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Executive summary

This policy brief highlights the critical need to address the complex and compounding impacts of climate extremes, driven by climate change and non-climate factors, to ensure effective disaster risk management and climate adaptation interventions. The brief provides insights from the COMPASS EU-funded project (2024–2026), which aims to develop advanced methods for attribution of compound climate events and their impacts, offering actionable recommendations for policymakers to mitigate future risks.

Key findings include:

1. **Compounding and cascading impacts**: Climate extremes often interact with other hazards and socio-economic drivers, amplifying their effects. Policies must account for these dynamics to avoid ineffective or harmful interventions.
2. **Data limitations**: High-quality local data on exposure, vulnerability, and impacts are essential for robust impact attribution and policy design. Enhanced data collection and open sharing, particularly in developing regions, should be prioritized.
3. **Counterfactual and scenario-based approaches**: Methods such as counterfactuals and future scenario analysis can "stress test" policy responses, helping to prioritize and optimize interventions to reduce human and economic losses.
4. **Global-to-local insights**: Leveraging both global and local datasets ensures scalable solutions while addressing regional and context-specific vulnerabilities.

By integrating these findings, policymakers can better design and implement interventions that address both climate and non-climate drivers of risk, enhancing resilience and reducing the impacts of future compound climate events. The current brief aims at facilitating the science-to-policy interfacing, and the transfer of the COMPASS experience into the policy and decision-making fields, informing policy and planning around adaptation, loss and damage, or disaster recovery.

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1. The policy relevance of compound climate event attribution

Climate change is contributing to the increasing frequency and intensity of climate and weather extremes across many regions of the world[1][2]. These extremes – such as floods, droughts, and heat waves - have caused significant socio-economic impacts including loss of life, food insecurity, critical infrastructure damage, ecosystem degradation and permanent or temporary displacement of people. As global emissions continue to drive climate change, the frequency and intensity of these events will continue to increase in many regions.

Climate change attribution studies aim to assess the contribution of human emissions to the probability and intensity of climate extremes[3]. To date, most attribution studies have focused on establishing the contribution to a single hazard (e.g. extreme rainfall) with analysis of impacts, exposure, and vulnerability as supplementary information. However, in reality, extreme weather events such as such as heavy rainfall, heatwaves, tropical cyclones compound with other climate-related hazards, and non-climate drivers that lead to devastating impacts[4]. A failure to consider these compounding and cascading hazards and non-climate drivers raises risks of misguided and ultimately ineffective policy and planning interventions.

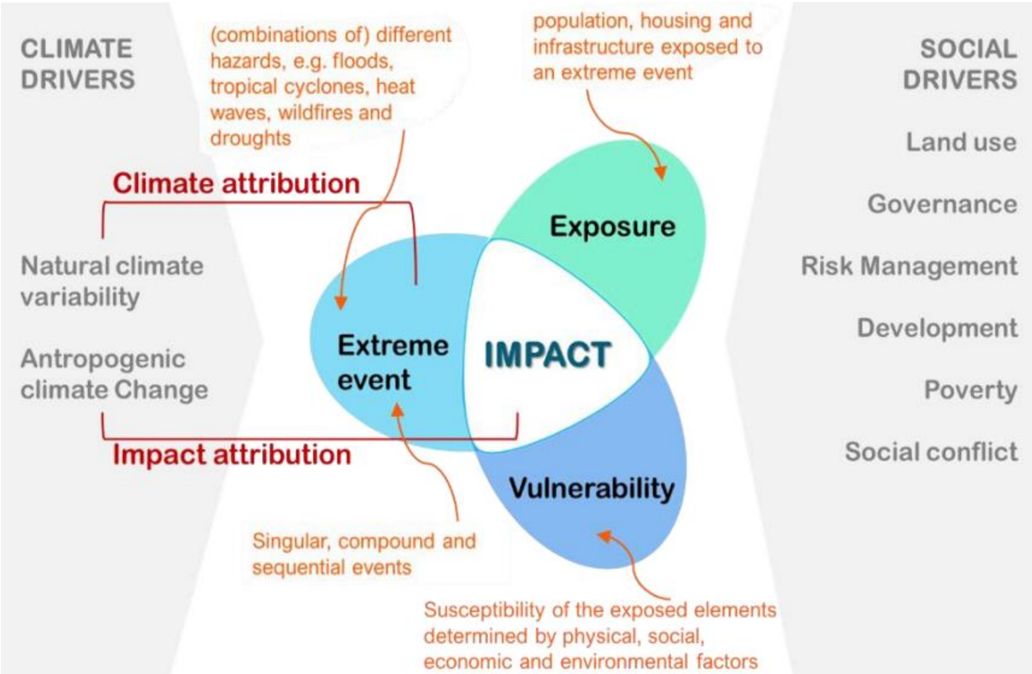

Figure 1. Risk framework adapted from the Intergovernmental Panel on Climate Change (IPCC)[5].

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[1] Seneviratne, S. I., Zhang, X., Adnan, M., Badi, W., Dereczynski, C., Luca, A. D., ... & Allan, R. (2021). Weather and climate extreme events in a changing climate.

[2] Clarke, B., Otto, F., Stuart-Smith, R., & Harrington, L. (2022). Extreme weather impacts of climate change: an attribution perspective. *Environmental Research: Climate*, *1*(1), 012001.

[3] Trenberth, K. E., Fasullo, J. T., & Shepherd, T. G. (2015). Attribution of climate extreme events. *Nature climate change*, *5*(8), 725-730.

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[5] Ara Begum, R., R. Lempert, E. Ali, T.A. Benjaminsen, T. Bernauer, W. Cramer, X. Cui, K. Mach, G. Nagy, N.C. Stenseth, R. Sukumar, and P.Wester, 2022: Point of Departure and Key Concepts. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A.

These more complex dynamics are often difficult to establish, especially in the context of crises where reliable data may not exist. They are, however, critical to effective interventions. Mis-diagnosing the nuances of vulnerability and exposure, especially across different age, gender, and ethnic groupings, and in the dynamic situations of crises, can even result in interventions that inadvertently increase risk for some communities.

Understanding these complex unfolding events more comprehensively can provide valuable insights to guide effective responses ranging from improved disaster risk management through to climate adaptation and resilience programs. The *COMPound extremes Attribution of climate change: towardS an operational Service* (COMPASS) research project (2024-2026) is contributing to building new attribution methods through a range of data and analysis developments tested in real world use cases. COMPASS will consider 8 different use cases across the globe in order to develop general and scalable approaches to compound impact attribution.

2. Conceptualizing risk

The Intergovernmental Panel on Climate Change (IPCC) risk framework describes risk, or the possibility of a negative impact, at the intersection of the hazard (e.g. flooding), people or infrastructure exposed to the hazard, and the vulnerability of those people or infrastructure (Figure 1). The scale of negative impact depends on the magnitude of the hazard, the degree of exposure, and the level of vulnerability.

While the components of the framework are relatively simple, in practice these three components can be quite complex to quantify and to account for their interactions. As seen in the case above, one flooding event may compound with a previous event, making the hazard worse but also influencing the vulnerability of the population already affected from the first hazard. Long-term drivers can also influence risk. High tides compounding with storm surge are exacerbated by sea level rise resulting in more extreme coastal inundation. Getting reliable data on exposure is challenging as well as understanding societies' vulnerability. People displaced into temporary shelters by a tropical cyclone become more exposed to heat extremes or non-climate hazards such as gender-based violence.

Box. 1: Highlighting complex and compounding impact pathways

On the 3rd of November 2020 hurricane Eta made landfall on the east coast of Nicaragua and proceeded to track westward degrading to tropical depression status as it crossed into southeast Honduras.

- Extreme rainfall across northern Honduras resulted in nearly 100 deaths due to flooding and landslides
- 90,000 homes were damaged and170,000 people evacuated to temporary shelters.

Many of these communities had barely anytime to recover when, 12 days later, Hurricane Iota made landfall in Honduras again.

- Iota caused 13 deaths due to landslides
- Cut off access to whole regions, and submerged an international airport for a month.
- Further flooding was compounded and exacerbated by saturated soils and persistent flooded areas caused by Eta

Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 121–196, doi:10.1017/9781009325844.003

- People displaced into temporary shelter after Eta have been more exposed to Iota.

Eta and Iota impacted a region that was already struggling with:
- The impact of an extended regional drought (2014-2019),
- A Dengue fever outbreak in 2019, and
- The economic and social impacts of COVID-19.

Rapid urbanization, potentially accelerated by the loss of rural livelihoods during the drought, had stretched the infrastructure and services of urban centers resulting in large vulnerable urban populations. Constrained resources limited early warnings and disaster responses. Communities cut off by damage from Eta did not receive warnings about Iota, potentially further exacerbating avoidable impacts.

More information: https://storymaps.arcgis.com/stories/8fd49dccaf0f4b719a7aa6b5a2e0201a

3. The need for a global to local approach

A central element of impact attribution analysis is determining population and economic exposure to hazards. For example, the availability of exposure data varies significantly across different countries and through different historical periods. Future exposure scenarios have been produced at global scale but may not reflect sub-national variability. The COMPASS project is tackling this challenge through a "global to local" approach that, through upscaling and downscaling of global and national datasets, enables the seamless use of the best openly available local level data to be used where available, and for global datasets to substitute where local data is not available.

4. Advancing counterfactuals and storylines methods to understand risk

We can evaluate how the impact of a tropical cyclone on a coastline would have been different if sea level was at pre-industrial levels rather than heightened by climate change. The description of a plausible alternative event to the observed event is called counterfactuals. Most recent attribution studies create counterfactuals to explore the role of climate drivers in the impact of the event. However, non-climate counterfactuals, e.g. alternative adaptation scenarios, can also be used to explore the role of factors such improved early warning systems and preemptive evacuation. Storylines as " physically self-consistent unfolding of past events, or of plausible future events or pathways"[6] can be particularly useful to develop such counterfactuals.

COMPASS is developing a range of counter-factual datasets for tropical cyclones, extra-tropical cyclones, and winter storms. These counterfactuals consider the contribution of human emissions to changes in sea-level, rainfall intensity, and wind speeds. The counter-factual hazard datasets, combined with damage functions and exposure data, are used to drive impact models to estimate the change in impact relative to the observed hazard.

For instance, counter-factual hazard data for storm Xynthia revealed that climate change-induced increases in sea-level, storm surge, and wave height, increased 10-12% in fatalities, people affected, and

[6] Shepherd, T.G., Boyd, E., Calel, R.A. *et al.* Storylines: an alternative approach to representing uncertainty in physical aspects of climate change. *Climatic Change* **151**, 555–571 (2018). https://doi.org/10.1007/s10584-018-2317-9

economic losses. However, the analysis also highlighted the important role of decreasing vulnerability and changing exposure over the past 50 years in determining the observed impacts.

5. Planning for future extremes

Understanding the climate and non-climate drivers of historical impacts provides important evidence to inform policy and planning responses and to understand how future impacts may unfold.

COMPASS will use the datasets and methods developed to understand past events and extend the analysis to consider how such events, and their impacts, may unfold under different future climate and socio-economic scenarios. Therefore, it is critical to understand how responses such as early warning systems, can reduce exposure and vulnerability and therefore impacts.

For example, how would the impacts from a tropical cyclone similar to Freddy, that caused devasting impacts in East Africa in 2023, be changed given further increases in sea-level, wind speeds, storm surge, and rainfall intensities? How could these impacts be reduced by appropriate interventions based on evidence from past event attribution studies?

6. Recommendations

While COMPASS has significant progress still to make until 2026, initial recommendations based on prior work and early project outcomes include:

1. There is increasing evidence of the compounding and cascading nature of impacts related to climate extremes. It is essential that policy responses consider these dynamics if interventions are to be effective.
2. Furthermore, it is essential to better understand and quantify uncertainties in the attribution statements.
3. Exposure, vulnerability and impact data are significant constraints to effective impact attribution. Data is often lacking and also without good quality local data on who and what are exposed, and what impacts have been observed, it is challenging to provide robust evidence-based required to inform policy. Policies should encourage and, where possible, mandate enhanced collection and open sharing of relevant data and support databases and collection effort for high- quality local level data, especially in developing regions.
4. Considering counterfactuals and future scenarios that include policy responses has the potential to “stress test” policy interventions prior to implementation. This can assist in the prioritization and design of such interventions to maximize reductions in human and economic impacts resulting from future compound extremes.

By bringing together an understanding of how compounding climate hazards and non-climate drivers result in human and economic impacts, and how these impacts may change in the future, policy makers can ensure that disaster risk management, adaptation, and resilience interventions are appropriate and effective in mitigating future impacts.

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