs/2007/cop13/eng/06a01.pdf

United Nations (2013): Report of the Conference of the Parties on its nineteenth session, held in Warsaw from 11 to 23 November 2013. Available at: https://unfccc.int/resource/docs/2013/cop19/eng/10a01.pdf#page=6

United Nations (2015): Report of the Conference of the Parties on its twenty-first session, held in Paris from 30 November to 13 December 2015. Available at: https://unfccc.int/resource/docs/2015/cop21/eng/10a01.pdf

UN (2021a), "Resolution 48/13 adopted by the Human Rights Council on 8 October 2021. The right to a clean, healthy and sustainable environment", available at: https://documents-dds-ny.un.org/doc/UNDOC/LTD/G21/268/03/PDF/G2126803.pdf?OpenElement.

UN (2021b), "States must prioritize health and equality over profits and vaccine hoarding, UN experts say", available at: https://www.ohchr.org/en/press-releases/2021/11/states-must-prioritize-health-and-equality-over-profits-and-vaccine-hoarding.

UN (2022), "Tracking SDG7 - The Energy Progress Report", available at: https://trackingsdg7.esmap.org/data/files/download-documents/sdg7-report2022-full_report.pdf.

UNDP (2022), "Blue, greener, better. How Small Island Developing States are leading climate action", available at: https://feature.undp.org/bluer-greener-better/.

UNDRR (2021), International Cooperation in Disaster Risk Reduction. Available at: https://www.preventionweb.net/publication/international-cooperation-disaster-risk-reduction-target-f

UNEP (2022), "Adaptation Gap Report 2022. Too Little, Too Slow – Climate adaptation failure puts world at risk", United Nations Environment Program, 02 November 2022, available at: https://www.unep.org/resources/adaptation-gap-report-2022.

UNEP (2021a), "Adaptation Gap Report 2021", available at: https://www.unep.org/resources/adaptation-gap-report-2021.

UNEP (2021b), "In historic move, UN declares healthy environment a human right", UNEP News, available at: https://www.unep.org/news-and-stories/story/historic-move-un-declares-healthy-environment-human-right.

UNFCCC Secretariat (2014), Report of the executive committee of the Warsaw International Mechanism for Loss and Damage associated with climate change impacts. FCCC/SB/2014/4. Paris.

V20 and G7, A joint G7 and V20 ambition: Working towards a Global Shield against Climate Risks. Available at: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwiax9HA3Oz6AhWSw4UKHSDxDuEQFnoECBwQAQ&url=https%3A%2F%2Fwww.bmz.de%2Fresource%2Fblob%2F122148%2Fdd6e2de2c73cc601344b1461cf62042b%2Fglobal-shield-information-note-v20-g7-data.pdf&usg=AOvVaw35v_4okbGKvoPn2blzij7Z.

Visser, H., Petersen, A.C. and Ligtvoet, W (2014), "On the relation between weather-related disaster impacts, vulnerability and climate change", *Climatic Change*, Vol. 125, p. 461–477, available at: https://doi.org/10.1007/s10584-014-1179-z.

Waldhoff, S., Anthoff, D. Rose, S. and and Tol, R. S. J. (2014), "The Marginal Damage Costs of Different Greenhouse Gases: An Application of FUND", *Economics*, vol. 8, no. 1, 2014, pp. 20140031, available at: https://doi.org/10.5018/economics-ejournal.ja.2014-31.

Walsh, L. and Ormond-Skeaping, T. (2022), "The Cost of Delay. Why finance to address loss and damage must be agreed at COP27", Loss and Damage Collaboration, available at: https://uploads-ssl.webflow.com/605869242b205050a0579e87/6355adbb4f3fdf583b15834b_L%26DC_THE_COST_OF_DELAY_.pdf.

Wehner MF. and Reed KA. (2022), "Operational extreme weather event attribution can quantify climate change loss and damages", *PLOS Climate*, Vol. 1, Issue 2, available at: https://doi.org/10.1371/journal.pclm.0000013.

Zhang, X. et al. (2013), "Attributing intensification of precipitation extremes to human influence", *Geophysical Research Letters*, Vol. 40, Issue 19, p. 5252-5257, available at: https://doi.org/10.1002/grl.51010.