Working Paper

The Costs of Inaction

Calculating climate change-related loss and damage from extreme weather in Small Island Developing States

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Photo front cover: Pacific Climate Warriors in Vanuatu. Photo credit: 350.org

Abstract

Small Island Developing States (SIDS) have had considerable success in getting climate-induced loss and damage on to the international policy agenda, as evidenced by the decision at COP27 to create a specific Loss and Damage Fund. However, the hard task of harnessing adequate support to address loss and damage hinges on being able to calculate what constitutes 'loss' and 'damage', both retrospectively and prospectively. This paper contributes to that conversation. It presents estimates of the impacts of extreme weather events due to climate change in SIDS over the past 23 years and projections of expected loss and damage by the year 2050.

Using information from extreme event attribution (EEA) analysis, this paper finds significant loss and damage attributable to climate change in SIDS: from 2000 to 2022, a total of 10,113 deaths associated with extreme weather events were recorded in SIDS, of which anthropogenic climate change was responsible for 38%. Annual economic losses of US$1.7 billion can be attributed to climate change, representing 0.8% of the collective gross domestic product (GDP) of SIDS every year. For small, undiversified SIDS economies, this is extremely significant. On average, SIDS suffer higher levels of loss and damage than non-SIDS across all income groups. For instance, SIDS experience five times more climate change-attributable deaths (per million of population) than non-SIDS in low- and lower middle-income countries.

Collectively, floods and storms are projected to produce cumulative climate change-attributable loss and damage of $56 billion in SIDS under a 2°C warming scenario by 2050. This would represent 11% higher average annual loss and damage over the next 23 years (2023–2045) than over the past 23 years (2000–2022). These projections likely underestimate the potential loss and damage that may occur in SIDS, because of limited data and because indirect economic impacts (e.g. loss of GDP, loss of revenues) and loss and damage due to slow-onset events have not been included in the analysis.

The paper offers recommendations to help inform the development of adequate financial mechanisms, including the Loss and Damage Fund, for coping with these seemingly inevitable impacts of climate change in SIDS. Firstly, mechanisms to address loss and damage need to focus on loss and damage under a 2°C+ scenario. Secondly, there needs to be a clearer articulation, and calculation, of the indirect costs of climate change, which could be significant. And finally, data gaps need to be filled as a matter of urgency, including through more attribution studies in SIDS and other highly vulnerable countries.

Acknowledgements

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Contents

Acronyms

AIS	Atlantic, Indian Ocean and South China Sea
AOSIS	Alliance of Small Island States
COP	Conference of the Parties to the UNFCCC
DRR	Disaster risk reduction
EEA	Extreme event attribution
EM-DAT	International disaster database
FAR	Fraction of attributable risk
GDP	Gross domestic product
GHG	Greenhouse gas emissions
IPCC	Intergovernmental Panel on Climate Change
L&D	Loss and damage
LDC	Least developed country
MVI	Multidimensional Vulnerability Index
ODI	Overseas Development Institute
SIDS	Small Island Developing States
SLOL	Statistical loss of life
UNDRR	United Nations Office for Disaster Risk Reduction
UNFCCC	United Nations Framework Convention on Climate Change
VSL	Value of statistical life

1 Introduction

In 2022, the 27th session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP27) in Sharm el-Sheikh, Egypt, saw the historic agreement to establish a dedicated Loss and Damage Fund and funding arrangements to help vulnerable countries address the impacts of climate change. Small Island Developing States (SIDS) had been seeking redress for climate-related loss and damage[1] for some time, but their efforts had been consistently thwarted – in part, because of the complexities of creating an adequate mechanism. The agreement to create a Loss and Damage Fund is a necessary first step in a much longer process to design and implement a mechanism that can deliver on the promise of genuine climate justice.

This paper seeks to contribute to that process by providing a set of methods for calculating and assessing the impacts of extreme weather events in SIDS. Obstacles abound, some of which are inherent to the problem of prediction and others (such as data gaps) to the specific SIDS condition. The aim of this study is to move the discussion on measuring 'loss' and 'damage' forward, such that SIDS and other highly vulnerable countries have the evidence needed to secure adequate finance and provide compensation to those affected, to better cope with the impacts of a climate crisis for which they bear little responsibility.

1.1 Vulnerability of SIDS

There is growing scientific evidence to suggest that SIDS will be the first and worst impacted by climate change (IPCC, 2022). The Alliance of Small Island States (AOSIS) was formed in the late 1980s to draw attention to, and negotiate on behalf of, small islands whose existence was threatened by climate impacts, and this agenda has gathered momentum over several decades. The creation of the UN SIDS category, with dedicated international conferences – the fourth of which will be held in Antigua and Barbuda in 2024 – and the impact SIDS had on the Paris Agreement in 2015 are testament to their importance and influence as a group of countries. Central to this effort has been recognition that climate change will have particularly adverse consequences in SIDS due to structural geographical and economic factors. Some are low-lying atoll states and hence highly vulnerable to rising sea levels, and all are vulnerable to biodiversity loss and coastal erosion as a result of warming oceans and acidification (IPCC, 2022). Almost all SIDS are located in the tropics and hence highly exposed to tropical cyclones and flooding.

SIDS suffer disproportionately high macroeconomic and fiscal impacts from extreme weather due to their small population size, limited resources, narrow sector specialisation and human resource capacity constraints (Wilkinson et al., 2023). As these events increase in frequency and intensity, SIDS will be forced to take on more debt, reducing their ability to invest in resilience, which will in turn limit their capacity to respond when the next disaster occurs. Climate change will thus precipitate a vicious cycle in SIDS, undermining opportunities for sustainable development (Wilkinson et al., 2023).

Climate change is an important factor driving the increase in number of disasters associated with extreme weather (IPCC, 2022). Globally, there has

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[1] Following the IPCC Sixth Assessment Report (IPCC, 2022), this paper uses the lowercase 'loss(es) and damage(s)' to refer broadly to harm from (observed) impacts and (projected) risks from climate change that can be economic or non-economic (Mechler et al., 2018). The term 'Loss and Damage' (capitalised letters) is used to refer to political debates, policies and funding arrangements under the United Nations Framework Convention on Climate Change (UNFCCC).

been a significant increase in the frequency and intensity of weather-related disasters over the past few decades (UNDRR, 2022), with most recorded losses linked to extreme weather events.[2] In SIDS,[3] weather-related disasters have resulted in $38 billion of economic damages from 2000 to 2022, or 75% of the total recorded disaster losses from all disaster types in SIDS.

However, it is not clear what proportion of these extreme weather damages can be attributed to climate change. Understanding the influence of anthropogenic climate change on the frequency, intensity and duration of extreme events, and thus on their impact, is critical for taking action to prepare and respond.

1.2 Climate-induced loss and damage

Parties to the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement (Article 8.1) recognise the importance of averting, minimising and addressing loss and damage associated with the adverse effects of climate change, but the lack of official definition of 'loss and damage' is proving to be a major obstacle to governments and international organisations taking appropriate action (Cao et al., 2023).

The concepts of 'loss' and 'damage' are largely treated as synonymous and can result from the occurrence of sudden-onset extreme weather events such as cyclones, floods and heatwaves, as well as slow-onset events, or processes, such as sea level rise, desertification and ocean acidification (UNFCCC, 2021).[4] Loss and damage can be categorised as economic or non-economic, as shown below.

- Economic loss and damage includes loss of physical assets, goods and services that are commonly traded in markets (e.g. loss of income, damage to infrastructure and property).
- Non-economic loss and damage can be considered as the remainder of the impacts and risks that are not commonly traded in markets. Such loss and damage could include human losses (loss of life and health), societal loss and damage (loss of cultural heritage, territorial loss and loss of indigenous knowledge) and environmental losses (loss of biodiversity and ecosystem services).

In the literature on disaster risk reduction (DRR), disaster losses and damages are further classified as being direct or indirect (ODI and UNDRR, 2023). This distinction is particularly relevant for this study because it has implications for the quantification of loss and damage. Direct damage is the monetary value of the partially destroyed physical asset, assuming the destroyed asset will be restored to pre-disaster conditions (in quantity and quality). These damages are usually quantified in economic terms and estimates are available for many disasters. However, some damages are direct but difficult to quantify. For example, in the case of a culturally significant site being destroyed, assigning a monetary value to the loss and replacement value cannot account for the lost social and cultural significance that the site represents to a community.

Indirect losses, on the other hand, are the secondary effects that arise from the direct loss and damage that disrupt the flow of goods and services until assets are rehabilitated or rebuilt and some degree of 'recovery' has taken place. Unlike direct damages, indirect losses are difficult to quantify because they often spill out beyond the affected area, are cascading and may have long time lags – materialising decades later (Newman and Noy, 2023).

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[2] Extreme weather events or weather-related natural hazards include storms, floods (including heavy rains), landslides, drought, extreme temperatures and wildfires.

[3] There are 38 UN member states categorised as SIDS.

[4] Outside of the UNFCCC, a number of classifications and interpretations of climate-related loss and damage have been developed, including in relation to how and why these phenomena occur. For instance, a widely used taxonomy on loss and damage categorises them as risks that can be avoidable or unavoidable and they may, in certain circumstances, be unavoidable (see Verheyen and Roderick, 2008; Mechler et al., 2019).

1.3 Focus of the study

This study examines recorded loss and damage from extreme weather events that could be attributed to anthropogenic climate change in 37 out of the 39 UN designated SIDS, excluding Nauru and Singapore (see Table 1). It analyses the dynamics of these losses and damages in SIDS from 2000 to 2022 and compares with estimates for non-SIDS in the same income level groups.

Owing to data availability and estimation difficulties with respect to slow-onset events, this study focuses on extreme weather events only. Similarly, this study considers only the direct damage estimates (specifically human loss and asset damages) of extreme weather events that are readily available for a wide range of countries including SIDS. The indirect, macroeconomic and fiscal consequences (e.g. loss of income or revenue) of climate-related loss and damage in SIDS are assessed using secondary evidence from published case studies.

The authors present preliminary projections of expected loss and damage due to climate change by the year 2050 and offer recommendations for developing adequate financial mechanisms for addressing Loss and Damage in SIDS.

Table 1 List of 39 UN member SIDS, classified by their geography and income levels (World Bank 2022 classification)

	Low income	Lower-middle income	Upper-middle income	High Income
Caribbean SIDS		• Haiti*	• Belize • Cuba • Dominica • Dominican Republic • Grenada • Guyana • Jamaica • Saint Lucia • Saint Vincent and the Grenadines • Suriname	• Antigua and Barbuda • Bahamas • Barbados • Saint Kitts and Nevis • Trinidad and Tobago
Pacific SIDS		• Kiribati* • Micronesia • Papua New Guinea • Samoa • Solomon Islands* • Timor-Leste • Vanuata	• Fiji • Marshall Islands • Palau • Tonga • Tuvalu*	• Cook Islands • Nauru • Niue
Atlantic, Indian Ocean and South China Sea (AIS) SIDS	• Guinea-Bissau*	• Cabo Verde • Comoros* • Sao Tome and Principe*	• Maldives • Mauritius	• Seychelles • Singapore

* 'Least developed country' (LDC)[5].

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[5] 'LDCs' is a category used across the UN system and in much development literature: http://www.un.org/development/desa/dpad/least-developed-country-category.html. In this paper, the authors would like to acknowledge current debates which question the use of this terminology and its ahistorical framing. They seek to challenge the power relationships and assumptions inherent in ideas about progress and development. Although in this instance we employ the term 'LDCs' to situate this report within the current literature, we will continue interrogating the appropriateness of the term and working with our partners to develop more appropriate language and terminology.

2 Methodology

This study builds on analysis by Newman and Noy (2023), using information from EEA that estimates the degree to which anthropogenic greenhouse gas (GHG) emissions had changed the likelihood of specific extreme weather events. These estimates allow us to quantify the climate change-induced component of the loss and damage caused by such events. A detailed description of data and methods used can be found in Appendix 1. A summary of the methodology is presented below.

EEA analysis typically calculates a probabilistic metric known as the fraction of attributable risk (FAR). An FAR describes the portion of the risk of a specific hydro-meteorological event that has already occurred – such as rainfall during Hurricane Maria in 2017 – that is a result of anthropogenic GHG emissions. FAR values lie between 0 and 1, where 1 means that the event would have been impossible without anthropogenic climate change.[6] By contrast, a FAR value of 0 means that climate change had no discernible influence on the probability of occurrence of that specific event (Jézéquel et al., 2018; Newman and Noy, 2023).

The FARs are extracted from existing attribution studies conducted globally during the reference period of the last 23 years (2000–2022). Newman and Noy (2023) compiled a global dataset of FARs from attribution studies for specific events, matched with socioeconomic cost data for the same events using the baseline data for this study from the EM-DAT database (CRED, 2023) over the period 2000–2019. This study adds to the dataset by including newer attribution studies conducted in 2021–2022 and makes effort to extend the analysis to all data available for 37 SIDS selected for this study. Likewise, the socioeconomic cost data for 2021–2022 from EM-DAT is also extracted and matched to the additional extreme weather events with FARs.

The final dataset includes 216 matched extreme weather events that occurred over the past 23 years (2000–2022), including five matched events from SIDS. The 216 matched events cover 56 countries including four SIDS (Bahamas, Dominican Republic, Haiti and Papua New Guinea) and are taken from a total of 135 attribution studies (many of the studies are regional, covering multiple events).

Overall, there are very few attribution results for SIDS. The attribution results for SIDS focus on floods, storms and droughts, with no identified attribution study for other disaster types such as heatwaves and wildfires. The authors therefore use regional and global averages of FARs for different event types to approximate limited or missing attribution results for SIDS. For instance, event-specific FARs for SIDS are based on the global averages, as well as the regional average for the Americas and Oceania, since 29 out of 39 UN member SIDS are from these two regions.

To estimate the direct costs associated with the FAR, a value needs to be given to loss of life. As in Newman and Noy (2023), this study uses a 'value of statistical life (VSL)' of $7.0837 million per life lost. To maintain equity and enable comparison, the same VSL value is used for all countries, regardless of time and place of death.

Climate change-attributable loss and damage caused by the sample (matched) events is quantified by combining the data on direct economic damages with the attributable share of

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[6] See Appendix 1 for the formula for calculating FAR.

the risk of these events (i.e. FARs). The following formula is used to calculate climate-attributed loss and damage for an event i in the master dataset (Newman and Noy, 2023):

$$CC\_loss \; \& \; damage_i = FAR_i * socio\_economic \; cost_i$$

The FARs for loss and damage calculations in SIDS (and other country groups) are extrapolated using both regional (continental) and global averages for each event type. Loss and damage is then analysed spatially (by SIDS), temporally (over years) and by event type, based on the data records in EM-DAT over the selected period. Loss and damage estimates are calculated for loss of life (deaths), affected people (including displaced and injured persons) and economic damages. All monetary values are adjusted for inflation and presented in 2020 US dollars.

Estimates of loss and damage are analysed using collective descriptive statistics for all extreme weather-attributed loss and damage, as well as for individual event types and SIDS. Case study examples are then used to better understand the macroeconomic and fiscal implications of different climate-attributed losses and damages. The possible impacts of climate change on the frequency of extreme weather events in the future are based on IPCC (2021) projections. This study uses linear extrapolation to estimate expected loss and damage from 2023 to 2050. Based on this analysis, the authors then draw implications and recommendations for the design and development of a Loss and Damage Fund and funding arrangements.

As highlighted by Newman and Noy (2023) and Noy et al. (2023), this methodology has a range of limitations related to the inequitable distribution of attribution studies, as well as deficits in the quality and quantity of data available for loss and damage estimation. A discussion of these limitations is provided in Appendix 1.

3 Climate change-attributed loss and damage in SIDS

3.1 Aggregate estimates of loss and damage

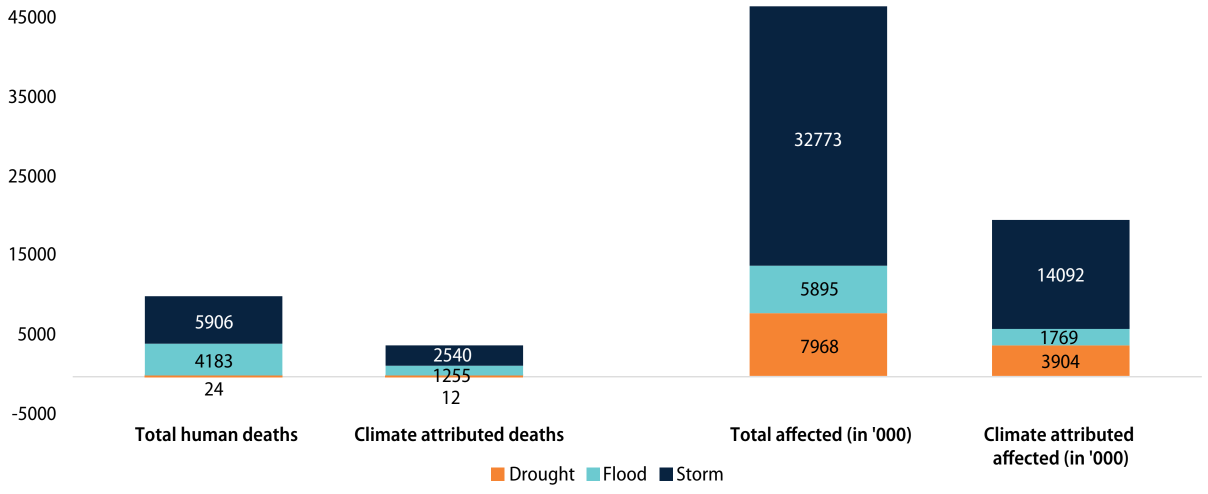
Estimates of human and economic loss and damage from extreme weather events across all SIDS for the period 2000–2022 that can be attributed to anthropogenic climate change are presented in Figures 1 and 2.[7]

From 2000 to 2022, a total of 10,113 deaths associated with climate-related events were recorded in SIDS, of which anthropogenic climate change is responsible for an estimated 38% (a total of 3,806 deaths) (Figure 1). Nearly 20 million of the 46.6 million total numbers affected by extreme weather from 2000 to 2022 can be attributed to climate change.

Climate change is responsible for 39% ($41.3 billion) of total economic losses[8] recorded (Figure 2), of which 65% are due to loss of life, measured as statistical loss of life (SLOL).[9]

A further breakdown of the attributed loss and damage reveals that storms contribute 77% and floods 23% to total attributed loss and damage. This is expected, since 56% of the total events recorded in EM-DAT for SIDS during the period 2000–2022 were storms, while only 36% were floods. The contribution of storms to total attributable losses is also particularly high because of high numbers of attributed deaths (67% of total attributed deaths) and people affected (71% of total attributed people affected).

Figure 1 Climate-attributed loss and damage (deaths and numbers affected) in SIDS during the period 2000–2022, cumulative and by event type



Note: Analysis is based on the disaster damage records of EM-DAT, using regional average FARs. Analysis includes 37 of the 39 UN Member SIDS, excluding Singapore and Nauru. All figures are in 2020 US$.

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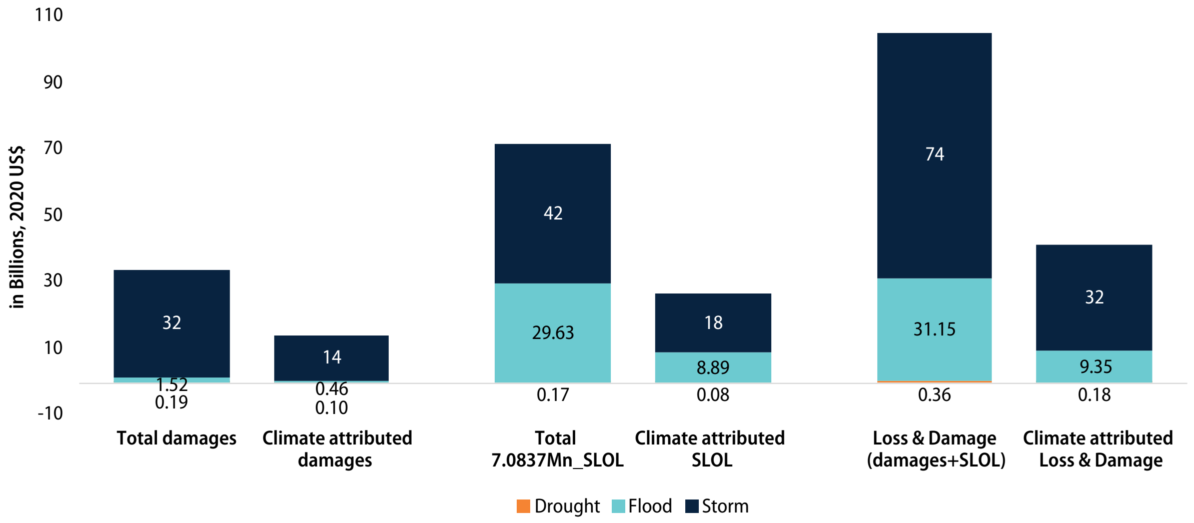
[7] Estimates presented in Figures 1 and 2 are based on the regional extrapolation of FARs.

[8] Total economic loss and damage includes both recorded damages from EM-DAT and SLOL.

[9] SLOL is calculated as $7.0837 per life lost.

Figure 2 Climate-attributable loss and damage (economic losses) in SIDS (2000–2022), cumulative and by event type



Note: Analysis is based on the disaster damage records of EM-DAT, using regional average FARs. Analysis includes 37 of the 39 UN Member SIDS, excluding Singapore and Nauru. All figures are in 2020 US$.

Drought events and impacts are significantly under-reported in SIDS. EM-DAT has a total of 434 recorded extreme weather events for SIDS during the period 2000–2022, of which only 33 are drought events. Out of these 33 events, only seven events have any recorded data on economic damage. In terms of human deaths, there is only one observation for drought-related deaths: for a drought in Papua New Guinea in 2015 (24 deaths). As a result, SIDS have a very low proportion of drought-related economic losses (8%) as a proportion of total attributable economic losses from all extreme weather events.

Of these total attributed economic losses and damages for 2000–2022, only 4% were insured across all SIDS. Insured losses for storms were 4%, while insurance coverage was even lower for floods at 1% of total attributed losses and damages.

Extrapolation of FARs and attributed loss and damage based on regional FAR averages (as discussed above) is not very different from global FAR averages.[10] This is similar to the results of Newman and Noy (2023), where mostly similar estimates were produced using both averaging methods.

3.2 Temporal distribution of loss and damage

On average, 150 deaths from extreme weather events in SIDS can be attributed to climate change annually during the period 2000–2022. Of these, storms accounted for an average of 108 deaths, followed by floods with 42 attributed deaths. Climate change is responsible for extreme weather affecting an average of nearly 900,000 people every year, which is nearly 60% of the total population of SIDS affected annually (1.5 million) during the same period (see Figure 3).

A peak in attributed human deaths can be observed in the year 2004. This is due to the

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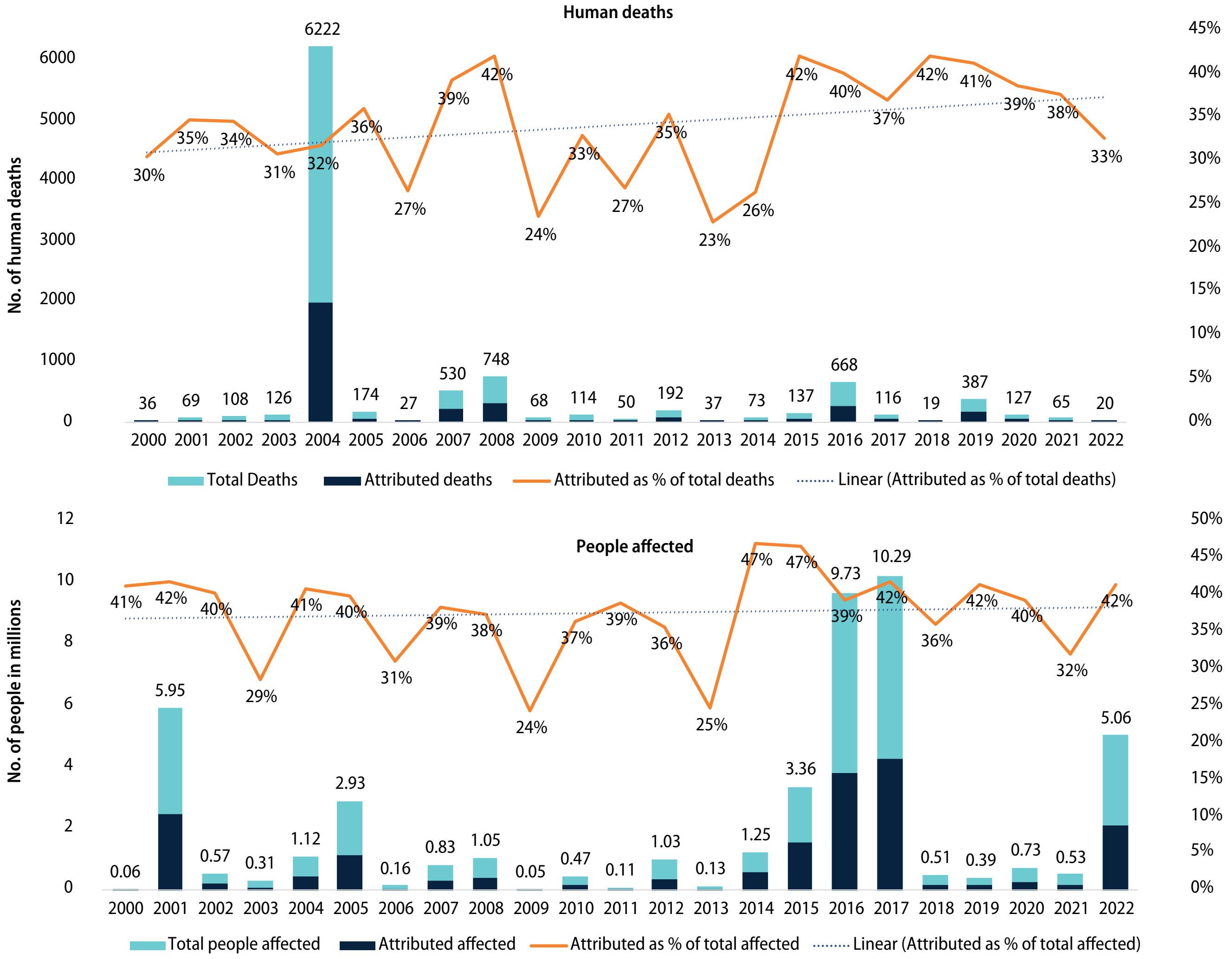
[10] See Appendix 2 for comparison of the regional and global FAR averages.

Figure 3 Annual distribution of climate-attributed loss and damage (deaths and people affected) in SIDS (2000–2022)



Note: Analysis is based on the disaster damage records of EM-DAT, using global average FARs. Analysis includes 37 of the 39 UN Member SIDS, excluding Singapore and Nauru. All figures are in 2020 US$.

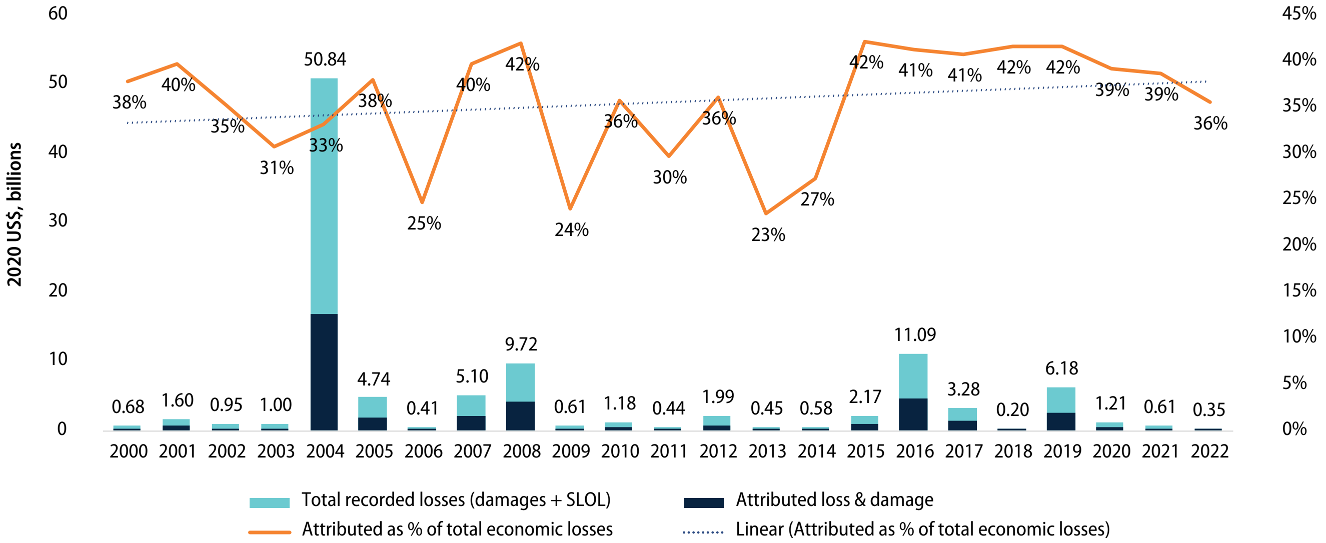
high mortality associated with Cyclone Jeanne, which hit Haiti on 22 September 2004 (2,754 total deaths, of which 1,157 attributed to climate change). It was also due to floods in May of the same year, affecting Haiti (2,665 total deaths, of which 613 attributed) and the Dominican Republic (688 total deaths, of which 158 attributed). This has also resulted in a higher attributed SLOL figure ($14 billion) for that year (Figure 4).

On average, annual economic losses of $1.7 billion can be attributed to climate change from 2000 to 2022. When expressed as a percentage of GDP, average annual economic loss is 0.8% of the collective GDP of SIDS (the highest being 9.5% of GDP in 2004). For small and largely undiversified economies in SIDS, attributed economic loss of such magnitude is extremely significant.

3.3 Spatial distribution of loss and damage

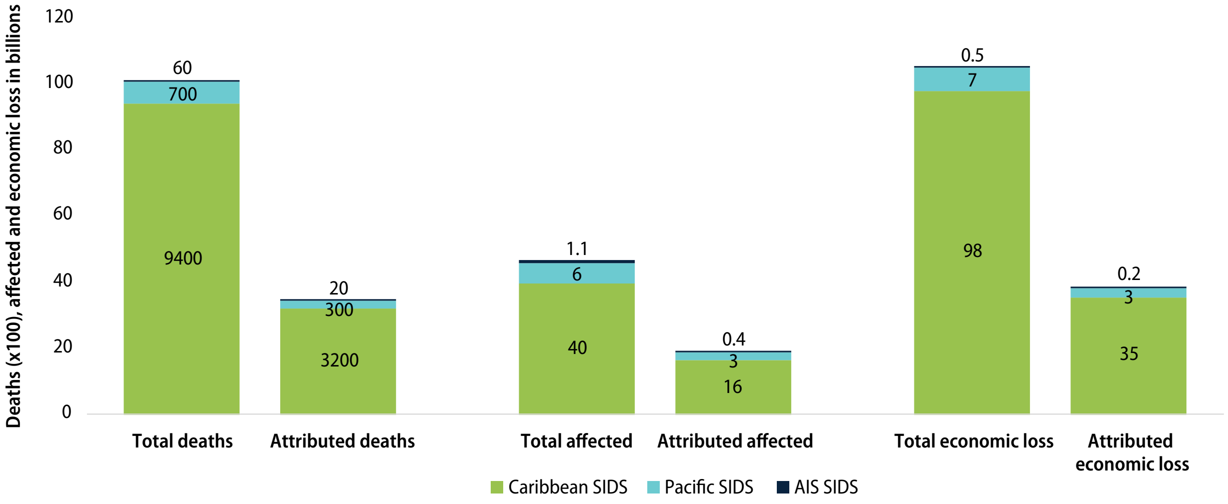
Most climate-attributed losses and damages are experienced in Caribbean SIDS: this region

Figure 4 Annual distribution of climate-attributed economic losses in SIDS (2000–2022)



Note: Analysis is based on the disaster damage records of EM-DAT, using global average FARs. Analysis includes 37 of the 39 UN Member SIDS, excluding Singapore and Nauru. All figures are in 2020 US$.

Figure 5 Distribution of climate-attributed loss and damage in SIDS by region (2000–2022)



Note: Analysis is based on the disaster damage records of EM-DAT, using global average FARs. Analysis includes 37 of the 39 UN Member SIDS, excluding Singapore and Nauru. All figures are in 2020 US$.

accounts for 92% of attributed deaths, 85% of attributed numbers affected and 93% of the economic losses of all SIDS (Figure 5). This is primarily driven by two factors: firstly, there are more recorded events (and accompanying losses) in the EM-DAT dataset for Caribbean SIDS than for Pacific SIDS or AIS SIDS;[11] secondly, Haiti is an outlier, with 80% of total attributed deaths in Caribbean SIDS. It's also worth noting that loss and damage from slow-onset events may well be higher in Pacific and AIS SIDS.

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[11] Out of 434 total SIDS events, 272 are recorded for Caribbean SIDS, 132 for Pacific SIDS and 32 for AIS SIDS.

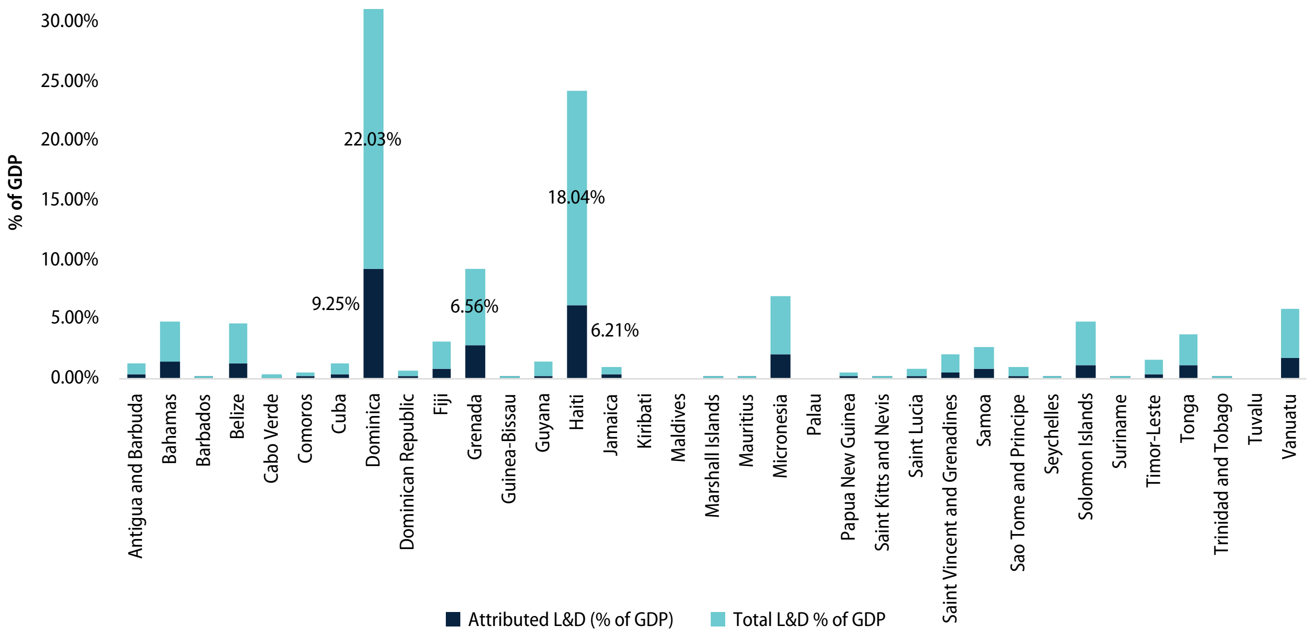
Attributed loss and damage figures increase slightly if additional data is included for Pacific SIDS from the DesInventar dataset (UNDRR, 2023), which includes smaller, mostly low-intensity events that are not already included in EM-DAT (see Appendix 3 for analysis of these additional events).

Table 2 presents disaggregated data on total and attributed loss and damage for all SIDS from 2000 to 2022. Haiti has suffered the highest death toll from extreme weather in SIDS, with 7,543 deaths, of which 2,566 can be attributed to climate change. This translates to 11 attributable deaths per million of population in Haiti. Dominica and the Bahamas have suffered the highest mortality rates from extreme events attributed to climate change, at 25 deaths per million and 20 deaths per million respectively.

Total economic losses for all SIDS over the 22-year period of analysis amount to $105 billion, of which $38.4 billion can be attributed to climate change. The Bahamas, Cuba, Dominica, the Dominican Republic and Haiti collectively account for 85% of the attributed economic losses, mainly due to higher mortality figures and associated SLOL estimates.

In Dominica, average annual climate-attributed loss and damage is 9.3% of GDP – the highest in all SIDS – followed by Haiti with 6.2% of GDP (Figure 6). In total, there are nine SIDS with attributed annual loss and damage of more than 1% of GDP. When expressed as a percentage of government revenues, the impact of climate change appears to be even more pronounced among SIDS (in comparison to other countries – see next section). On average, annual attributed economic losses represent 5.4% of government revenues across all SIDS – as high as 36.7% in Haiti and 54.7% in Dominica.

Figure 6 Average annual climate-attributed loss and damage in SIDS, as a percentage of GDP



Note: Analysis is based on the disaster damage records of EM-DAT, using global average FARs. Annual average over the period 2000–2022 is used to calculate estimates.

Table 2 Total and climate-attributed loss and damage related to extreme weather in SIDS

SIDS (cumulative 2000–2022)	Deaths		Affected		Total L&D (2020 US$ million) (Damages + SLOL)	
	Total	**Attributed**	**Total**	**Attributed**	**Total**	**Attributed**
Antigua and Barbuda	1	0	32,600	13,692	286	120
Bahamas	404	170	53,150	22,133	9,709	4,068
Barbados	2	1	8,680	3,646	21	9
Belize	55	23	413,075	162,472	1,310	547
Cabo Verde	13	5	171,243	78,911	93	34
Comoros	14	5	422,759	164,708	105	35
Cook Islands	1		8,552	3,592	90	38
Cuba	97	38	23,614,708	9,908,868	13,782	5,765
Dominica	96	40	107,757	45,258	2,770	1,163
Dominican Republic	999	277	4,786,439	1,441,181	8,115	2,372
Fiji	159	59	1,275,376	535,008	2,243	849
Grenada	39	16	60,000	25,200	1,494	628
Guinea-Bissau	8	2	202,083	84,384	57	17
Guyana	34	8	647,048	148,821	1,092	256
Haiti	7,543	2,566	8,571,213	3,834,243	56,109	19,309
Jamaica	71	28	869,311	366,785	2,546	1051
Kiribati			1,805	700		
Maldives			4,769	1,348		
Marshall Islands			32,824	16,170	5	3
Mauritius	17	5	31,271	13,118	195	66
Micronesia	53	22	153,631	72,580	388	163
Niue	1	0	702	295	62	26
Palau			22,738	10,694		
Papua New Guinea	224	91	3,153,728	1,442,043	1,683	682
Saint Kitts and Nevis			500	210	21	9
Saint Lucia	22	8	233,484	92,841	243	94
Saint Vincent and the Grenadines	17	5	50,460	13,081	300	86
Samoa	22	9	12,703	5,335	308	129
Sao Tome and Principe	8	2	219,668	50,524	57	13
Seychelles			14,235	5,136	10	4
Solomon Islands	127	40	287,701	103,719	930	291
Suriname	5	1	50,648	11,649	58	13
Timor-Leste	49	19	286,036	127,210	367	140
Tonga	1	0	132,906	55,821	232	97
Trinidad and Tobago	1	0	250,560	57,735	12	4
Tuvalu			20,317	9,355		
Vanuatu	30	13	431,449	180,458	705	296
Grand Total	**10,113**	**3,454**	**46,636,129**	**19,108,923**	**105,398**	**38,377**

Overall, total economic losses from extreme weather events annually cost SIDS 2.37% of GDP, with attributed losses making up around one-third of those costs. Similarly, average total economic losses represent 14% of revenue, with around one-third being attributed losses.

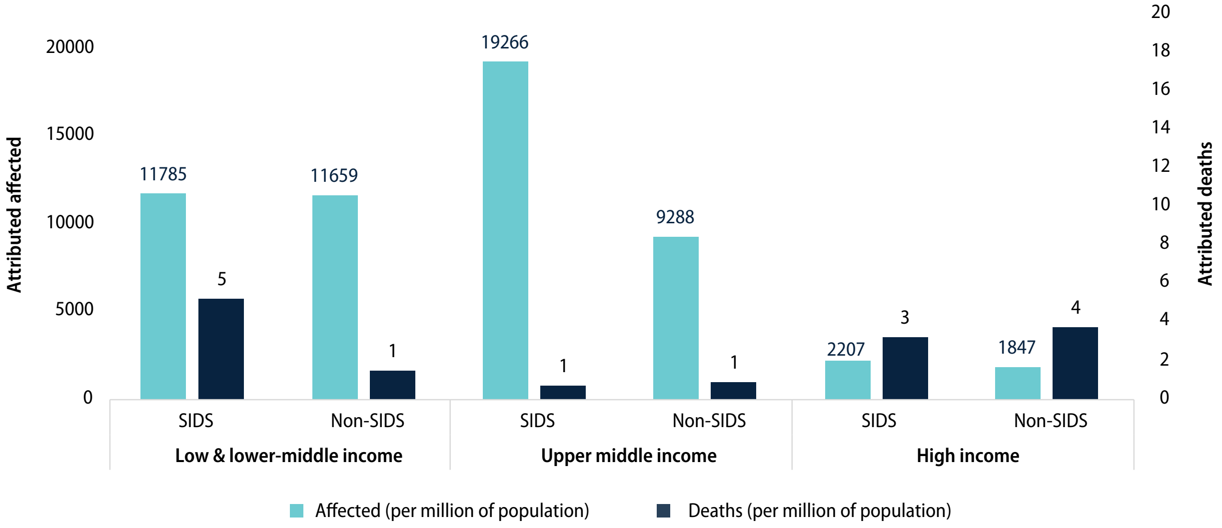
3.4 Where SIDS stand in relation to other country groups

Figures 7–9 compare human and economic loss and damage attributed to climate change from 2000 to 2022 in SIDS with those in other countries, using annual average estimates. All countries are categorised as low-income (1 SIDS, 26 non-SIDS), lower middle-income (12 SIDS, 44 non-SIDS), upper middle-income (17 SIDS, 39 non-SIDS) or high-income (8 SIDS, 62 non-SIDS), based on World Bank classification for the year 2022. For comparison with SIDS, low- and lower middle-income countries are considered as a single group, since Guinea-Bissau is the only SIDS country categorised as low-income.

As expected, loss and damage estimates are higher in SIDS than in non-SIDS countries. On average, SIDS experience higher loss and damage than non-SIDS across all income groups, in terms of both deaths and population affected (Figure 7). For instance, SIDS experience five times more climate change-attributable deaths (per million of population) than non-SIDS in low- and lower middle-income countries. This is despite the fact that the EM-DAT database has few records of loss and damage in SIDS from droughts, cold waves, wildfire or heatwaves (events that cause significant losses in non-SIDS).[12]

Average annual attributed economic losses as a percentage of GDP are significantly higher in SIDS than in non-SIDS across all income groups, especially in the low- and lower middle-income group (Figure 8). Similarly, as a percentage of government revenues, SIDS experience significantly more loss and damage due to climate change: three to five times more than non-SIDS across all income groups (Figure 9).

Figure 7 Average annual climate-attributed loss and damage (deaths and affected per million of population) in SIDS and non-SIDS from 2000 to 2022.



Note: Analysis is based on the disaster damage records of EM-DAT. Calculations exclude Cook Islands, Nauru, Niue and Singapore.

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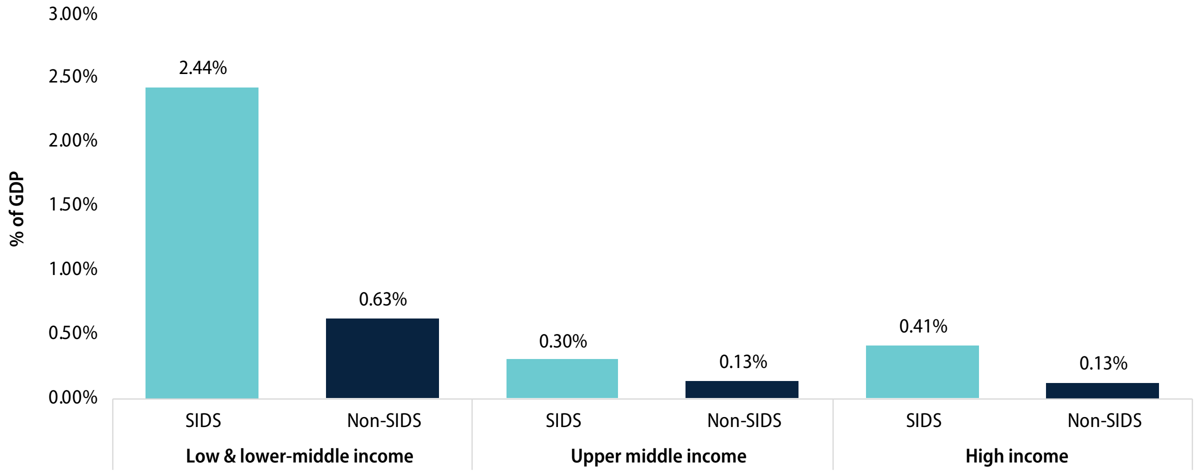
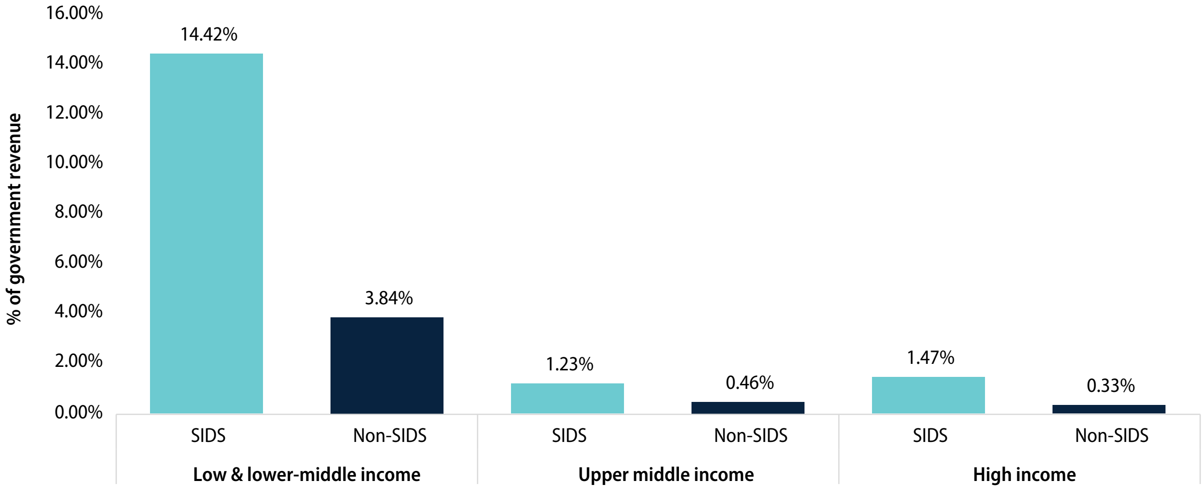
[12] EM-DAT has 33 drought events recorded for SIDS during 2000-2022, compared to 357 drought events for non-SIDS. There are no heatwave, cold wave or wildfire events recorded for SIDS, while for non-SIDS, there are 293 cold wave events, 178 heatwave events and 281 wildfire events during the same period.

Figure 8 Average annual climate-attributed economic losses (as percentage of GDP) in SIDS and non-SIDS (2000–2022)



Note: Analysis is based on the disaster damage records of EMDAT, using global average FARs. Calculations exclude Cook Islands, Nauru, Niue and Singapore. All figures are in 2020 US$.

Figure 9 Average annual climate-attributed economic losses (as percentage of government revenue) in SIDS and non-SIDS (2000–2022)



Note: Analysis is based on the disaster damage records of EMDAT, using global average FARs. Calculations exclude Cook Islands, Nauru, Niue and Singapore. All figures are in 2020 US$.

4 Discussion of indirect impacts

Direct damages caused by extreme weather events can impact economic activity through their effects on physical, human and natural capital and productivity, consequently affecting economic output. SIDS economies are hugely vulnerable to extreme weather, as they are highly specialised and rely on weather-dependent sectors such as agriculture, fisheries and tourism. However, there is only very limited information on the indirect economic impacts of extreme weather in SIDS, and studies that do exist focus mainly on tropical storms and floods and on the Caribbean region. There is very little information on the economic effects of droughts[13] in SIDS (Alexander and Thongs, 2023), or the broader economic effects of extreme weather in the other SIDS regions.

Some case studies and examples of aggregate, sectoral and fiscal effects are described below. Other studies not reviewed here focus on the effects of extreme weather in SIDS on production efficiency (Mohan et al., 2019), inflation (Heinen et al., 2019; Bensassi et al., 2017), the labour market (Mohan and Strobl, 2021b; Pecha Garzón, 2017), foreign reserves (Strobl et al., 2020), and exchange rates (Strobl and Kablan, 2017). None of these studies, however, estimate the proportion of indirect economic losses that can be attributed to climate change.

4.1 Indirect aggregate impacts

Following tropical storms and floods, SIDS face short-term contractions in economic output, as is documented for the Caribbean SIDS (Benson and Clay, 2001; Bertinelli and Strobl, 2013; Campbell and Spencer, 2021; Cashin and Sosa, 2013; Hsiang, 2010; Ishizawa et al., 2019; Rasmussen, 2004; Strobl, 2012) and the Pacific SIDS (Mohan and Strobl, 2017a; Narayan, 2003). An average hurricane in the Caribbean is estimated to reduce local-level income growth by 1.5% and country-level GDP by approximately 0.7%–0.8% in the year of the strike (Bertinelli and Strobl, 2013; Strobl, 2012). Based on the analysis of satellite measures of nightlight intensity, economic activity in the South Pacific was reduced by as much as 111% in the first few months in the islands affected by Cyclone Pam in 2015, an unusually destructive storm (Mohan and Strobl, 2017a).

An initial reduction in economic output after an extreme weather event is typically followed by an increase in economic activity. This is likely due to post-disaster reconstruction efforts, government programmes and foreign aid, which act as a standard 'Keynesian' boost to the economy (Acevedo, 2014; Campbell and Spencer, 2021; Crowards, 1999; Mohan and Strobl, 2017a). These short-term cyclical economic effects of extreme weather potentially influence SIDS business cycles more generally. In the Eastern Caribbean, the climate-induced effects on output were estimated to play a more important role in explaining short-run macroeconomic fluctuations than changes in external demand and in oil prices (Cashin and Sosa, 2013). Some studies suggest that extreme weather events may also affect medium- or long-term economic growth in SIDS (Acevedo, 2014; Kulanthaivelu, 2022).

The effects of extreme weather on individual GDP components vary in both direction and timing, which may explain some of the difficulties in identifying medium- and long-term aggregate impacts. Floods and storms are shown to depress private consumption (Mohan et al., 2018; Henry et al., 2020; Narayan, 2003). In

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[13] Droughts are the third most frequent disaster type in SIDS, after storms and floods (Gheuens et al., 2019).

Jamaica, an average hurricane leads to a decline in per capita consumption of 1.1%, but the effect materialises only in households living in buildings with low wind resistance (Henry et al., 2020). In contrast, government spending and investment increase, likely due to emergency assistance and reconstruction activities (Mohan et al., 2018; Ouattara and Strobl, 2013; Rasmussen, 2004). In the Caribbean, government spending is estimated to increase by 1.4 percentage points and investment to increase by 4.6 percentage points in the year of a hurricane strike (Mohan et al., 2018).

Extreme weather events can cause short-term negative effects on the trade balance, characterised by a reduction in exports and varied effects on imports (Crowards, 1999; Heger et al., 2008; Mohan and Strobl, 2013a, 2013b; Mohan, 2017a, 2023; Mohan et al., 2018; Narayan, 2003; Rasmussen, 2004). In the Eastern Caribbean, hurricanes are estimated to reduce exports of goods by 20% in the first four months after impact (Mohan, 2023). However, severe events can lead to wider effects. For example, Hurricanes David and Frederick in 1979 led to a decrease in banana exports from Dominica over the next three years equal to 45%, 60% and 26% of total merchandise trade (Mohan, 2017a). Impacts on imports vary, sometimes increasing (Crowards, 1999; Rasmussen, 2004), sometimes increasing and then decreasing (Mohan et al., 2018), and sometimes just decreasing (Mohan, 2023; Narayan, 2003). Even in the cases where imports decline, the fall in exports is typically larger, contributing to an overall fall in net trade (Narayan, 2003; Rasmussen, 2004). There is some evidence to suggest that the countries with more diversified exports experience relatively lower adverse impacts on their trade balance, with the less diversified economies also experiencing a surge in imports (Heger et al., 2008).

4.2 Indirect sectoral impacts

Agriculture and tourism are commonly identified as the most severely affected sectors. Short-term reductions in agricultural production and exports following hurricanes are widely documented for the Caribbean region (Benson and Clay, 2001; Campbell and Spencer, 2021; Hsiang, 2010; Mohan and Strobl, 2013a, 2013b; Mohan, 2017a, 2017b; Rasmussen, 2004). Adverse agricultural impacts appear to be more pronounced in the smaller islands and in the islands characterised by lower agricultural diversification (Mohan, 2017b; Mohan and Strobl, 2017b). The impacts are also heterogeneous across crop types, as crop types grown above ground (e.g. bananas) or sensitive to soil saturation (e.g. soil with high rate of water transmission) are relatively greater affected (Mohan, 2017b; Mohan and Strobl, 2017b; Spencer and Polachek, 2015).

The tourism sector is also very vulnerable, as identified in studies looking at short-term tourist arrivals in the Caribbean (Carballo Chanfón et al., 2023; Granvorka and Strobl, 2013) and in the Pacific SIDS (Saverimuttu and Varua, 2016, 2017). Hsiang (2010) suggests that hurricane-induced reductions in tourism income are mainly driven by reduced numbers of tourists rather than reduced income per visit. In the Caribbean, Carballo Chanfón et al. (2023) observe an immediate post-hurricane decline in tourist arrivals on both cruise ships and aeroplanes, with the cruise ship arrivals being roughly four times more affected and exhibiting a much slower recovery. In Vanuatu, cyclones have a negative impact on tourist arrivals lasting up to two quarters following a cyclone (Saverimuttu and Varua, 2016).

The agriculture and tourism sectors in SIDS suffer the largest impacts following extreme weather events, but many other sectors – including wholesale, retail, communication and mining –

can also be adversely affected (Hsiang, 2010; Saverimuttu and Varua, 2017). In the financial sector, specifically banking, negative shocks to both assets and liabilities often occur following hurricanes. In the Eastern Caribbean, hurricanes lead to an increase in deposit withdrawals – to which banks respond by reducing the supply of credit and selling liquid assets – and an increase in overall bank risk (Brei et al., 2019).

Positive impacts of extreme weather were detected in the construction sector in the Pacific (Mohan and Strobl, 2017a) and in the Caribbean (Campbell and Spencer, 2021; Hsiang, 2010), as a direct consequence of post-disaster reconstruction activities.

4.3 Fiscal impacts and debt

Extreme weather events can lead to significant fiscal impacts in SIDS – on fiscal revenue, fiscal expenditure and public debt. Hurricanes in the Caribbean lead to an increase in spending and a decrease in revenue, consequently contributing to larger fiscal deficits (Heger et al., 2008; King, 2014; Ouattara et al., 2018; Rasmussen, 2004). Current expenditure increases, while capital expenditures do not appear to be affected (Ouattara et al., 2018); and while revenue from income decreases, revenue from sales of goods and services and from tariffs increases (Ouattara et al., 2018; Mohan and Strobl, 2021c).

Given these effects on fiscal balances, and the need to finance reconstruction, SIDS resort to domestic and foreign borrowing, which leads to increasing public debt (Cavallo et al., 2023). In the Caribbean region, there is some evidence to support both an immediate increase (Lugay and Ronald, 2014; Mohan and Strobl, 2021a) and a longer-lasting increase (Acevedo, 2014; Rasmussen, 2004) in debt following extreme weather events. Lugay and Ronald (2014) find that an extreme weather event causing damage of 2% of GDP in the Eastern Caribbean is associated with an increase in debt-to-GDP ratio of 6.7%.

5 Future impacts of climate change in SIDS

This section presents estimates of future impacts of extreme weather events, based on projections in the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (IPCC, 2021). These projections typically show what are currently 20-year, 50-year or 100-year events becoming more frequent as the global temperature rises.

Following the guidance from the IPCC (2021), two scenarios of warming by the year 2050 are considered: 1.5°C and 2.0°C above pre-industrial levels. There is expected to be a 10% increase in what are currently 20-year flood events under a 1.5°C warming scenario, and a 22% increase under a 2.0°C warming scenario (IPCC, 2021, p. 1564). Tropical storms are expected to increase by 13% under a 2.0°C increase[14] in global temperature (IPCC, 2021, p. 1590). The report does not provide a projection for storms under a 1.5°C warming scenario. However, based on the 2.0°C warming estimate, a 6% increase in storm frequency could be assumed.

This study estimates projected climate-attributable loss and damage for floods and storms only. As discussed earlier (see Section 3.1), droughts are not included in this analysis because of a lesser number of events and associated economic loss data. Nevertheless, it is important to highlight that the IPCC recently concluded, with high confidence, that even with small increases in average global temperature, some regions will see an increase in drought frequency, and that this will be greater if the temperature increases are larger (IPCC, 2021, p. 1583).

Based on the suggested projections from the IPCC (2021), a new FAR value (see Table 3) is calculated for floods and storms, assuming 2050 as the year when the projected increase will be reached. For instance, compared with the average FAR for floods from 2000 to 2022, the FAR will increase by 10% by the year 2050 under a 1.5°C warming scenario.[15] The projected increase in FAR is linearly extrapolated between 2023 and 2050 to obtain yearly FARs. The average annual total economic

Table 3 Average yearly (2000–2022) and projected FAR values for floods and storms by 2050

Event type	Average regional FAR (2000–2022)	Projected FAR by 2050 using IPCC (2021) guidance
Floods		
1.5°C warming scenario	30%	36.4% (10% increase)
2.0°C warming scenario		43% (22% increase)
Storms		
1.5°C warming scenario	43%	46% (6% increase)
2.0°C warming scenario		50% (13% increase)

Note: Regional average FARs for Americas and Oceania are used to approximate FARs for SIDS

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[14] According to the IPCC (2021, page 1590), 'For a 2°C global warming, the median proportion of Category 4–5 TCs increases by 13%, while the median global TC frequency decreases by 14%, which implies that the median of the global Category 4–5 TC frequency is slightly reduced by 1% or almost unchanged'.

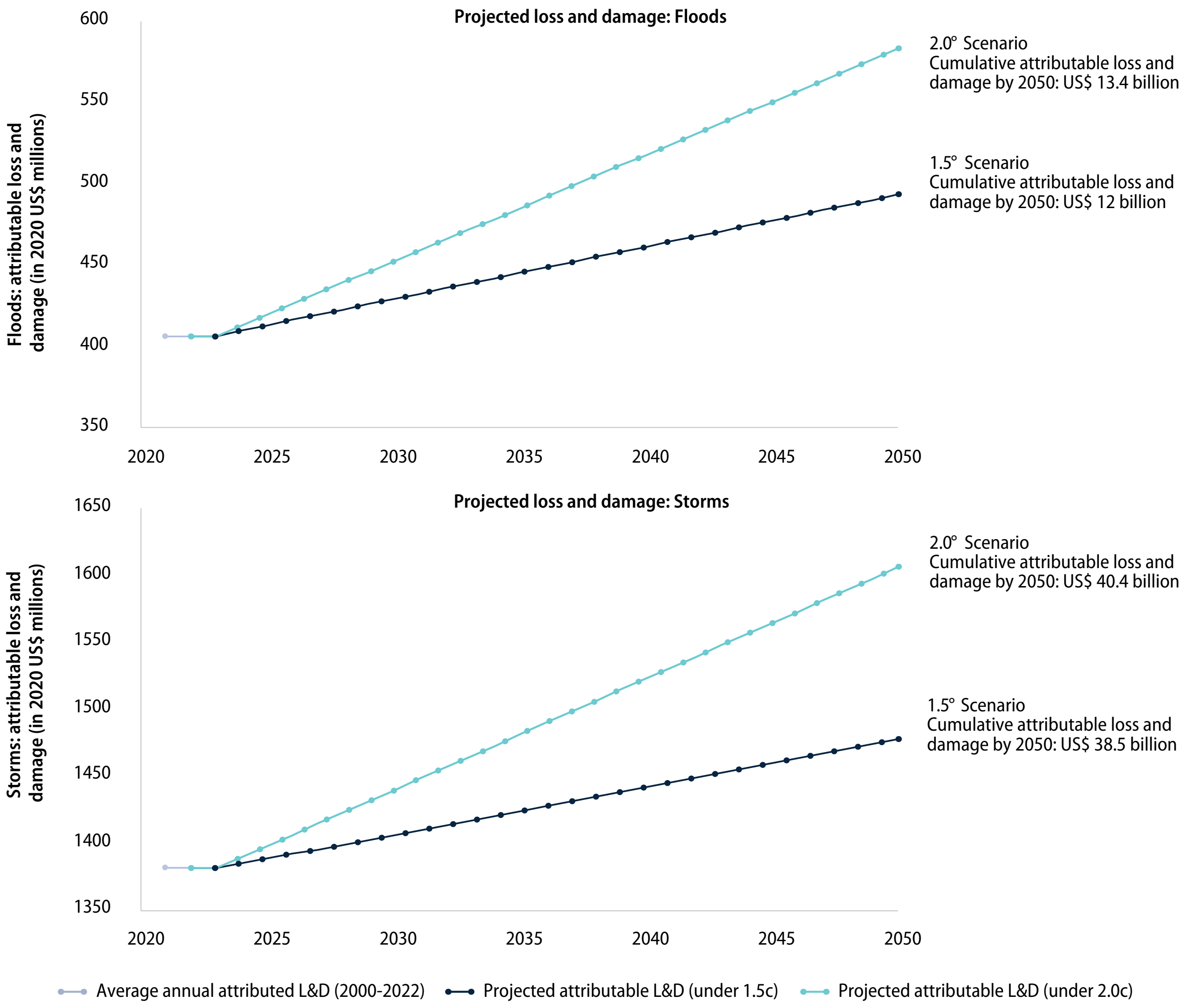
[15] In case of floods, for example, average FAR for floods is 30% during 2000-2022 (using regional averages), and the change by 2050 is 10% higher, then the new FAR is 1-(0.7*(1/1.1)) or 36%.

loss (damages and SLOL)[16] from 2000 to 2022, projected climate-attributable loss and damage for floods and storms is estimated.

As shown in Figure 10, under a 1.5°C warming scenario, floods could cause cumulative climate-attributable loss and damage of $12 billion by 2050. The projected loss and damage could be $13.4 billion under a 2°C warming scenario. Storms, on the other hand, are projected to inflict significantly higher losses of $38.5 billion and $40.4 billion under 1.5°C and 2.0°C warming scenarios, respectively.

Collectively, floods and storms are projected to cause cumulative climate-attributable loss and damage of $56 billion in SIDS under a 2°C warming scenario by 2050. This would represent 11% higher average annual attributed loss and damage over the next 23 years (2023–2045) than over the past 23 years (2000–2022).

Figure 10 Projected climate-attributable loss and damage from floods and storms by 2050



Projected loss and damage: Floods

2.0° Scenario
Cumulative attributable loss and damage by 2050: US$ 13.4 billion

1.5° Scenario
Cumulative attributable loss and damage by 2050: US$ 12 billion

Projected loss and damage: Storms

2.0° Scenario
Cumulative attributable loss and damage by 2050: US$ 40.4 billion

1.5° Scenario
Cumulative attributable loss and damage by 2050: US$ 38.5 billion

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[16] The average annual total economic loss for floods and storms in SIDS was US$ 1.4 billion and US$ 3.2 billion, respectively.

Notably, the projected climate-attributable loss and damage could still be an underestimation of the potential loss and damage that may occur in SIDS, for three main reasons: (i) limitations to data and methods (see Appendix 1); (ii) using only direct damage and loss estimates excluding indirect economic impacts of extreme weather events, which are likely to further inflate these estimates; and (iii) not including possible impacts of slow-onset events (particularly sea-level rise), which are likely to exacerbate loss and damage in SIDS (see IPCC, 2022).

6 Conclusions and policy recommendations

Climate change will threaten the viability of many SIDS. This has been clear for decades, as His Excellency Maumoon Abdul Gayoom, President of the Republic of Maldives, outlined in his 'Death of a Nation' speech in 1987. Recognition of these impacts has been key to the moral case made by SIDS for ramping up mitigation efforts to keep global warming below 1.5°C. This threshold looks set to be breached sooner than even the most pessimistic assessments predicted, and the limits to adaptation are becoming increasingly pronounced, precipitating the need for loss and damage finance. But better calculations of loss and damage, both past and present, are needed in order to mobilise adequate and timely finance, so measures can be taken to avoid welfare losses and support recovery, and to compensate those affected. This paper contributes to these efforts.

This analysis produces only preliminary estimates of loss and damage attributable to climate change. The focus is on extreme weather events as a first step. These have always been a way of life for SIDS; it is the frequency and intensity of these events that will change with the climate. It is also recognised that such events will have direct and indirect impacts, the former of which are easier to measure than the latter. This study has therefore focused on direct impacts in the first instance, while also outlining how indirect impacts can be analysed.

The loss and damage from extreme weather events attributable to climate change in SIDS is significant: from 2000 to 2022, a total of 10,113 deaths associated with climate-related events were recorded in SIDS, of which anthropogenic climate change was responsible for 38%. Annual economic losses of $1.7 billion can be attributed to climate change, representing 0.8% of the collective GDP of SIDS every year. For small, undiversified SIDS economies, this is extremely significant. On average, SIDS suffer higher levels of loss and damage than non-SIDS across all income groups, and these impacts are set to rise in the future, with annual climate-attributable loss and damage estimated to increase by 11% over the next 23 years.

What is clear is that covering these losses through domestic revenues would jeopardise the ability of SIDS governments to deliver basic services and welfare programmes, and hamper development progress. It would also precipitate a cycle in which already indebted SIDS governments have to take on more debt to recover from crisis, which in turn undermines their capacity to respond when the next crisis arises. This suggests that, if appropriate and timely steps are not taken, the economic consequences of climate change will render some SIDS unviable well before their islands sink beneath the sea or biodiversity is lost to coastal erosion and coral reef bleaching.

The primary implication for policymakers is that they urgently need to turn attention to the methodological task of calculation. This work is related to, and builds on, discussions about using the United Nations Multidimensional Vulnerability Index (MVI) to allocate development finance. The MVI identifies existing vulnerabilities facing SIDS including environmental ones (see Wilkinson et al., 2023), but support measures will need to look forward, based on assessments of how climate change overlays, and exacerbates, these vulnerabilities. This study constitutes the first stone, not the last word. Based on the analysis, this study puts forward three recommendations for loss and damage negotiators ahead of COP28 and beyond:

1. Focus on the 2°C+ scenario, as it is now very likely that 1.5°C projections will be breached, and loss and damage increases markedly with the additional 0.5°C of warming.
2. Better articulate the difference between direct and indirect costs. The former is easier to measure but represents only a portion of the total costs.
3. Address data gaps as a matter of urgency. SIDS have long suffered from this problem, but the costs of inaction have been hidden; now they are clear to see.

The first two recommendations are easier to implement than the third, which will require significant investment in regional statistical agencies. But the combination is crucial if the Loss and Damage Fund and related mechanism negotiated at COP27 are to have their intended impact.

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Appendix 1 Methodology and data

a Extreme event attribution (EEA)

The EEA methodology was first conceptualised by Allen (2003); it aimed to compare the modelled probability and intensity of an event that has already occurred, with and without anthropogenic emissions. EEA was first implemented by Stott et al. (2004) to estimate the attribution of the 2003 continental European heatwave to climate change.

A probabilistic metric – the fraction of attributable risk (FAR) – is calculated in EEA analysis to describe what portion of risk of an event that has occurred is a result of anthropogenic GHG emissions. This is known as the 'risk-based' approach to attribution (Otto, 2017). In this approach, the weather is simulated under current and counterfactual climate (without GHG emissions) to estimate the degree to which climate change has altered the risk of occurrence of an event. An alternative to this is an 'intensity-based' approach where the share of a specific dimension of the risk (e.g. rainfall) due to climate change is calculated. For example, Frame et al. (2020) use a risk-based approach, while Smiley et al. (2022) use an intensity-based approach, where both estimate the economic costs from Hurricane Harvey in 2017.

When risk of a climate event is increased due to anthropogenic GHG emissions ($P_1 > P_0$), the FAR value is calculated using the following formula, and will lie between 0 and 1:

$$FAR = 1 - \frac{P_0}{P_1}$$

P_0 = *Probability of a climatic event without anthropogenic GHG present*

P_1 = *Probability of an event occurring within current climate system (with anthropogenic GHG)*

Here, a FAR value of 1 means that the event would not have been possible without anthropogenic climate change, whereas a FAR value of 0 would mean that climate change had no influence on the probability of occurrence of that event (Jézéquel et al., 2018; Newman and Noy, 2023). In cases where the likelihood of an event decreases because of climate change (i.e. $P_1 < P_0$), the FAR value will be negative. Very few events in our dataset have a negative FAR value (almost all extreme cold temperature events have FAR<0).

As in Newman and Noy (2023), FARs for individual events can be extrapolated to a national, regional or global scale, and can be used in conjunction with socioeconomic costs of extreme events to estimate climate change-attributed loss and damage. This is important since it is not possible to obtain FAR scores for each extreme event given the paucity of FAR studies, especially for SIDS. Therefore, extrapolation of FARs for individual event types and regions is needed, based on explicit assumptions of aggregation and generalisability.

b Data collection and description

This study uses two major data sources: (i) attribution studies to extract FAR estimates, and (ii) the EM-DAT database (CRED, 2023) to collect socioeconomic cost data for climate events in 37 out of the 39 UN designated SIDS, excluding Nauru and Singapore. Additional data on macroeconomic indicators such as GDP and population is collected from the World Development Indicators (World Bank, 2023).

For the reference period of the past 23 years (2000–2022), the FARs are extracted from existing attribution studies conducted globally and listed in the Carbon Brief attribution database (CarbonBrief, 2023). Newman and Noy (2023) have compiled a global dataset of FARs from attribution studies for specific events, matched with socioeconomic cost data for the same events from the EM-DAT database over the period 2000–2019. The present study further extends this master dataset to include newer attribution studies conducted up until 2022. This study makes a specific effort to extend the analysis to all data available for SIDS, by matching the socioeconomic cost data from EM-DAT to additional events entered into the dataset after 2019.

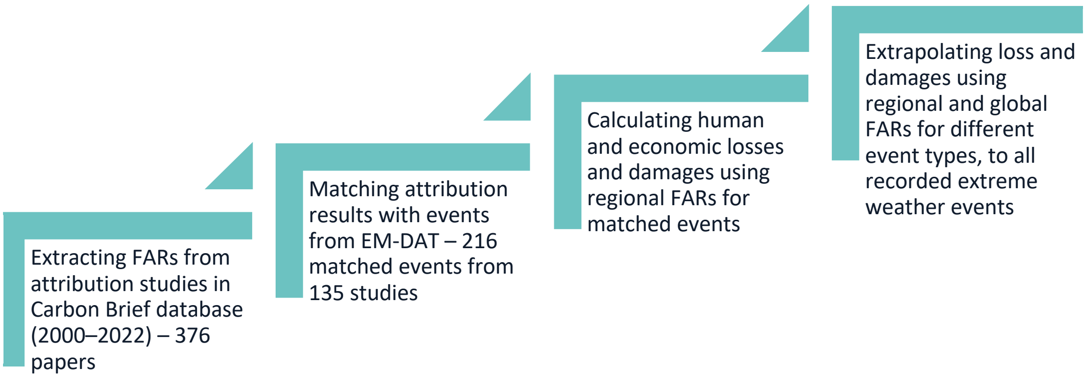
Figure A1 presents the hierarchical criteria applied by Newman and Noy (2023) in choosing the sample of climate extreme events to determine FARs, and then in extrapolating human and economic cost estimates from the EM-DAT database in conjunction with FARs for matched events. In cases where more than one study was available for a specific event, the attribution study with 'better' research quality[17] is used. Using temporal and geographical criteria, FAR measurements are then matched with events recorded in the EM-DAT database.

The master dataset includes 216 matched climate events that occurred during the period 2000–2022, including five matched events from SIDS. The matched events cover 56 countries, including four SIDS (Bahamas, Dominican Republic, Haiti and Papua New Guinea). Matched events are mapped from 135 attribution studies, as many of the studies (e.g. regional studies) covered multiple events. Unsurprisingly, 81% of the matched events occurred after 2013, owing to the increased frequency of EEA studies in recent years (Figure A2).

As shown in Figure A3, flood and heatwave had the largest share, each accounting for 34% of the attribution results, followed by drought (13%), storm (7%), wildfire (7%) and cold wave (5%). Attribution results were fairly distributed across continents, except for Africa which has only 9% of the related results.

The distribution of FAR results per continent, by event type, is presented in Figure A4. Out of the 216 matched events, 183 are associated with increased risk (FAR>0), while 25 events are associated with decreased risk of occurrence (FAR<0). The risk of eight events remains unchanged (FAR=0).[18]

Figure A1 Methodological process used in extracting FARs and extrapolating loss and damage



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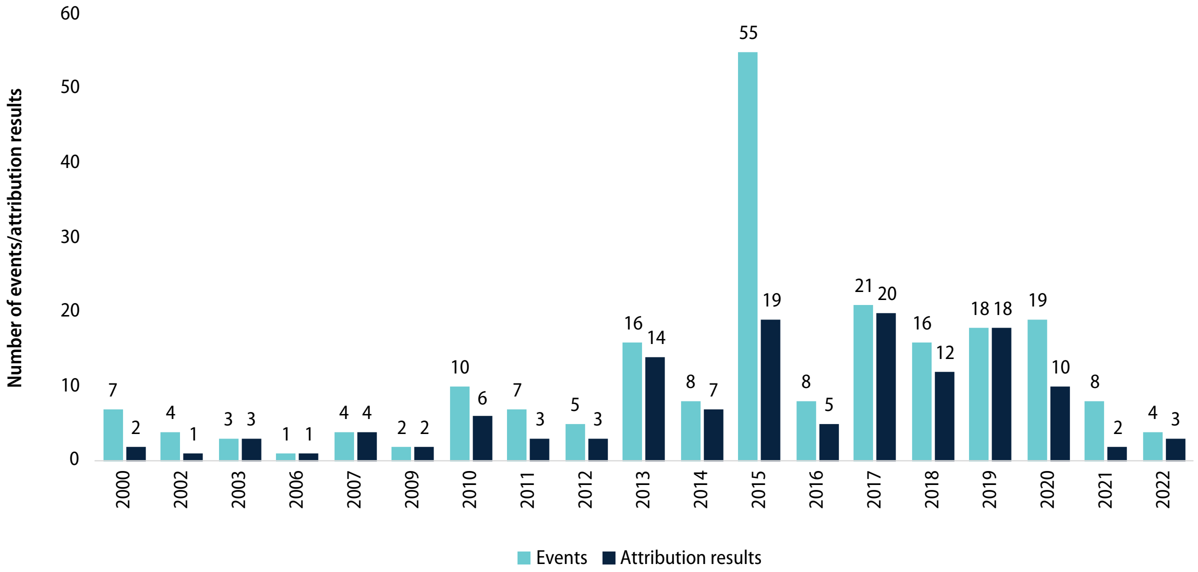
[17] To avoid any subjective judgement, Newman and Noy (2023) use Scimago Journal Rank (SJR) to determine research quality, where an FAR measurement is considered preferable if it comes from a higher SJR publication. For non-refereed studies (e.g. from the World Weather Attribution network), an average of SJR for all studies is used as proxy.

[18] FAR value between 0 and -0.1 is considered as unchanged risk.

Figure A2 Annual distribution of matched attribution results and number of events



Source: Updated from Newman and Noy (2023)

Figure A3 Distribution of matched attribution results by event type and continent

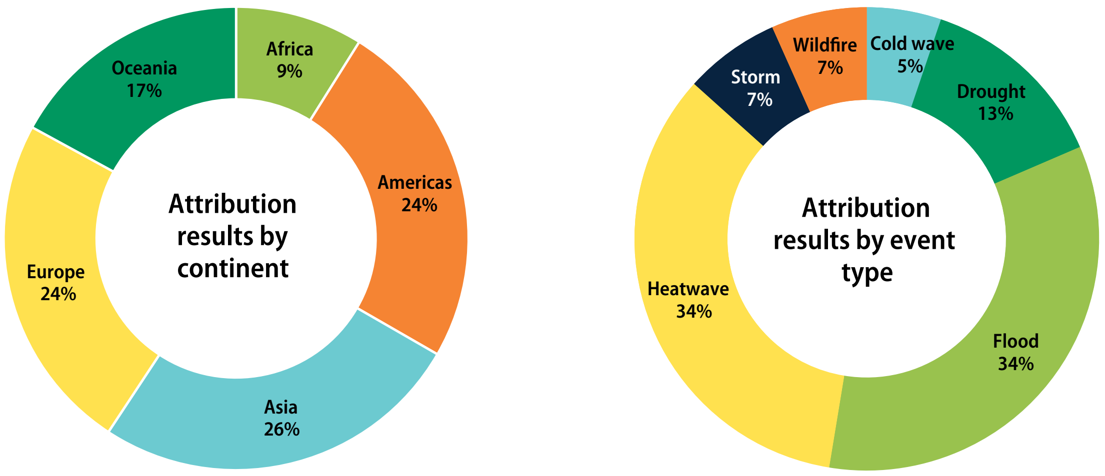
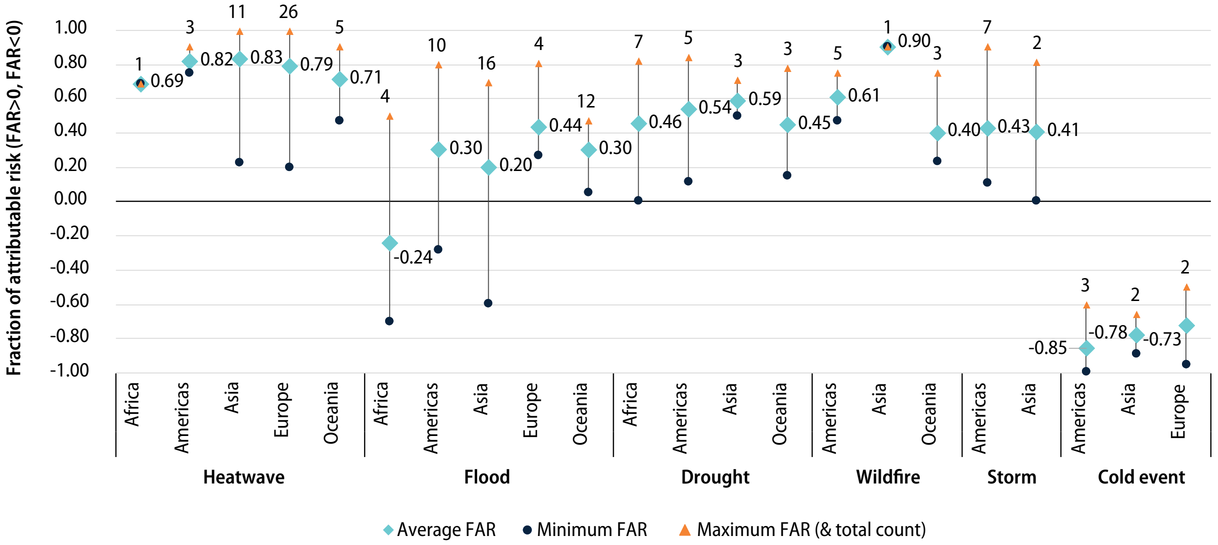


Figure A4 Distribution of FARs (minimum, maximum and mean) across matched events, by event type and continent



Source: Updated from Newman and Noy (2023)

Considering the global average of FARs, 50% of the risk of droughts is due to anthropogenic climate change. The average FAR for floods is rather lower at 23%, largely because floods have a wider range of FAR estimates – covering both positive and negative values. Storms have an average FAR of 42%, heatwaves 79%, and wildfires 57%. Cold waves carry a negative FAR of 79%, signifying a substantially decreasing risk due to climate change.

It is important to note that, for many combinations of continent and event type, there are very few or no attribution results, especially for SIDS. For instance, merely 2% of the results are from studies (three studies) conducted on events occurring in SIDS. Further, attribution results for SIDS are available only for flood, storm and drought events, with no identified attribution study for other disaster types such as heatwave and wildfire. Therefore, regional and global averages of FARs for different event types are used for SIDS.

There are a total of 7,403 events recorded in the EM-DAT database for the period 2000–2022. Out of these, 5,812 events have human and/or economic cost data recorded. For SIDS, 354 events (out of 434 total events – 82%) in the period 2000–2022 have human and/or economic cost recorded in the EM-DAT database.

c Measuring loss and damage from extreme weather events

Climate change-attributable loss and damage caused by these events is quantified by combining the data on direct economic costs with the attributable share of the risk of these events (i.e. the FARs). As in Newman and Noy (2023), the following formula is used to calculate climate-attributed loss and damage for an event i in the master dataset:

$$CC\_loss\ \&\ damage_i = FAR_i * socio\_economic\ cost_i$$

The FARs for loss and damage calculations in SIDS are extrapolated using both regional (continental) and global average methods. For instance, event-specific FARs for SIDS are based on average extrapolation for the Americas and Oceania, because 29 of the 38 UN member SIDS are from these two regions. As discussed in the previous section, in cases where no or a very low number of attribution studies are available, the global average of FARs for such an event type are used. Finally, spatial, temporal and per event (disaster type) loss and damage are estimated for SIDS, based on the data records in EM-DAT over the selected period.

As in Newman and Noy (2023), value of statistical life (VSL) calculations are used to assess the economic cost of human mortality. The study uses a VSL of $7.0837 million per life lost, which is an average of VSL estimates used by governments in the United States ($11.6 million) and the United Kingdom (£2 million). The same VSL value is used for all SIDS and all other countries, regardless of time and place of death, to maintain equity and enable comparison. By multiplying VSL estimates with total attributed deaths, attributed statistical loss of life (SLOL) is calculated. The attributed loss and damage, therefore, is a sum of attributed SLOL and economic damages.

d Limitations to data and methodology

EEA is a relatively new and evolving sub-field of climate science, and its use in impact attribution is even newer. As noted by Newman and Noy (2023), there is a notable range of limitations related to equitable distribution of attribution studies, and quality and quantity of data available for cost estimation. Some of these limitations are discussed below.

Overall, the limited number of attribution studies conducted are not equitably distributed across the world. Most of the attribution studies are conducted in high income countries and in China, with very few studies from lower income countries. Out of the 135 attribution studies selected for this study, over half of them are from North America and Europe, while only 9% are from Africa.[19] This imbalance in distribution of studies has resulted in loss of heterogeneity in estimates, and a reliance on regional averages for extrapolation of FARs for SIDS. Improved geographical coverage of attribution studies, and especially more attribution studies on extreme weather events in SIDS, would increase the robustness of the attribution estimates and consequently the estimated climate-attributed loss and damage (the ‘impact attribution’ studies).

A similar limitation is the uneven spread of attribution studies for different types of natural hazard. Heatwave and flood each have 34% of the total attribution results, out of the 135 attribution studies. In contrast, storm has only 7% of results associated with it, despite being one of the costliest event types. Newman and Noy (2023) note that the main reason for this discrepancy could be the difficulty in attribution of storm (and drought) compared with, for example, heatwave which has direct thermodynamic effects and relatively straightforward attribution (see also Noy et al., 2023).

Furthermore, unclear spatial and temporal boundaries of the events being analysed sometimes made it difficult to match FAR estimates with socioeconomic cost data. For example, in the present study there were a few attribution results where the ‘start’ and ‘end’ date of an event were not clearly defined and were thus difficult to match with EM-DAT data records.

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[19] However, there are some recent attempts, particularly by the World Weather Attribution (WWA) network, to balance this out. WWA attribution studies can be accessed here.

The framing of an event attribution study can also introduce differences in FAR estimates. Although recent analysis of results from EEA studies that have used different framings indicated that only relatively minor differences in results may arise due to these framing differences (Stone et al., 2022).

Beyond the EEA methodology and attribution data, there are also many limitations to the socioeconomic cost data from EM-DAT used in this study. When comparing EM-DAT with the alternative DesInventar dataset, Panwar and Sen (2020) discuss the limitations of EM-DAT in terms of its quality (missing observations and validity), geographical coverage and granularity.[20] Further, EM-DAT, by virtue of its event inclusion criteria,[21] includes only 'intensive' events and leaves out many 'extensive' events (low impact but frequently recurring events). Such events may not be significant individually but when aggregated over time could account for significant economic cost (see Appendix 3).

It is also important to reiterate that EM-DAT provides estimation of the direct cost (human deaths, people affected and economic losses) of disasters, and not the indirect macroeconomic and fiscal impacts and non-economic losses (e.g. biodiversity loss, loss of culture). Information on these dimensions is vital for policymakers to fully understand climate change-attributed losses and damages and their wider social and economic impacts.

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[20] Noy (2016) compares the EM-DAT and DesInventar records for the Pacific SIDS.

[21] EM-DAT records human and economic losses on the basis of at least one of the following criteria: (i) 10 fatalities, (ii) 100 people affected, (iii) a declaration of state of emergency, and (iv) a call for international assistance.

Appendix 2 Comparison of regional and global FAR averages for SIDS

Table A1 presents a comparison of attributed loss and damage for SIDS based on regional (Americas and Oceania) average FARs with those based on global average FARs. On an aggregate level, differences between the estimates obtained by these two methods are not significant. However, for the present analysis, the regional average method does produce 30% higher attributed costs for floods in SIDS.

Table A1 Climate-attributed loss and damage, using regional and global averages for FARs

Disaster type	Type of losses and damages	Regional average FAR extrapolation	Global average FAR extrapolation	Regional – Global FAR extrapolation ratio
Flood	Deaths	1,255	962	130%
	Affected	1,768,523	1,355,867	130%
	$7.0837m SLOL	8,889	6,815	130%
	Damage	457	350	130%
	Total L&D	9,346	7,166	130%
Drought	Deaths	12	12	98%
	Affected	3,904,274	3,988,334	98%
	$7.0837m SLOL	83	85	98%
	Damage	95	97	98%
	Total L&D	179	182	98%
Storm	Deaths	2,540	2,481	102%
	Affected	14,092,453	13,764,722	102%
	$7.0837m SLOL	17,990	17,571	102%
	Damage	13,778	13,458	102%
	Total L&D	31,768	31,029	102%

Note: Analysis includes 37 UN Member SIDS, excluding Singapore and Nauru. Total L&D includes damage estimates from EM-DAT and SLOL calculated at $7.0837 million per life lost.

Appendix 3 Additional data on loss and damage in SIDS from DesInventar database

The DesInventar database is the official database for the Sendai Framework for Disaster Risk Reduction, for monitoring progress on implementation. There are many extensive events (low intensity, high frequency) globally that are not captured in EM-DAT because of its event inclusion criteria. This is also true for SIDS. The additional data on loss and damage has been extracted by matching individual events from both the datasets using event type, name, date and year. Using global average FARs for floods and storms, Table A2 summarises additional data on deaths, people affected and economic damages that is not included in EM-DAT for SIDS from 2000 to 2022.

Table A2 Additional data from DesInventar on loss and damage (L&D) for SIDS, not included in EM-DAT for 2000–2022

Year	**Deaths**		**Affected**		**Total L&D (damages + $7.0837m SLOL) $m**	
	Total	**Attributed**	**Total**	**Attributed**	**Total**	**Attributed**
2000	5	2	160,200	61,698	57.44	20.05
2001			62,480	26,150	6.38	2.67
2002	8	2	11,500	4,830	297.42	111.36
2003	2	0	40,000	14,900	21.18	5.11
2004	13	5	13,200	3,796	127.03	49.64
2005	2	0	1,600	672	114.06	29.46
2006	4	2	784	329	37.21	15.63
2007	80	32	40,138	9,258	795.61	301.45
2008	1	0	4,978	1,901	8.52	1.96
2009	18	5	130,821	40,201	171.92	45.84
2010	1	0	11,321	4,755	91.54	38.43
2011	1	0	38,056	14,833	31.15	7.59
2012	1	0	61,581	14,164	7.99	3.35
2013			43,626	10,034	0.00	0.00
2014	4	1	2,300	966	30.98	10.07
2015					0.00	0.00
2016	2	1	137,185	57,618	15.29	4.97
2017	2	1	10,000	4,200	14.96	6.28
2018	2	1	89,250	37,485	14.60	6.13
2019	2	1			14.34	6.02
2020	2	0	3,000	1,260	14.31	3.29
2021						
2022						
Total	**150**	**54**	**862,020**	**309,049**	**1,872**	**669**

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