Policy brief

The price of a changing climate: extreme weather and economic loss and damage in SIDS

Vikrant Panwar, Emily Wilkinson and Ilan Noy

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Key messages

- The impacts of extreme weather events on economic growth and fiscal balances are harder to estimate than the direct, more visible impacts on people and assets. But in Small Island Developing States (SIDS), this indirect loss and damage is significant.
- From 2000 to 2022, indirect economic loss and damage in SIDS may have reached $107 billion, of which $39 billion (36%) can be attributed to climate change.
- The combined direct and indirect impacts in SIDS that we can measure may have totalled $141 billion, with 38% attributable to climate change.
- By 2050, this cumulative attributable loss and damage in SIDS alone could reach $71.6 billion under a 1.5°C climate change scenario and $75.2 billion under 2°C.
- The Fund for Responding to Loss and Damage should develop a budget support mechanism to help governments of SIDS and other vulnerable countries address the increasingly severe impacts of extreme weather on their economies.
- An increase in concessional finance will also be needed, particularly for severe weather events, to support rapid recovery in key sectors. This can help reduce the indirect impacts on economic output.

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Acronyms

AIS	Atlantic, Indian Ocean and South China Sea
EEA	extreme event attribution
FAR	fraction of attributable risk
FRLD	Fund for Responding to Loss and Damage
GDP	gross domestic product
GHG	greenhouse gas
IELD	indirect economic loss and damage
LIC	low-income country
LMIC	lower-middle-income country
SIDS	Small Island Developing States
VSL	value of statistical life

1 Introduction

Only $700 million has been pledged to the new Fund for Responding to Loss and Damage (FRLD), while some estimates put total needs at $671 billion annually by 2030 (Richards et al., 2023). The FRLD Board will hold its first formal discussion on the operating model at the next board meeting in December 2024, with the aim of agreeing by April 2025 what the FRLD will support and how. Consideration will certainly be paid to supporting governments struggling to respond to the immediate economic loss and damage from extreme weather events – such as loss of income and damage to infrastructure and property – but the indirect effects[1] could easily be ignored or underestimated, as they are not well understood.

Because the economies of Small Island Developing States (SIDS) are small, undiversified, heavily reliant on imports and highly exposed to climate shocks – most being located in the tropics and having very fragile ecosystems – they experience disproportionally high levels of loss and damage from extreme weather in relation to their gross domestic product (GDP). Moreover, a significant proportion of these losses can be directly attributed to climate change using extreme event attribution (EEA) studies, which estimate the degree to which anthropogenic greenhouse gas (GHG) emissions have changed the likelihood of specific extreme weather events, and from which the fraction of attributable risk (FAR) can be calculated.

A 2023 ODI study into direct loss and damage from extreme weather events in SIDS (Panwar et al., 2023) found that the cumulative direct economic losses from 2000 to 2022 totalled $42 billion, of which $18 billion can be attributed to climate change. Annually, this represents 0.8% of the collective GDP of SIDS. However, beyond these immediate impacts – which were relatively easy to estimate based on recorded disaster data – there are also indirect, or longer-term, economic effects of floods, tropical cyclones/hurricanes and drought in SIDS, which are less understood, let alone attributed to climate change.

These ‘growth’ and ‘fiscal’ impacts are the focus of this policy brief; they are drawn from additional analysis conducted in 2024 for 35 out of the 39 UN member SIDS across the Caribbean, Pacific and Atlantic, Indian Ocean and South China Sea (AIS) regions (Table 1). To estimate climate-attributable indirect economic loss and damage (IELD) from extreme weather events in SIDS, this analysis draws information from two sources: (i) a meta-analysis of existing empirical literature on indirect economic and fiscal impacts of extreme weather events, and (ii) EEA studies (see Frame et al., 2020b; Panwar et al., 2023; and Newman et al., 2023). Further information on the data and methods is provided in Annex 1 and in Panwar et al. (2024).

1 Indirect effects refer to the secondary impacts that arise from a disruption in the flow of goods and services, that continue to occur until the destroyed assets are rebuilt. They can be experienced in the form of both economic and non-economic loss and damage.

There are significant implications for the FRLD and other funding arrangements being drawn up to help vulnerable countries address climate-related loss and damage.

Table 1 List of 39 UN member SIDS, classified by their geography and income levels (World Bank 2023 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 • Vanuatu	• Fiji • Marshall Islands • Niue • Palau • Tonga • Tuvalu	• Nauru • Cook Islands
Atlantic, Indian Ocean and South China Sea SIDS	• Guinea-Bissau	• Cabo Verde • Comoros • Sao Tome and Principe	• Maldives • Mauritius	• Seychelles • Singapore

2 A meta-analysis of indirect economic losses

This policy brief is based on a meta-analysis of research into the macro-fiscal impacts of extreme weather events (see Annex 1). A summary of the findings from the meta-analysis is presented below.

2.1 Indirect macro-fiscal impact of extreme weather events

Calculating the indirect economic impacts of extreme weather events is a complex task. Generally, three kinds of approaches have been used to estimate the various economic impacts of extreme weather events:

- Applying econometric methods and tools to observed data from past events, to identify the statistical relationships that typically govern the post-disaster economy.
- Building a theoretical model to approximate the functioning of an economy and how a 'shock' would lead to damage (typically the destruction of infrastructure).
- Looking at the statistical relationships between inputs and outputs in an economy in 'normal' times to estimate the likely result of the destruction of some inputs due to a shock.

The second two approaches generally assume that the way the economy functions in 'normal' times does not dramatically change after a disaster – an assumption that may be questioned in the aftermath of a catastrophic event.

Since 2000, a number of studies have looked at the indirect impacts of climate and disaster shocks on GDP and GDP growth, as well as on fiscal spending and tax revenue (see for example Skidmore and Toya, 2007; Raschky, 2008; Mechler, 2009; Noy, 2009; Noy and duPont, 2018; Panwar and Sen, 2019; and Botzen et al., 2019). A few observations can be drawn from these studies:

- Disasters linked to droughts, tropical cyclones and floods have identifiable adverse effects on economic growth (usually measured as GDP per capita growth) and other macro-fiscal indicators (e.g. agricultural value added, industrial value added, public debt and spending), particularly in low-income countries.

- Some extreme weather events of 'moderate'[2] intensity can have a positive impact on growth. This is particularly true for moderate floods, which can increase agricultural productivity, leading to a favourable impact on overall economic activity. In some cases, post-disaster recovery and reconstruction investments and the accompanying fiscal expansion can also stimulate economic growth.
- Severe disasters almost always have a negative impact on economic growth and macro-fiscal indicators.
- Long-term consequences of disasters (including those linked to slow-onset events) remain unclear, and may only be observable locally.

2.2 Growth impacts of extreme weather events

Extreme weather events have an average negative effect on GDP per capita growth in developing countries (defined here as low- and lower-middle-income countries according to the World Bank's current classification). As shown in Table 2, for example, a typical (moderate) flood could reduce GDP growth by 0.37 percentage points. A typical tropical cyclone or hurricane, on the other hand, can reduce GDP growth by 1.4 percentage points. In some cases, floods can also have a 'positive' impact on GDP growth, because of their favourable impact on agriculture and post-disaster reconstruction activities (Loayza et al., 2012; Fomby et al., 2013; Campbell and Spencer, 2021). As expected, the average effects of severe floods and tropical cyclones on growth are several times higher than for moderate ones.

For SIDS specifically, the average effect of severe storms on growth is significantly higher than for developing countries overall. Storms are by far the most destructive extreme weather events in SIDS (Panwar et al., 2023), resulting in nearly $32 billion in direct economic damages from 2000 to 2022 (more than 95% of the total economic damages). The impact of floods on GDP growth in SIDS is low, however, compared with other developing countries. The collective impact of all extreme events is also significantly higher for SIDS than for developing countries overall.

As mentioned above, flood events of moderate intensity can also have a positive impact on agricultural growth (an average of 0.4 percentage points), due to their favourable impacts on agricultural productivity (see Loayza et al., 2012; Panwar and Sen, 2019). Similarly, a moderate-intensity flood can increase non-agricultural growth (including industrial, manufacturing and services growth), largely due to post-disaster reconstruction activities (Campbell and Spencer, 2021). This is also similar for moderate-intensity cyclones, which can increase non-agricultural growth by an average of 0.22 percentage points.

2 Moderate-intensity disasters cause significant damage but are typically localised and are manageable by local or regional authorities, for example medium-scale floods or storm surges. Their impact is notable but does not require extensive government financing and external aid. Severe-intensity disasters, on the other hand, result in widespread destruction, overwhelming local capacities and requiring national or international assistance, for example large earthquakes, tsunamis or major hurricanes. Their impact is catastrophic and long-lasting, and results in significant financial burden for the government.

Table 2 Estimates of the impact of extreme weather events on GDP per capita growth

Impact on GDP per capita growth (in percentage points)				
All studies with GDP per capita growth impact estimates (41)	**Severity**	**Average**	**Minimum**	**Maximum**
Floods	Typical	-0.37	-3.06	0.996
	Severe	-1.84	-3.97	-1
Storms (tropical cyclones/hurricanes)	Typical	-1.4	-4.64	-0.29
	Severe	-3.19	-7.6	-1
Collective impact	Typical	-0.8	-3	0.47
	Severe	-2.97	-11.68	-0.87
SIDS focused studies (14)				
Floods	Typical	-0.12	-0.2	-0.1
	Severe	-1	-1	-1
Storms (tropical cyclones/hurricanes)	Typical	-0.85	-1.66	-0.55
	Severe	-5.73	-7.6	-3
Collective impact	Typical	-0.91	-3	0.12
	Severe	-5.29	-11.68	-2

Note: collective impact does not reflect the sum of estimates for floods and storms; it is extracted from the meta-analysis where average collective effects on growth caused by extreme weather events were reported.

Source: authors, based on meta-analysis of existing literature

Severe floods and storms almost always have a negative impact on agricultural, non-agricultural and overall GDP growth, cancelling out any positive impact of moderate-intensity events (Cunado and Ferreira, 2014). On average, severe cyclones may decrease agricultural growth by 1 percentage point and non-agricultural growth by 2.93 points. These effects on growth trajectories are largely due to the large-scale destruction of capital and assets, inflicting financial losses that exceed the reconstruction capacity of resource-constrained countries such as SIDS (Hallegatte and Dumas, 2009; Panwar and Sen, 2019).

2.3 Fiscal impact of extreme weather events

Extreme weather events negatively impact public finances by increasing post-disaster government spending and eroding tax revenues, which reduces government income (Noy and Nualsri, 2011; Panwar and Sen, 2020). This dual impact often forces governments to seek external financing in the form of debt, especially in the absence of post-disaster financial support, leading to significantly higher borrowing costs to secure immediate funds (Ghesquiere and Mahul, 2010; Panwar and Sen, 2020). For small economies such as SIDS, frequent and large-scale disasters may trigger sovereign debt defaults and increase the 'sovereign default premium' – the additional cost for having defaulted in the past (Rasmussen, 2004; Ouattara et al., 2018).

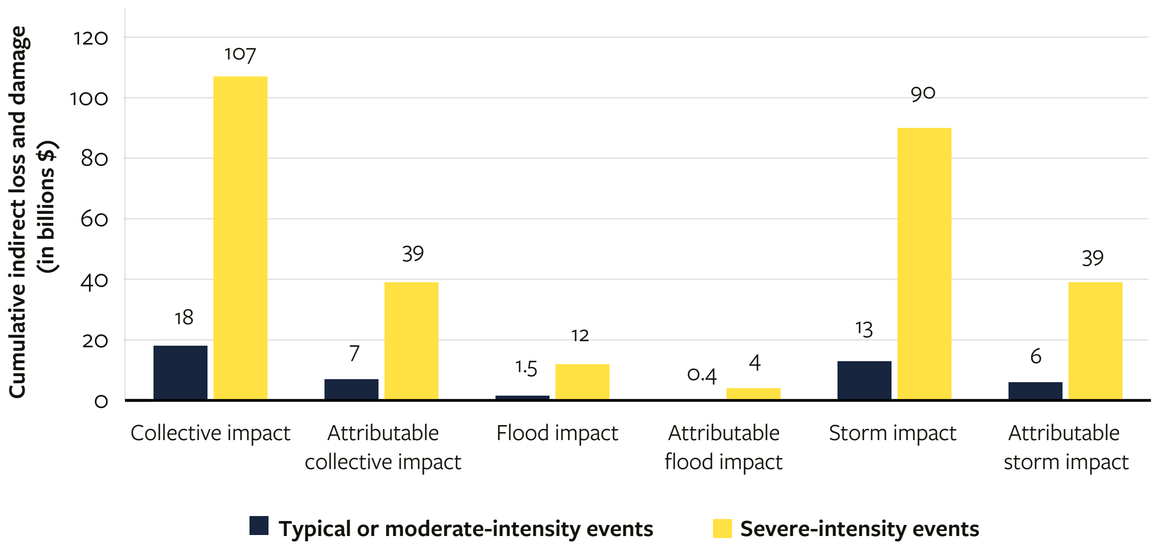
Results from the meta-analysis support these conjectures. On average, a typical storm can increase public expenditures by 2.2% (of GDP) and reduce revenues by 3.03% in developing countries. Moreover, even a moderate storm can raise budget deficits by 0.7% of GDP, while the collective impact of extreme weather events can increase it by about 3% of GDP. Similarly, the level of public debt can rise by as much as 4.7% of GDP. As with growth impacts, the impact of severe events on public expenditure, revenues and debt is significantly higher than that of moderate-intensity events. There is not, however, enough evidence in the studies considered for this meta-analysis to estimate the precise effect on revenues of severe storms.

3 Climate-attributable indirect economic loss and damage in SIDS

3.1 Aggregate indirect economic loss and damage estimates

Collectively, from 2000 to 2022, 'severe' extreme weather events in SIDS may have caused an estimated total of $107 billion in IELD,[3] of which $39 billion could be attributed to climate change (Figure 1). For severe tropical cyclones alone, the estimated total IELD during the same period could be as high as $90 billion, of which climate change may have been responsible for $39 billion. There are large differences in the estimates for 'typical' (moderate) events and for severe events. For instance, typical floods in SIDS may have caused $0.4 billion in IELD during the period 2000–2022, compared with $4 billion caused by severe floods.

Figure 1 Estimated indirect economic loss and damage in SIDS (2000–2022)



Note: Collective impact does not reflect the sum of estimates for floods and storms; it is extracted from the meta-analysis where collective average growth effects caused by extreme weather events were reported.

3 Except for floods, IELD estimates based on SIDS-specific studies are significantly higher than those calculated based on a full sample of studies (i.e. using estimates for developing countries overall). Such comparison is useful as it can offer a range of estimates for different extreme events. For instance, a typical tropical cyclone during the period 2000–2022 may have caused an estimated total IELD between $13 billion and $22 billion in SIDS. This brief presents estimates generated using SIDS-specific studies. See Panwar et al. (2024) for a full comparison.

3.2 Regional distribution of IELD estimates

There are regional differences in the estimates of IELD across different disaster types (Table 3). For example, the Caribbean region experienced the highest climate-attributable estimated IELD due to tropical cyclones/hurricanes, accounting for about 91% of the total for SIDS. This is primarily because the EM-DAT dataset records more events for Caribbean SIDS – 272 out of a total of 434 events – than for Pacific or AIS SIDS. Another reason is that four SIDS – the Dominican Republic, Cuba, Haiti and the Bahamas – contribute more than 80% of the total attributable IELD in Caribbean SIDS. Also, the studies reviewed focus on extreme weather events, while IELD from slow-onset events is likely to be higher in Pacific and AIS SIDS (Panwar et al., 2023).

Collectively, studies reviewed in the meta-analysis suggest that SIDS may have experienced IELD equivalent to about 1.8% of their GDP, with 39% attributable to climate change. Some SIDS may have experienced IELD exceeding 2% of their annual average GDP, including the Dominican Republic (2.3%), Fiji (2.3%), Haiti (3%), Papua New Guinea (2.1%) and Cuba (2.2%). In absolute terms, the Dominican Republic and Cuba suffered the highest cumulative impacts, each amounting to nearly $34 billion, followed by Haiti ($9.3 billion) and Papua New Guinea ($8.5 billion).

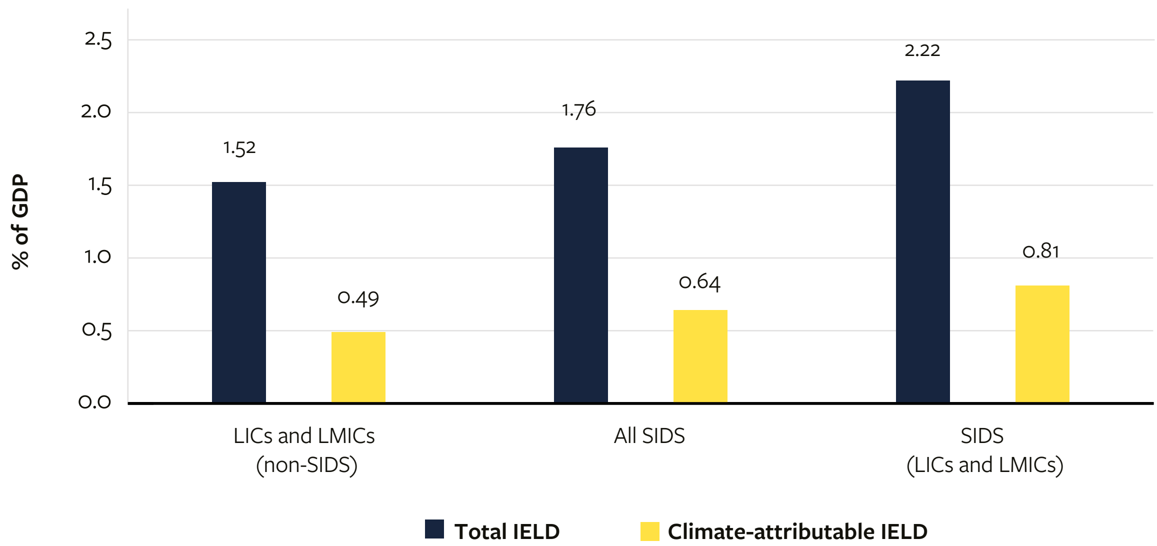
Table 3 Estimated indirect economic loss and damage in SIDS regions, 2000–2022

Type of extreme weather event	Region	Collective indirect impact (million $)		Storm indirect impact (million $)		Flood indirect impact (million $)	
		Total	Attributable	Total	Attributable	Total	Attributable
Typical event	AIS	595	217	302	130	36	11
	Caribbean	15,786	5,762	12,155	5,227	1,234	370
	Pacific	2,035	743	885	381	181	54
Severe event	AIS	3,457	1,262	2,036	875	298	89
	Caribbean	91,765	33,494	81,940	35,234	10,282	3,085
	Pacific	11,827	4,317	5,969	2,567	1507	452

3.3 Comparison between SIDS and other developing countries

Figure 2 compares the estimated IELD in SIDS with non-SIDS low-income countries (LICs) and lower-middle-income countries (LMICs).[4] The data show that both the total IELD and the portion attributable to climate change are higher in SIDS than in other LICs and LMICs (as a percentage of GDP). On average, SIDS may have experienced a total IELD equivalent to 1.76% of their GDP, compared with an average impact of 1.52% of GDP in non-SIDS LICs and LMICs. This impact is even greater when focusing on LICs and LMICs that are also SIDS, as opposed to those that are not. The same pattern holds for climate-attributable IELD: SIDS within the LIC and LMIC categories experience an impact that is 0.32 percentage points higher than non-SIDS in the same income groups.

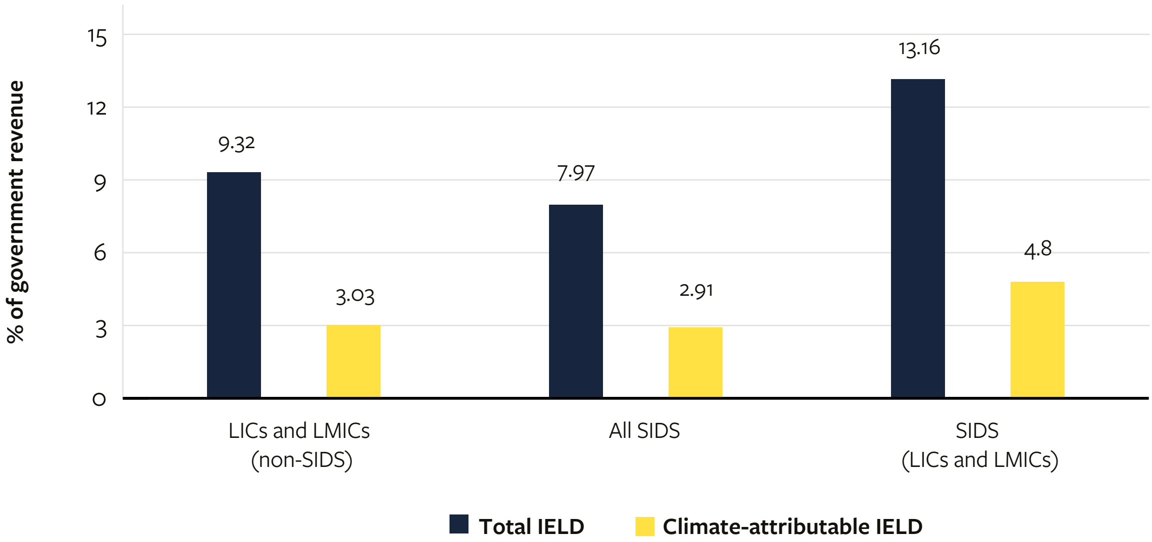
Figure 2 Estimated average annual IELD due to 'severe' weather events in SIDS and non-SIDS as a percentage of GDP (2000–2022)



The total IELD as a percentage of government revenue, however, is higher in non-SIDS than in SIDS (Figure 3), although the climate-attributable IELD is nearly identical between SIDS and non-SIDS. Nevertheless, when focusing specifically on LICs and LMICs, the estimated total and climate-attributable IELD are significantly higher in SIDS compared with non-SIDS within the same income groups.

4 Guinea-Bissau is the only LIC in SIDS and therefore LICs and LMICs are combined to make a meaningful comparison between SIDS and non-SIDS.

Figure 3 Estimated average annual IELD due to 'severe' weather events in SIDS and non-SIDS as a percentage of government revenue (2000–2022)



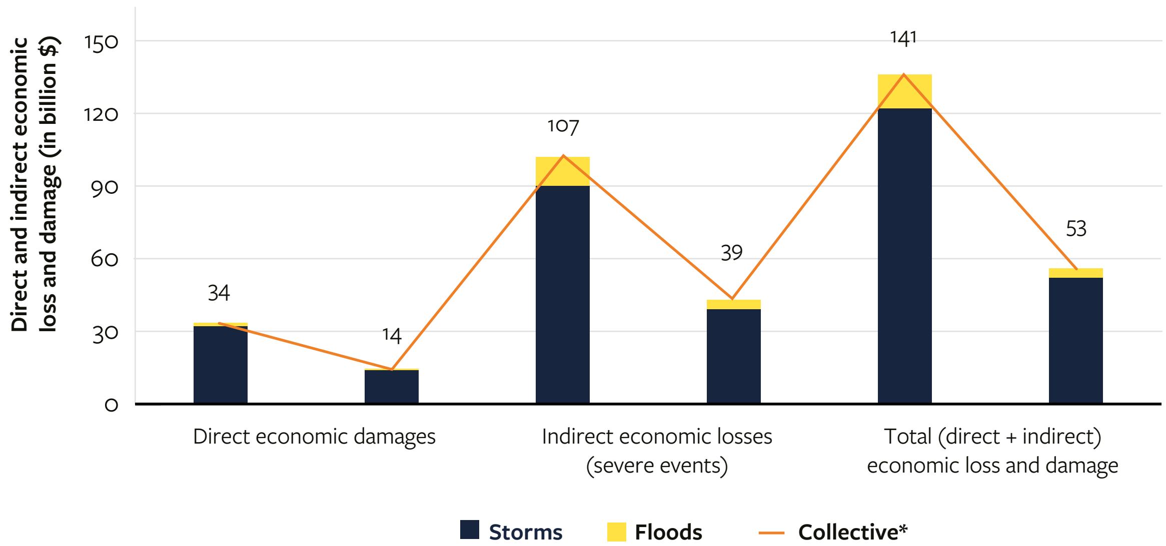
3.4 Combining the direct and indirect economic loss and damage estimates

It is useful to combine the direct and indirect economic loss and damage estimates to understand the total costs of extreme weather events in SIDS. However, these calculations have several inherent limitations:

1. The estimates of *direct* damage sometimes include the costs of reconstruction of destroyed and damaged assets. This metric of the costs of (re)construction, however, is part of standard GDP calculations (as a positive contribution to GDP) if and when that reconstruction actually takes place. As such, the two parts of the costs (direct and indirect) essentially 'cancel' each other.
2. Direct damage estimates are often based on the market price of destroyed and damaged assets, i.e. the economic value of these assets when traded in markets (e.g. privately owned residential and commercial buildings). However, since the economic value of destroyed assets (at least in principle) also encapsulates future revenues generated by those assets, by counting the price of the destroyed asset and the future lost stream of revenue, we would be double counting the loss as both a direct and indirect impact.
3. A similar challenge arises when we consider whether to include injuries and deaths in these aggregated metrics. Mortality costs can be estimated based on value of statistical life (VSL) calculations (Panwar et al., 2023), but the VSL can be construed as already including a stream of future income (productivity) that the deceased person would have generated had they still been alive. As such, combining the VSL estimates and estimates of the decline in future economic activity would also be double counting.

Acknowledging these caveats, the combined impact of direct economic loss and damage (excluding VSL accounting for mortality and morbidity) and IELD from 'severe' weather events can be estimated at around $141 billion in SIDS (Figure 4). Of this total, climate change could be responsible for $53 billion. On an annual basis, this translates to a total loss of $6.1 billion in SIDS, with $2.3 billion attributable to climate change each year. When estimates for mortality are included, the average annual economic loss and damage rises by about 50% to $9.3 billion, nearly $3.4 billion of which could be due to climate change.

Figure 4 Combined estimates of direct and indirect economic loss and damage in SIDS (2000–2022)

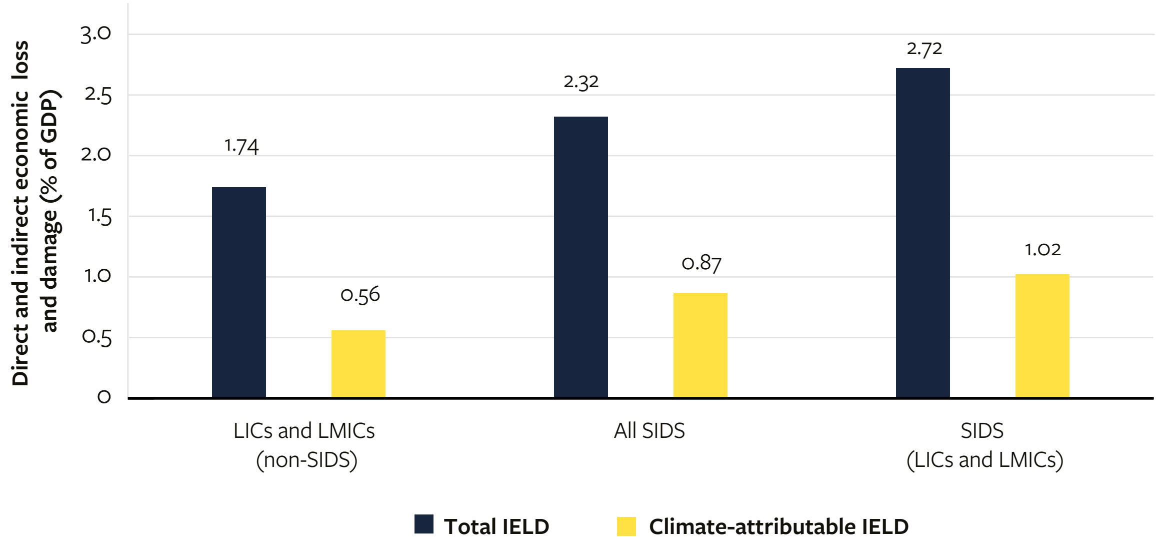


Note: The direct economic damages do not include value of statistical life (VSL). Estimated IELD is for severe events.

When expressed as a percentage of GDP, the combined direct and indirect economic loss and damage across SIDS was equivalent to 2.3% of GDP for 2000 to 2022 (Figure 5). Of this combined impact, an average 0.9% of GDP could be attributed to climate change. As with IELD, SIDS face significantly higher levels of combined direct and indirect economic loss and damage than other LICs and LMICs.[5]

5 Including VSL (mortality) in direct economic loss and damage increases the estimated combined climate-attributable economic loss and damage from 0.9% to 1.4% of GDP in SIDS.

Figure 5 Combined direct and indirect economic loss and damage in SIDS and non-SIDS, as a percentage of GDP (2000–2022)



Note: The direct economic damages do not include value of statistical life (VSL). Estimated IELD is for 'severe-intensity' extreme weather events.

4 Future projections of climate-attributable economic loss and damage

Building on methods developed by Panwar et al. (2023), this section estimates future direct and indirect economic loss and damage from extreme weather events using projections from the IPCC Sixth Assessment Report (IPCC, 2021). These projections indicate that events with 20-, 50- and 100-year return periods will become more frequent as global temperatures rise due to GHG emissions. The focus here is on projections for floods and tropical cyclones, noting however that the IPCC emphasises that even small rises in average global temperatures will lead to increased drought frequency in future in some regions, including in SIDS (IPCC, 2021: 1583).

Two warming scenarios by 2050 are considered: 1.5°C and 2.0°C above pre-industrial levels.

- What are currently 20-year flood events are expected to increase by 10% under a 1.5°C warming scenario, and by 22% under a 2.0°C scenario (IPCC, 2021: 1564). Tropical cyclones are projected to increase in frequency by 13% under a 2.0°C temperature rise (IPCC, 2021: 1590).
- Since the report does not provide projections for tropical cyclones under a 1.5°C scenario, a 6% increase in storm frequency is assumed based on the 2.0°C estimate.

Using these IPCC projections, new fraction of attributable risk (FAR) calculations can be produced for floods and tropical cyclones, assuming the projected increases are reached by 2050. For example, if the average FAR for tropical cyclones was 43% from 2000 to 2022, a 6% increase by 2050 under a 1.5°C warming scenario would result in a new FAR of $1 – (0.57 \times (1/1.06))$ or 46%. The projected increase in FAR is extrapolated in a linear way up to 2050 to obtain yearly values for these FAR estimates.

The loss and damage projections are at best indicative of the potential direct and indirect costs of extreme weather events in the future, because they omit factors that could either decrease or increase exposure and vulnerability to the shocks. Risk-reducing factors include adaptation investments and future changes in income and population in SIDS, while risk-enhancing factors could include increased income inequality.

As highlighted by Panwar et al. (2023), loss and damage projections remain largely underestimated, due to data limitations (including missing observations and under-reporting) and the exclusion of slow-onset events (especially sea-level rise and temperature increase), and non-economic loss and damage from the calculations.

As shown in Table 4, the cumulative impact of direct[6] and indirect economic loss and damage from tropical cyclones/hurricanes could be $66.1 billion by 2050, under a 1.5°C climate change scenario. This could rise further to $69.1 billion under a 2°C climate change scenario. Floods, on the other hand, could generate total economic loss and damage to the tune of $5.5 billion under 1.5°C and $6.1 billion under 2°C scenarios. Collectively, the cumulative impact of economic loss and damage caused by floods and storms could be between $71.6 billion and $75.2 billion under the two climate change scenarios by 2050.

Table 4 Projected climate-attributable economic loss and damage in SIDS by 2050

Climate extreme	Average FAR (2000-2022)	Projected new FAR under different warming scenarios	Projected cumulative attributable loss and damage per scenario		
			Direct economic loss and damage (excl. VSL)	Indirect economic loss and damage	Combined economic loss and damage
Floods					
1.5°C warming scenario: median ~10% increase in probability of occurrence (1-in-20 year)	30%	36%	$0.6 billion	$5.1 billion	$5.5 billion
2.0°C warming scenario: ~22% increase in probability of occurrence (1-in-20 year)		43%	$0.7 billion	$5.6 billion	$6.1 billion
Tropical cyclones/hurricanes					
1.5°C warming scenario: 6% increase in probability of occurrence (1-in-50 year)	43%	46%	$17.4 billion	$51 billion	$66.1 billion
2.0°C warming scenario: 13% increase in probability of occurrence (1-in-50 year)		50%	$18.1 billion	$53.2 billion	$69.1 billion

Note: Direct economic damages exclude VSL and therefore are lower than previous projections (see Panwar et al., 2023) that do include VSL estimates. Combined economic loss and damage estimates are based on annual averages for direct and indirect economic loss and damage.

6 Direct economic loss and damage only includes economic damage as reported in EM-DAT. It does not include VSL mortality estimates, which constitute about 68% of the total direct economic loss and damage, as reported by Panwar et al. (2023).

5 Conclusions

The direct and indirect economic loss and damage associated with extreme weather in SIDS is significant and growing. Yet the growth and fiscal impacts that materialise in the years after an extreme weather event are not well recorded or understood. Estimates presented here are tentative, but the analysis suggests that these medium-term economic impacts may be significantly higher than the direct, immediate impacts, which are better understood and have gained more attention in informal discussions so far on the operational model for the FRLD.

Whether through the FRLD or other funding arrangements, SIDS will need support in addressing these increasing impacts. With more frequent intense tropical cyclones, rainfall and flooding expected under both 1.5°C and 2.0°C scenarios, the growth potential of these small economies will be severely limited as will their governments' abilities to deliver basic services. The FRLD should include a budget support mechanism that can help SIDS and other vulnerable countries to address the growth and fiscal impacts of climate-induced extreme weather. An increase in concessional finance for recovery will also be needed, particularly after severe weather events. By supporting rapid recovery in key sectors such as agriculture, loss and damage finance can help ameliorate the knock-on effects on economic output.

The analysis of IELD presented in this policy brief also underscores the importance of focusing loss and damage finance on SIDS as particularly vulnerable countries. Not only do they experience more severe immediate GDP losses than other countries with similar income levels, but they are also disproportionately affected in terms of growth and fiscal balances, making it even harder to recover from climate-induced extreme weather events. As severe weather events become more frequent, and SIDS find themselves in a constant state of recovery, there will likely be further negative effects on long-term economic growth prospects.

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Annex 1 Data and methods

To estimate climate-attributable indirect economic loss and damage (IELD) from extreme weather events in SIDS, this study draws information from two main sources: (i) a meta-analysis of existing empirical literature on indirect economic and fiscal impacts of extreme weather events, and (ii) extreme event attribution (EEA) as used in Frame et al. (2020b), Panwar et al. (2023) and Newman and Noy (2023). Both these sources, along with the analytical approach, are discussed in detail in Panwar et al. (2024). A summary of the data and methods is presented below.

Meta-analysis of macro-fiscal impacts of extreme weather events

This study uses information from a meta-analysis of existing empirical studies on how extreme weather events affect economic growth, the fiscal position of governments and other macroeconomic indicators. This approach allows findings from many different studies to be aggregated to average out differences; it depicts the estimated average impact of extreme weather events on macroeconomic indicators. The meta-analysis used in this study includes empirical studies published from 2000 to 2023. The meta-analysis focused on floods and storms – the most relevant extreme weather events in 35 of the 39 UN member SIDS.[7]

Based on the inclusion criteria (see Panwar et al., 2024), the meta-analysis included a total of 64 published studies, covering macroeconomic growth effects and fiscal impacts of extreme weather events. These studies have an average sample size of 66 countries and cover an average of 30 years of data. Table A1 shows the number of supporting studies by variables, covering estimates for the full list of 64 studies.

7 Most of the existing empirical studies analyse the impact of flood and storm, along with earthquake and drought. For SIDS, a specific focus of such studies has been on tropical storms/hurricanes.

Table A1 Number of studies in the meta-analysis by variables and estimates

Type of variable	Unit of change	Count of supporting studies (full sample = 64)	Count of statistically significant estimates
GDP per capita growth	percentage points	41	80
GDP per capita	percentage (%)	14	24
Agricultural growth	percentage points	6	15
Non-agricultural growth	percentage points	5	18
Budget balance (as % of GDP)	percentage (%)	4	5
Public expenditure	percentage (%)	6	12
Public debt (as % of GDP)	percentage (%)	6	11
Public revenue	percentage (%)	7	15

Extreme event attribution data and analysis

This study builds on analysis by Frame et al. (2020b), Newman and Noy (2023) and Panwar et al. (2023) to quantify the climate change-induced component of IELD from extreme weather events. EEA methods estimate how anthropogenic greenhouse gas emissions have altered the likelihood and intensity of specific extreme weather events. EEA uses ensembles of climate models, historical observational data and extreme statistical analysis to determine the influence of climate change on such events. There are three main approaches in EEA: probability-based, intensity-based and a hybrid approach (Stott et al., 2016; Otto, 2017; van Oldenborgh et al., 2021).

Newman and Noy (2023) use probability-based EEA, which quantifies the differences in the likelihood of an extreme event occurring in a non-climate change world versus the current situation of anthropogenic climate change.[8] This probability-based approach uses the fraction of attributable risk (FAR) – a probabilistic metric ranging from -1 to 1, where a FAR of 1 implies the event would have been impossible without anthropogenic climate change and a FAR of 0 means climate change had no discernible influence on the event's probability.[9]

Frame et al. (2020b) and Newman and Noy (2023) developed an extreme events impact attribution approach (EEIA) that uses these EEA estimates of the FARs and pairs them with direct

8 The intensity-based approach calculates the share of an event's intensity attributable to climate change, such as determining how much heavier a rainfall event was due to climate change. Hybrid approaches combine extreme value statistics with climate model ensembles to assess both the intensity and the probability of events in a climate change context versus no climate change (see van Oldenborgh et al., 2021).

9 A FAR of -1 means that the event is no longer (statistically) possible in the current climate conditions (but was possible prior to climate change).

damage data from past disasters, to estimate the share of direct damages that are attributable to climate change (Noy et al., 2024). Here, instead of pairing these FAR estimates with direct damage data, we identify the indirect losses using the meta-analysis described above.

The 'master dataset' of attribution studies from Panwar et al. (2023) includes 216 matched extreme weather events that occurred from 2000 to 2022, derived from 135 attribution studies. Attribution studies are not equally distributed across continents, with only 12 studies focusing on Africa. There are very few or no attribution results for many combinations of continent and event type, especially for SIDS, where there are only three attribution studies with useful FAR estimates. Attribution results for SIDS are available only for floods, storms and drought events, with no identified studies for other hazard types. A detailed account of the attribution data is presented in Panwar et al. (2023).

Analytical approach

Building on the meta-analysis of existing studies into macroeconomic impact from extreme weather events and the information from the EEA dataset compiled by Panwar et al. (2023), this study calculates the IELD using the following steps.

The process begins by calculating the average indirect effects of disasters on GDP growth, categorised by disaster type, using meta-analysis. Where data permit, the average GDP growth impact is also assessed, based on disaster severity and for specific country groups such as SIDS or middle-income countries.

This average impact of disasters on GDP growth is considered as 'foregone' growth, reflecting additional growth which could have been achieved by affected countries, if the disaster had not occurred.

As a next step, 'potential' growth can be calculated, which is the sum of actual observed growth and foregone growth:

[potential growth = actual growth + foregone growth]

The first step is repeated for other macroeconomic variables such as sectoral growth (agricultural and non-agricultural) and fiscal impact variables (e.g. tax revenue, spending). Although the average effects of extreme events on such variables are discussed in the next section, they are not used to calculate the cost of IELD. Such cost is based solely on the average GDP per capita growth estimates mentioned above.

In the next step, we estimate the monetary value of indirect losses with the help of the estimates described above. First, the growth rate formula is used to calculate 'potential' GDP per capita (GDPpc), before calculating overall 'foregone' GDP in dollar terms. The following formula is used to calculate potential GDP per capita:

$$\text{growth rate of } GDPpc_2 = (GDPpc_2 - GDPpc_1) / GDPpc_1$$

Rearranged, this becomes:

$$GDPpc_2 \text{ (potential GDPpc)} = (\text{growth rate of } GDPpc_2 \times GDPpc_1) + GDPpc_1$$

In this formula, $GDPpc_1$ and $GDPpc_2$ represent GDP per capita at two different time periods. The growth rate of GDPpc is the potential growth rate derived in the previous step.

Potential GDP per capita is multiplied by population figures for the respective country and year to obtain potential overall GDP, measured in dollars. The following formula is then used to calculate foregone GDP, which can also be termed as IELD from extreme events:

$$\text{foregone GDP or IELD (\$)} = \text{potential GDP (\$)} - \text{actual GDP (\$)}$$

Finally, using the information from the extreme event attribution studies, climate change-attributable IELD is calculated. In this step, the average global or regional FAR values are used to calculate the climate-attributable indirect impact on GDP growth. The climate-attributed loss and damage for each event is calculated by multiplying the FAR by the socioeconomic cost of the event, using the formula:

$$\text{climate-attributable } IELD_i = FAR_i \times IELD_i$$

The estimates of attributable indirect losses are then statistically described and analysed for all extreme weather-attributed loss and damage, as well as for individual event types and separately for SIDS.

This study also considers future projections of the direct and indirect loss and damage caused by extreme weather events, based on IPCC (2021) guidance. It uses linear extrapolation to estimate expected loss and damage up to 2050, considering potential increases in the frequency and intensity of extreme weather events due to climate change.

Caveats

Beyond the caveats already discussed in Panwar et al. (2023), there are three other concerns that are worth detailing here and that pertain specifically to this attempt to quantify the indirect attributed damage and loss in SIDS.

First, the meta-analysis we conduct on estimates of average decline in GDP growth following disasters is taken from literature most of which does not include a specific focus on SIDS. Since some of the literature reports more adverse impacts for SIDS (when SIDS are treated as a separate grouping), it is likely that the estimates we use here are understating the indirect impacts on SIDS.

The second important caveat – one that is frequently discussed in economic textbooks, but not much outside of them – is about the relevance of GDP as the best metric to explain what happens to an economy after a disaster, when it is the changes in the composition of GDP that may be much more important. More broadly, GDP is seen by many as a misleading metric for how well an economy is doing, even in tranquil times. If one were specifically interested in the economy as a way to understand people's well-being, then GDP becomes an even more problematic metric. Typically, consumption may be considered a better measure or proxy for household wellbeing, although still an imperfect one. However, besides Mechler (2009), we have not been able to find other work that has estimated the impact of extreme events on consumption.

The third issue is whether one can use the FAR attribution metric with indirect costs. When using intensity attribution studies, one may need to resort to assumptions about a linear damage function that connects hazard intensity to damages (see Frame et al., 2020a). However, when aggregating across countries and time, and most importantly across many events, the linearity assumption is no longer required. The FAR metric estimates changing frequencies, so one can legitimately argue that changing frequencies implies different numbers of events, and if events are roughly similar in magnitude, these estimates are valid. When events vary dramatically in magnitude, and when the analysed sample includes a 'bad throw of the dice' (i.e. unusually large adverse events), then one could argue that the algorithm we use here may over-estimate the attributed losses. Therefore, we would like to insist that our estimates can legitimately be used for groups of countries, but are potentially less useful for single countries or for small numbers of observations.

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ODI
203 Blackfriars Road
London SE1 8NJ

+44 (0)20 7922 0300
info@odi.org

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odi.org/facebook
odi.org/twitter