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DATA ARTICLE

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A harmonized country-level dataset to support the global stocktake regarding loss and damage from climate change

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Abstract

Under the Paris Agreement, parties should undertake a global stocktake of progress toward meeting the goals of the agreement and tackling climate change. The first global stocktake will be undertaken in 2023, and an assessment of loss and damage from climate change is an important part of the process. Loss and damage refer to the impacts of climate change felt when mitigation and adaptation efforts are inadequate or absent. Much data, including metrics and indicators relevant for loss and damage, are held in existing global databases, but these are disparate and cannot easily be combined and compared to support the global stocktake. We combine relevant primary data sources to provide a harmonized country-level global dataset containing relevant indicators of recorded losses and damages from climate-related events; exposure to climate-related events; country vulnerability and adaptation readiness; scientific studies of climate change attribution; financial support for climate adaptation; and contextual governance conditions. The indicators are standardized against country population and GDP where relevant. We describe original data sources, processing steps, and an overview of key indicators in the dataset. We also compare the assembled data to existing global risk databases; namely, the INFORM risk index and the World Risk Index. This comparison, provided in the Supporting Information, shows a large amount of redundancy among vulnerability and governance indicators, and we suggest that creators of new databases and risk indices be clear about data limitations and the gaps that specific indices attempt to fill in the global data landscape. We recommend the standard use of ISO codes in future databases of this nature, as well as clear metadata regarding how overseas territories are treated relative to their sovereign state, and information on dissolution and creation of states over time.

KEYWORDS

climate change, global stocktake, human development, loss and damage, natural hazards, paris agreement, risk, vulnerability

1 | INTRODUCTION

"Loss and Damage" (L&D), which deals with the impacts and consequences of climate change, has become known as the "third pillar" of the United Nations Framework Convention on Climate Change (UNFCCC), alongside mitigation and adaptation. L&D is formalized in the Warsaw International Mechanism (2013) and Article 8 of the Paris Agreement (2016), and has been conceptualized as the failure of sustainable development involving not only insufficient mitigation and adaptation but also differential exposures and vulnerabilities of people and places (Boda et al., 2020, 2021). As the third pillar of international climate change policy, L&D is a central part of the 2023 global stocktake to assess progress under the Paris Agreement (Article 14); however, meaningful compilation of data from L&D–related research and action is difficult, and information gaps are large (Thomas et al., 2020). The global stocktake related to L&D will require compilation of empirical evidence from local case studies (Thomas et al., 2020), as well as regional and global datasets and model outputs that are relevant to holistically assessing L&D, understanding its causes and consequences, and identifying data gaps (Harrington & Otto, 2020; Otto et al., 2020).

L&D is more than just the impacts of extreme weather events and slow onset change, so the global stocktake related to L&D should include a holistic assessment of information on all contributing factors. L&D is a function of exposure to hazards that are attributable to anthropogenic climate change (Otto, 2017; Stott et al., 2016); the vulnerability of exposed people or places to sustaining impacts (Cardona et al., 2012); the capacity and support for adaptation and risk management (UNFCCC, 2012); the functioning of governance systems and appropriate climate policies (Khan & Roberts, 2013; Roberts & Pelling, 2018); and the actual economic and non-economic losses and damages that occur (Boda et al., 2021; Tschakert et al., 2019). Much relevant country-level information on these factors of L&D is housed in existing global databases, which are often used in the fields of risk management and disaster risk reduction (e.g., CRED, 2009; Pidcock et al., 2020; UNEP, 2013). Although these data do not provide the nuanced evidence of L&D and subsequent knowledge gained through the rich context of case studies and event-specific measurement, they are, nonetheless, relevant for informing the global stocktake and ongoing UNFCCC debates.

Multiple challenges arise when using existing databases to holistically assess L&D because data are not directly comparable and cannot be simultaneously evaluated among countries. The first problem is that population and monetary data are often given in absolute terms (e.g., the EM-DAT records the number of people affected or total monetary damage sustained). Although this is useful, it also means that countries of different population sizes and GDPs cannot be compared without standardizing against indicators contained in other databases. This raises the second problem—countries do not always easily align across databases because country names differ among databases and ISO country codes are not always used. Third, the inevitable emergence and dissolution of sovereign states over time (e.g., the Soviet Union) creates challenges for global temporal analyses. Thus, a standardized approach to aggregate and disaggregate data for these countries over time is required across different databases. Fourth, overseas and outlying territories of countries may or may not be treated separately from their sovereign states depending upon decisions made by different database curators. Finally, challenges exist in combining statistical data recorded by the country (or other geopolitical unit) with modeled data expressed in grid cells.

Here, we address and resolve some of the challenges faced when leveraging data contained in different databases to inform research and policy on L&D from climate change. Our result is a harmonized global dataset containing the relevant components for exploring and evaluating existing knowledge about L&D, including: recorded losses and damages, hazard exposure, vulnerability, adaptation readiness, event attribution studies, climate adaptation financing, and governance indicators. We use the best data currently available globally, and the data resolution is at the country level, which is relevant for global analyses and UNFCCC discussions (with Member States as the parties), but we acknowledge that within-country variation is also important and not captured in our dataset. Data are standardized relative to country population and GDP and are a snapshot in time—either from a single recent year or averaged over recent decades. The data can inform the Paris Agreement global stocktake, as well as other global initiatives, such as the Sendai Framework for Disaster Risk Reduction (UNISDR, 2015), by highlighting data gaps and needs. Finally, we clearly discuss the caveats in using this dataset, and we give some simple recommendations for the curation of the source databases used that will reduce certain problems in the future.

2 | METHODS

2.1 | Key variables

Loss and damage from climate change is a complex phenomenon with many influencing factors and resultant outcomes. Impacts from climate-related extremes (rapid or slow onset) can be recorded as economic and non-economic losses and damages, but the existence of impacts alone does not necessarily constitute L&D from climate change. Scientific attribution of a particular event to anthropogenic climate change is also required—increasingly in the form of probabilistic extreme event attribution or Fractional Attributable Risk (Hulme, 2014; Otto et al., 2020; Stott et al., 2016)—as is the association of these impacts beyond mitigation of and adaptation to climate change (Boda et al., 2020). A long history of risk science has established important contributing factors for L&D, including exposure of people or capital to hazards, as well as the vulnerability of those people or capital to sustaining impacts (Cardona et al., 2012). Adaptation is an important mechanism to reduce climate risk in exposed and vulnerable systems, so capacity and support (or lack thereof) for adaptation are also important variables when considering L&D (UNFCCC, 2012), as are approaches to climate-smart or climate-ready governance (Boyd & Juhola, 2015). In Table 1, we describe important variables for a stocktake on global L&D and briefly summarize why each is relevant to the issue. For detailed information on the various theories underlying each variable discussed in Table 1, we kindly refer the reader to the literature cited as a starting point.

2.2 | Data sources

We assemble data on key variables relevant for the global stocktake from a wide variety of sources (Table 2), which we describe in this section. Our aim was to harmonize these various data into our country-level dataset; substantial data processing was required to transform the original data from each source. We describe our data processing steps in Section 2.3. Users of our dataset should consult the original databases for specific original metrics. The original databases remain authoritative. Changes and updates to the original databases after the access dates listed in Section 2.3 are not captured in our dataset. While the Inclusive Wealth Index (Table 2) is not explicitly relevant to L&D (Table 1), it is included in our dataset for additional contextual information that users may find relevant.

The most prominent academic database with global coverage of disaster impacts is EM-DAT (CRED, 2009), although more comprehensive databases exist for a reduced set of countries (e.g., DesInventar) and for particular event types (e.g., Dartmouth Flood Observatory). EM-DAT records the reported number of deaths, number of people affected, and estimated monetary damages from natural and technological disasters from 1900 until the present. Disasters included in EM-DAT are those that resulted in 10 or more reported deaths, 100 or more people reportedly affected, or where a state of emergency was declared or international assistance was called for (CRED, 2009). Disaster types particularly relevant for a stocktake of L&D from climate change include droughts, floods, storms, heatwaves, and bushfires. However, factors other than climate change also influence such disasters (e.g., land use change and forest management). Events are grouped by country, year, and disaster type in EM-DAT. We use the data from EM-DAT to calculate a relative estimate of the annual average number of deaths, number of people affected, and monetary damages for each country, standardized by country population and GDP in the year of each event.

Estimated human and economic exposure to natural hazards globally is provided by the United Nations Environment Programme's (UNEP) Global Risk Data Platform (UNEP, 2013). The platform integrates hazard, vulnerability, and risk models from various agencies and institutes, including UNEP, The World Bank, United States Geological Survey, World Meteorological Organization, Oak Ridge National Laboratory, Columbia University, Dartmouth University, and the University of Grenoble. Hazards included in the platform that are particularly relevant for L&D are tropical cyclones, floods, droughts, and bushfires. Exposure data are provided as global grids at the resolution of 0.1 degrees (approximately 11.1 km at the equator). Data are expressed as expected average annual population (number of people) or GDP (USD, year 2000 equivalent) exposed, with 2010 population and GDP as the reference. We use these data to estimate for each country the average annual population and GDP exposed to the relevant hazards. Importantly, heatwaves are not included as hazards in this platform, whereas they are in EM-DAT.

Extreme event attribution science involves estimating the probability that a particular climate-related event was more likely to occur under current atmospheric greenhouse gas concentrations than under hypothetical conditions that exclude all anthropogenic emissions since the beginning of the industrial revolution (Stott et al., 2016). Carbon Brief provides a systematic catalog of 405 attribution studies/events globally (as of 2021/02/25) in their climate attribution map (Pidcock et al., 2020). Their catalogue lists studies by event, geographic location, and study outcome (i.e., whether the event was made "more severe or more likely to occur" due to anthropogenic climate change). The geographic location is sometimes global, but other times regionally or locally specified. For each country, we assemble the total number and number of "more severe or more likely to occur" attribution studies from Carbon Brief's catalog that could be identified for that country or region within which that country lies. Global studies are excluded here because they are not particularly relevant for country-level L&D evaluation.

TABLE 1 Key variables relevant to L&D

Variable	Description	Key references
Losses and damages	Recorded economic and non-economic losses and damages incurred because of a climate-related event. Note that losses and damages (lower case "l" and "d") can be relevant for but are not necessarily L&D, which concerns the impacts of events attributable to anthropogenic climate change. Also note that *recorded* losses and damages do not necessarily capture the *actual* losses and damages that occurred. Losses and damages can also occur from non–climate-related events (e.g., earthquakes), but these are not considered here.	Roberts and Pelling (2018) Tschakert et al. (2019) Boda et al. (2021)
Exposure to climate-related hazards	People, capital, ecosystems, etc. located in places where a climate-related hazard event may occur. If an event (e.g., flood) occurs in an uninhabited floodplain, for example, then there is no exposure to people from that hazard. However, when a flood occurs in a city, people and capital are inevitably exposed to that hazard. Climate change–related events will not occur similarly in all places, and different segments of a community in a place may be differentially exposed to hazards, depending on historical development and land use planning and zoning. Exposure to hazards is distinct from vulnerability in that it does not imply anything about the conditions of the people, capital, and ecosystems exposed.	Cardona et al. (2012) Birkmann and Welle (2015)
Event attribution	Attribution studies linking particular events to anthropogenic climate change. Attribution science determines the probability of a climate-related event (e.g., a tropical cyclone) exceeding a certain intensity and/or frequency under climate model scenarios with pre-industrial levels of greenhouse gases in the atmosphere and scenarios with current anthropogenic greenhouse gas levels. Attribution is necessary to connect losses and damages from a particular event with an assessment of and debate around L&D and potential litigation and compensation.	Stott et al. (2016) Otto (2017) Otto et al. (2018)
Vulnerability	Vulnerability reflects the propensity and susceptibility of people, capital, and ecosystems to suffer impacts when exposed to a hazard event. This is related to any underlying conditions in the exposed elements that may render them more fragile or unable to cope with external stress brought on by an event. Vulnerability is fundamental to L&D because it assesses the susceptibility and coping capacity of people and places exposed to climatic stress. Appropriate strategies to reduce losses and damages must reduce both exposure and vulnerability.	Kelly and Adger (2000) Füssel (2007) Cardona et al. (2012) Birkmann and Welle (2015)
Adaptation readiness and financing	An important factor in assessing the potential for L&D is the availability of global funding mechanisms and support for adaptation planning with a country. Although not always correlated with a country's capacity to adapt, or reduce vulnerability (and thus losses) to climate-related events, financial aid for adaptation planning and climate readiness are measurable at the global scale as part of a suite of potential indicators of a country's adaptive capacity.	Birkmann and Welle (2015) Chen et al. (2015) Hong et al. (2020)
Governance frameworks including explicit climate policies	Governance variables are important as they reflect our actions/attempts to intentionally steer societal processes to achieve common goals, in this case to mitigate and/or adapt to the impacts of climate change. Approaches include myriad arrangements of multi-level actors, institutions, policies, and their interactions, which can produce mitigation support and adaptation strategies and eventually reduce L&D due to climate change impacts. Governance frameworks ideally also incorporate approaches to achieving normative goals, such as legitimacy, justice, participation, accountability, and transparency.	Bisaro and Hinkel (2016) Lesnikowski et al. (2017) Persson (2019)

The Human Development Index (HDI) is a means for tracking and evaluating the level of development within countries beyond economic-based assessments alone (UNDP, n.d.). The HDI is provided by the United Nations Development Programme (UNDP) and comprises four indicators across the three dimensions of life expectancy,

TABLE 2 Data sources and download dates for the key variables relevant for Loss and Damage in the global stocktake that we assemble in our harmonized dataset

Dataset	Proxy for	Source	Date downloaded
EM-DAT	Losses and damages	https://public.emdat.be/	2020/03/25
UNEP Global Risk Data Platform	Exposure to hazards	https://preview.grid.unep.ch/	2019/11/21
Carbon Brief Attribution Studies Map	Event attribution	https://www.carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world	2021/08/25 (version update 2021/02/25)
Human Development Index (HDI)	Vulnerability	http://hdr.undp.org/en/data (country-level and incomplete) https://doi.org/10.5061/dryad.dk1j0 (grid-level and gaps filled)	2019/11/05 2020/07/14
Notre Dame Global Adaptation Initiative (ND-GAIN)	Adaptation readiness	https://gain.nd.edu/our-work/country-index/download-data/	2019/11/05
OECD Climate-Related Development Finance (CRDF) Database	Global adaptation financing	http://www.oecd.org/dac/financing-sustainable-development/development-finance-topics/climate-change.htm	2021/01/21
Climate Laws, Institutions and Measures Index (CLIMI)	Climate policies	https://www.ebrd.com/documents/comms-and-bis/chapter-4-political-economy-of-climate-change-policy-in-the-transition-region.pdf	2020/10/13
Worldwide Governance Indicators (WGI)	Governance situation	https://datacatalog.worldbank.org/dataset/worldwide-governance-indicators	2019/11/05
Inclusive Wealth Index (IWI)	Natural and social capital	https://www.unenvironment.org/resources/report/inclusive-wealth-report-2018	2019/12/04

education, and Gross National Income (GNI). Non-economic indicators of development, such as HDI, are important when considering economic and non-economic L&D because they reflect capabilities (e.g., education) that are not addressed with economic indicators, such as GNI (or GDP) alone. We take the HDI for the year 2017 as the most recent available data at the time of data assembly.

The Notre Dame Global Adaptation Initiative (ND-GAIN) provides an index of countries' vulnerability to climate disruptions and their readiness to adapt (Chen et al., 2015). The country index (referred to henceforth as ND-GAIN) is a composite index made up of 45 indicators (36 vulnerability indicators and nine readiness indicators). The vulnerability indicators reflect concerns across food, water, health, ecosystem services, human habitation, and infrastructure sectors. For example, the projected changes in food crop (cereal) yields under the RCP 4.5 climate change scenario, as well as estimated population growth as a proxy for food demand, are used as indicators of vulnerability within the food sector (Chen et al., 2015). The readiness indicators cover economic, governance, and social conditions that affect a country's readiness to adapt. For example, access and use of mobile and land-line telephones, as well as broadband internet, are used as indicators of a country's information communication technology infrastructure, which influences their society's adaptive capacity and ability to respond to emergencies (Chen et al., 2015). We take the ND-GAIN for the year 2017 as the most recent available data at the time of data assembly.

Finance is central to climate change adaptation, particularly in developing countries. Article 9 of the Paris Agreement stipulates that "developed country parties shall provide financial resources to assist developing country parties with respect to both mitigation and adaptation in continuation of their existing obligations under the convention" and that "other parties are encouraged to provide or continue to provide such support voluntarily" (UN, 2015). The Organisation for Economic Co-operation and Development (OECD) Assistance Committee compiles all reported bilateral and multilateral climate-related finance in their Climate-Related Development Finance (CRDF) database (OECD, 2018). The CRDF data are disaggregated by objective (e.g., mitigation, adaptation) since 2010, and we sum all adaptation-related finance received by each country from 2010–2018.

Governance approaches, specifically resource and/or climate approaches deemed as "good governance" (e.g., transparent, equitable, accountable, etc.), are central to addressing climate change, and we include several governance indicators here. The climate policy landscapes of 95 countries are captured in the Climate Laws, Institutions, and Measures Index (CLIMI) (Steves & Teytelboym, 2014). The CLIMI is comprised of 12 variables that reflect the political economic determinants of climate change policy, grouped into four key policy areas: international cooperation, domestic climate framework, sectoral fiscal or regulatory measures or targets, and cross-sectoral fiscal or regulatory measures (Steves & Teytelboym, 2014). To assess other governance factors that may affect a country's ability to adapt to climate change or avoid and address L&D, we also include the Worldwide Governance Indicators (WGIs) of the World Bank (World Bank, n.d.). The WGIs include six dimensions of governance: voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law, and control of corruption. Several of these dimensions are also included in the ND-GAIN. We take the WGIs from 2017.

Finally, we take the Inclusive Wealth Index (IWI) of the UNEP (UNEP, 2018) as another potentially important contextual factor for the global stocktake. The IWI estimates the social (not monetary) value of a country's capital assets, including natural capital, human capital, and produced capital (UNEP, 2018). Although these indices/indicators are not explicitly relevant for the global stocktake of L&D, they inform about the state of affairs regarding government and the environment in different countries. We take the IWI from 2014 as the most recent year available at the time of data assembly.

2.3 | Data processing

Our aim in creating this dataset was to harmonize and summarize existing data to provide a global overview of variables relevant for a stocktake on loss and damage. In order to overcome problems of comparability across different databases, we standardized several variables to per capita and per unit GDP and averaged them over time. Our resultant dataset provides a comparable snapshot across relevant variables globally at the resolution of individual countries, using ISO 3-digit codes as the unique identifier of each country. We use the term "country" here, but in reality our dataset also contains entries for states that have dissolved since 1970 (e.g., the Soviet Union) and territories that are treated separately from their sovereign states because of complete data availability for these territories (e.g., Sint Maarten and New Caledonia). We do not retain the disaggregated information from original databases; these should be referred to for detailed original data. In this section, we describe the data processing conducted to harmonize and summarize the various databases. All processing was conducted in R version 4.0.2 or ArcGIS 10.6. Input files from each original data source can be found in the Supporting Information, along with the R Markdown containing all processing steps.

2.3.1 | Processing of EM-DAT losses and damages

For each country, we summed the total number of people affected, total deaths, and total economic damages recorded in EM-DAT for all events classified as droughts, floods, storms, extreme temperatures, or bushfires from 1970–2019, inclusively. We acknowledge that some of these events are not purely climatic in nature and that other factors can be influential (e.g., land use change and forest management). However, climate change is expected to be an important driver of these types of events (e.g., Australian bushfires; van Oldenborgh et al., 2020).

Next, we calculated the annual number of people affected and total deaths as a fraction of population in each country for the year of each event. We used United Nations' (UN) annual population estimates to the nearest thousand. We then calculated the average and maximum of these annual fractions for each country over two time periods: 1970–2019 and 1990–2019 (unless stated otherwise below). The latter period was chosen because 1990 was a key year in the emergence of many sovereign states that exist today and because awareness of anthropogenic climate change increased rapidly around this time. Missing data and NAs were treated as zeros in the averaging because *recorded* losses and damages are important for the global stocktake and so we treat an empty entry as zero recorded losses or damages for that year in that country. We emphasize that *recorded* losses and damages are not necessarily *actual* losses and damages, which is important because potential data gaps likely exist for the global stocktake (Harrington & Otto, 2020; Thomas et al., 2020).

Exceptions to the time periods mentioned above for population calculations are as follows. For all post-1990 sovereign states, we include data from the first year of sovereignty or from the first non-zero record in EM-DAT, whichever is earliest. This accounts for those countries for which data may not have been reported before their sovereignty and also for countries where data exist in the database before their sovereignty, which suggests that reporting already occurred in that place. For example, South Sudan became sovereign in 2011, but EM-DAT contains non-zero data as early as 2008, so we will include all years from the first non-zero entry (2008) even though this is before sovereignty (2011). In contrast, Lithuania became sovereign in 1990, but the first non-zero entry in EM-DAT is 1993. In this case, we do take all entries from 1990, even though the first non-zero entry is later.

Certain territories are treated as follows for the population calculations. Outlying territories of sovereign states are treated separately from their sovereign state if they have population and EM-DAT data. If population data are missing, the EM-DAT data are added to their sovereign country total. For the Netherlands Antilles (ANT) prior to dissolution in 2010, we sum the population data for the constituent territories (Aruba [ABW], Curaçao [CUW], Sint Maarten [SXM], and Bonaire, Sint Eustatius and Saba [BES]). Two events are recorded in EM-DAT for the Netherlands Antilles: Hurricanes Hugo (1989) and Luis (1995), which struck the Leeward Islands (SXM and BES) but not the Leeward Antilles (ABW and CUW). Thus, per capita affected and per capita deaths from ANT prior to 2010 are included for the calculations of SXM and BES but not ABW and CUW. For Yemen (YEM), EM-DAT records for North (YMN) and South (YMD) Yemen are combined under YEM from 1970–1990 because disaggregated population data are not available for this period.

Finally, we calculated the annual monetary damage as a fraction of GDP in each country for the year of each event. We used UN annual GDP estimates in US dollars at current prices (i.e., prices for each year, not a constant price). World Bank annual GDP estimates were used for outlying US territories, which are missing from UN estimates. We then calculated the average and maximum of this annual fraction for each country over the two time periods stated above, but excluding 2019 due to unavailable GDP estimates for that year at the time of calculation.

Certain territories are treated as follows for the GDP calculations. Outlying territories of sovereign states are treated separately from their sovereign state if they have GDP and EM-DAT data. If GDP data are missing, the EM-DAT data are added to their sovereign country total. American Samoa (ASM), Guam (GUM), US Virgin Islands (VIR), and Northern Mariana Islands (MNP) are included under the USA from 1970–2001 and treated separately from 2002–2018, corresponding to GDP data availability. East and West Germany (DFR and DDR) are included under Germany (DEU) prior to reunification for GDP calculations. Taiwan (TWN) is treated separately from China, and GDP data was obtained from the Government of Taiwan's statistical database and converted to US dollars at current prices using historical annual exchange rates from 1984 onward.

2.3.2 | Processing of UNEP exposure data

For each country, we calculated the average annual population and GDP exposed to cyclones, droughts, floods, and bushfires based on the global exposure grids from the UNEP Global Risk Data Platform (UNEP, 2013). In each cell of these grids, economic exposure is given as expected average annual GDP exposed in US dollars (year 2000 equivalent) and population exposure is given as expected average annual population exposed. The reference year for both GDP and population is 2010. For cyclone exposure, the reference period is 1970–2009 for winds and 1975–2007 for surges. For drought exposure, the reference period is 1980–2001. Only cyclones of the Saffir–Simpson category 5 are included in the UNEP data for wind exposure. For flood exposure, the reference period is 1999–2007. For bushfire exposure, the reference period is 1997–2010. Note that no exposure data for extreme temperatures were available, but events of this type are included in the calculations of EM-DAT losses and damages.

First, we rasterized the detailed world political boundaries of Pope (2017) to a resolution of 2.5 arcminutes (approximately 4.6 km at the equator) to align with exposure grids (except the bushfire exposure grids). We rasterized the polygons using maximum combined area and polylines using maximum combined length. Then, we took the polyline cell value where polygon cell values were null to account for coastal areas missed in the polygon rasterization. Next, we summed all GDP and population exposed in all grid cells within each unique territory in the grid. We then aggregated territories into their sovereign states according to whether they were aggregated or kept separate for the EM-DAT population and GDP analyses described above.

Bushfire exposure grids (provided at 0.1 degree resolution, not 2.5 arcminutes) were treated as follows. First, the UNEP GRDP fire density grid was divided by 100 to give the expected average number of events per grid cell per year. In the original grid, a value of 100 indicates one event per year; thus, we divide by 100. Next, the LandScan gridded population for 2010 (Bright et al., 2011) was obtained and aggregated to 0.1 degrees to align with the fire density grid. LandScan population was used for consistency with other UNEP GRDP exposure calculations. We then multiplied the population grid with the adjusted fire density grid to give the number of inhabitants potentially exposed to fire events each year in each grid cell. For country summaries, we resampled our new bushfire exposure grid to 2.5 arcmins using the nearest neighbor to align with the country grid. This assumes that all 2.5 arcmin cells whose center is within each original 0.1 degree grid have the same fire exposure. Some edge effects occur, but this method reduces errors along country borders that would be introduced if a separate 0.1 degree country grid was used.

Finally, we summed the population and GDP exposures for all event types for each country and calculated the average annual per capita and per unit GDP exposure using 2010 population and GDP estimates for each country. The year 2010 was used to align with the year of reference for population and GDP in the exposure data. GDP estimates for 2010 in US dollars at current prices were converted to year 2000 equivalent to align with GDP exposure data. Final calculations were checked for spurious outliers in exposure, which resulted in the exclusion of population exposure to drought for Comoros (COM) and population and GDP exposure to fire for Montserrat (MSR).

Because we summarized UNEP exposure data according to our country grid created from the political boundaries of Pope (2017), many more territories contain exposure data than EM-DAT data. We treated outlying territories separately from their sovereign state if they are also kept separate in EM-DAT, and we could obtain population and GDP estimates (as described above). Uninhabited southern, military, some disputed (e.g., Spratly Islands), and Antarctic territories are excluded. Territories that were aggregated with their sovereign state for exposure analyses are listed in Table 3. Western Sahara, although disputed, is included under Morocco.

2.3.3 | Processing of attribution studies

In order to gauge the geographic distribution of climate change attribution studies, we incorporated Carbon Brief's global map of attribution studies (Pidcock et al., 2020) into our dataset. While Carbon Brief's data are recorded by study (and event when multiple events are considered in a single study), our dataset required that studies be summarized by country. This was not a trivial transformation, and we stress that the original attribution studies should be consulted for precise details. We present a global overview of the distribution of studies, which has some geographic uncertainties due to the processing steps described here.

We first gave each attribution study a unique identifier in the form of "att*XXX*", where *XXX* is numeric from 001 to 405; for example, "att001" and "att405". The attribution studies along with IDs are contained in the input file "Carbon_Brief_Attribution_data_R.csv" in the Supporting Information.

Next, we collated for each country the attribution studies that covered all or part of that country. This was determined by the geographic coverage of each study. Studies that focused on locations within a single country were allocated to those countries in our dataset. Studies that focused on a region (e.g., "East Africa") that was specified

TABLE 3 List of territories aggregated with their sovereign state for exposure analyses. ISO codes are given in parentheses

Sovereign state	Territory
Australia (AUS)	Cocos (Keeling) Islands (CCK) Christmas Island (CXR)
Denmark (DNK)	Faroe Islands (FRO) Greenland (GRL)
France (FRA)	Saint Barthélemy (BLM) Guadeloupe (GLP) French Guiana (GUF) Saint Martin (French part) (MAF) Martinique (MTQ) Mayotte (MYT) Réunion (REU) Saint Pierre and Miquelon (SPM) Wallis and Futuna (WLF)
Morocco (MAR)	Western Sahara (disputed territory) (ESH)
New Zealand (NZL)	Tokelau (TKL)
Portugal (PRT)	Azores Islands (AZO)
Spain (ESP)	Canary Islands (SPI)
United Kingdom (GBR)	Falkland Islands (Islas Malvinas) (FLK) Guernsey (GGY) Gibraltar (GIB) Isle of Man (IMN) Jersey (JEY) Pitcairn (PCN) Saint Helena, Ascension and Tristan da Cunha (SHN)

by a latitude and longitude bounding box were allocated to all countries that intersected that box. The exception to this was when only a very small part of a country (based on visual judgement) intersected the box, in which case that country was not considered to be included. North African and Near Eastern countries intersect the bounding box used in some broad European studies, in which case they are included. When a study region was specified to a particular river basin, we allocated the study to all countries fully or partly within that geographic unit. When a particular storm or cyclone season was specified, but no countries or coordinates were given, we allocated the study to all countries listed to be affected by that storm or cyclone season on the relevant Wikipedia page. We excluded all global and entire northern hemisphere studies, as well as those conducted on ocean temperatures or sea ice without specific reference to a particular country.

The regions to which we allocated each attribution study are described in the input file "Carbon_Brief_Attribution_regions_R.csv" contained in the Supporting Information. Each region is specified for the respective attribution study by "creg_*XXX*", which corresponds to the study's unique number from its "att*XXX*" ID. Attribution studies that were specified to countries, not regions, in Carbon Brief's database are not included in the regions input file because the allocation in our dataset was based simply on countries.

Once attribution studies had been allocated to their respective countries, we calculated for each country the total number of studies and the number and fraction of studies found to be "more severe or more likely to occur" because of climate change. A total of 339 (84%) of the 405 attribution studies were allocated to countries in our dataset. Two of these 339 entries were then excluded as duplicates of another study.

2.3.4 | Processing of vulnerability, adaptation, and governance indicators

For the HDI, ND-GAIN, and WGIs, we include the data for the year 2017, which was the latest year of availability for two of these three datasets at the time of processing. Each indicator was joined to the respective country in our dataset using the ISO 3-digit code. For WGIs, we include only the indicator value estimate and not the percent rank or upper and lower uncertainty values.

Not all countries in our dataset have data for the HDI, ND-GAIN, and WGIs. Gap filling from another source was only possible for the HDI. We filled gaps in the UNDP's HDI dataset using the global gridded HDI data of study by Kummu et al. (2018) for 2015, which was the latest year of availability. We resampled the 5 arcminute HDI grid to 2.5 arcminutes using the nearest neighbour to align with our country grid, and then calculated the average HDI within each country's territory. This spatially-averaged HDI was used to fill gaps at the country level. Even after filling gaps in the HDI, three present-day countries in our dataset were missing HDI data: Niue, Nauru, and Tuvalu.

The CLIMI is only provided as one snapshot in time by Steves and Teytelboym (2014), so we take this value. The CLIMI data do not contain ISO codes, so we matched country names in the CLIMI data to country names in our dataset, and then joined the two. Country names that did not match were manually checked and joined. Gaps in the CLIMI could not be filled from another source.

The most recent available data for the IWI was from the year 2014 (UNEP, 2018), so we used this year. IWI data were manually copied from Annex 2, Table A2.2 of the 2018 Inclusive Wealth Report (UNEP, 2018). No ISO codes are given in the IWI data, so we again matched country names and corrected them manually. Note that the IWI is provided in constant 2005 US dollars, which differs from the GDP data used previously for EM-DAT and UNEP exposure data calculations. We also include the growth in the IWI, calculated as the change from 1990–2014 as a percentage of 1990.

2.3.5 | Processing of adaptation finance

For adaptation finance from the CRDF we sum all finance specified as "adaptation-related" received by each country from 2010–2018, inclusively. All amounts were treated in constant 2018 US dollars, which is recorded in the original dataset along with the current prices. Only those financial flows recorded to individual countries are included; other flows to regions are excluded here because it is not possible to determine the fraction received by countries within the region specified. We could determine individual country recipients for 75.9% of the total $170.8 billion of adaptation-related finance reported from 2010–2018. The remaining 24.1% excluded from our dataset is recorded in Table 4.

2.3.6 | Summary of processed dataset

Our dataset contains 60 fields (Table S1) with 267 countries and territories, each identified with their unique ISO 3-digit code. Completeness of each field in our dataset depends on data availability in the original sources. The most incomplete field in our dataset is for CLIMI, which contains data for only 95 countries. Most fields relating

TABLE 4 Regional adaptation-related development finance from 2010-2018 not allocated to countries in our dataset

Region	Million USD (2018 eq.)
Developing countries	24,199.0
Africa	3,032.2
Africa (North of Sahara)	93.3
Africa (South of Sahara)	4,803.1
America	1,867.4
Asia	1,645.6
Caribbean	677.8
Caribbean & Central America	941.7
Central Asia	412.8
Europe	1,278.2
Far East Asia	376.5
Middle East	256.3
Oceania	645.6
South & Central Asia	132.6
South America	529.7
South Asia	196.7
States Ex-Yugoslavia	13.9
Total	41,102.4

Note: Unallocated finance shown here represents 24.1% of total adaptation-related development finance reported in the OECD CRDF data for this time period.

to exposure, vulnerability, losses and damages, and governance have in the range of 215–240 entries (Table S1). Summaries and global maps of selected indicators in our dataset are provided in the Supporting Information (Figures S1–S5). We also provide in the Supporting Information a comparison of selected indicators in our dataset against existing risk databases, and we find a high degree of redundancy, particularly among vulnerability, adaptive capacity, and governance metrics (Figures S6 and S7). The final processed data are provided as a .csv file in the Supporting Information.

3 | DISCUSSION

Empirical and modeled data on factors relevant for L&D are essential for the global stocktake under the Paris Agreement (Thomas et al., 2020). Our harmonized dataset provides such a resource for quickly identifying countries that have been hard hit by climate-related disasters and objectively comparing recorded impacts to exposure and vulnerability across countries. Countries with high exposure and vulnerability, but low recorded losses and damages, may indicate data gaps in recording the impacts of climate change (Harrington & Otto, 2020). Identifying these potential data gaps is important so that certain places are not overlooked in the global stocktake because of lack of data. Our dataset reveals insights regarding attribution studies of extreme events, which are necessary to link recorded losses and damages to policy debates around L&D. The capacity for *performing* attribution studies (e.g., accessibility of data/models) predominantly exists in developed countries, and the focus of these attribution studies has also been *on* the countries with this higher capacity (e.g., USA, China, Australia, and UK) (please see Supporting Information for details). This indicates a misalignment between the attribution of particular events and hotspots of exposure, vulnerability, and impacts—another potential data gap relevant for the global stocktake. Another imbalance is that confidence is higher in attribution of temperature-related events than precipitation-related events. Our dataset also provides a resource to quickly compare climate adaptation financing relative to exposure, vulnerability, and recorded impacts.

Several data and analysis needs beyond those addressed with our dataset remain urgent for the global stocktake. First, we have no records of non-economic losses and damages (NELDs) globally. In fact, the relative absence of NELDs from the L&D discourse to date is a blind spot in our ability to understand and address L&D (Tschakert et al., 2019). As long as the focus remains on economic conceptualization of losses and damages, then solutions will also be framed within this paradigm. Alternatively, nature-based solutions are gaining momentum under the first two pillars of the UNFCCC (mitigation and adaptation) (Seddon et al., 2020), and a greater focus on NELDs under the third pillar (L&D) fits well with a paradigm shift beyond economic and technological solutions. Second, we must understand the role of climate, disaster, and risk governance and the impacts of governance approaches both when interpreting results from the dataset and as a point of limitation for data available. Political conditions in certain countries may 1) create outliers that are seen in the dataset and/or 2) limit the data that are available. As an example of an outlier, human right violations in the Central African Republic have precipitated boycott and restrictions on trade and aid by other countries, which might explain low adaptation financing despite high exposure and vulnerability seen in the data (Figures S2A, S3, and S5). As an example of missing data, political instability and civil war in South Sudan until 2020 might explain the lack of available information to estimate the ND-GAIN adaptation readiness index for this country (Figure S3). Before diving into deep interpretation of this dataset, researchers should consider theoretical and potentially ethical questions such as does the dataset have retrospective and/or predictive power? What type of questions are appropriate to ask using this dataset? And how does the context of how the original data were collected and combined impact what can/should be asked using the dataset?

There are several important limitations and caveats for the dataset compiled and described herein. First, these data are only as good as their sources, and we know that the impacts of climate change are underreported in certain places (Harrington & Otto, 2020). Second, we sourced data on losses and damages solely from EM-DAT, which is available for all countries but focuses on larger events. The database used under the Sendai Framework for Disaster Risk Reduction, DesInventar, contains more details within countries for more events, but it is limited to around 90 countries globally, so was not used here. However, the cumulative effects of smaller and localized events are likely particularly important for L&D, and these should be explored further using DesInventar for particular cases. Third, our country-level processing of EM-DAT data considers only domestic losses and damages and not those that may be embedded in global trade (e.g., increased costs of commodities as a result of a drought in a distant country). Fourth, as mentioned above, EM-DAT does not capture the multitude of non-economic losses and damages, which are important (Tschakert et al., 2019). Fifth, we include climate adaptation finance but exclude evidence of actual adaptation actions or funded projects, a catalog of which is central to the global stocktake. A novel application using machine learning to scour academic literature for evidence of adaptation has recently been provided by Berrang-Ford et al. (2021), whose findings could be compared to our dataset to assess whether adaptation finance is or is not a good indicator of where adaptation is actually taking place. Sixth, our dataset is static—it contains no annual information (which is aggregated during our processing) and is not currently set up to be updated with future iterations of the source databases. Thus, it is likely relevant for the upcoming 2023 global stocktake, but perhaps not subsequent ones. Seventh, future projections of certain factors affecting L&D are possible but are excluded here. Sources of these could be climate and integrated assessment models as well as future socio-economic developments under different scenarios (e.g., Andrijevic et al., 2020). Finally, L&D is highly contextualized; the nuance of factors such as the climate policy regime, governance frameworks, and engagement of civil society in governance, as well as in climate adaptation on the ground, cannot be fully captured here, nor can the limitation of political realities, such as legacies of colonialism and structured inequality across class, race, ethnicity, and gender, within a particular country or region. The benefit of this dataset is likely limited to a static global snapshot of data gaps (e.g., Africa), regional patterns, and concerning discrepancies between L&D and support for adaptation. Nonetheless, our work here may serve as a rallying call for scholars to engage in deep contextual research *in* these places of contradiction and obvious potential for L&D.

One critical issue for L&D and the global stocktake that we have so far kept to the side is that of loss and damage from slow onset events (e.g., sea-level rise, salinization). Such events are fundamental to the Warsaw International Mechanism for L&D, reflected in the fact that the L&D agenda was championed by the Alliance of Small Island States as early as the 1990s. Slow onset events are not typically recorded in EM-DAT and, thus, are also not covered by our dataset. However, indirect connections may exist between slow onset and extreme events that are recorded here. For example, flooding associated with drainage congestion or storm surge damage could both be exacerbated by sea-level rise. Attribution studies have also focused primarily on extreme rather than slow onset events, leaving another potential gap in L&D knowledge, although alternative approaches to attribution of slow onset events exist (e.g., thermodynamic reasoning or statistical analyses; see Hulme, 2014). Slow onset events may be particularly destructive in terms of non-economic losses and damages (e.g., loss of homelands, culture, identity) and should receive attention in the global stocktake despite their exclusion from our dataset.

Finally, we make several recommendations for custodians and developers of climate, risk, or L&D databases in the future, as well as for researchers leveraging them for policy-relevant analyses. First, be aware of the proliferation of global risk indices. Our correlation analyses (see Supporting Information) revealed a lot of redundancy among these metrics. Researchers and agencies developing such indices should ensure they conduct comprehensive reviews of what is already out there and how their new or proposed product fills a gap in the data landscape. Second, include ISO codes for countries in global databases, as well as information on sovereignty (e.g., years of sovereignty, preceding and subsequent states) if applicable. Such information is essential for longitudinal analyses of such indicators and for comparing across databases. Finally, clarify in the metadata or user guide which territories are included or separated from their sovereign states. This is important to avoid double counting or omitting certain data. These recommendations, along with our dataset, will hopefully ease the use of the wealth of information that exists and is highly relevant for the global stocktake, as well as for disaster, risk, and other studies in the future.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Murray W. Scown: Conceptualization (equal); Data curation (lead); Formal analysis (lead); Funding acquisition (supporting); Investigation (lead); Methodology (lead); Visualization (lead); Writing and revising (lead). **Brian C. Chaffin:** Funding acquisition (supporting); Writing and revising (supporting). **Annisa Triyanti:** Writing and revising (supporting). **Emily Boyd:** Conceptualization (equal); Funding acquisition (lead); Project administration (lead); Writing and revising (supporting).

DATA AVAILABILITY STATEMENT

The harmonized dataset is available as a .csv file, along with all code and files required, in the Supporting Information of the article and on the digital repository figshare.com (https://doi.org/10.23644/uu.14769675).

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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