



**Guidance note on qualitatively assessing
vulnerability factors, including non-climate
compounding factors, in attribution studies**
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Deliverable 3.2 – Guidance note on qualitatively assessing vulnerability factors in attribution studies

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Executive summary

Extreme event attribution (EEA) studies have become a critical tool for understanding how climate change influences the likelihood and severity of extreme weather events. However, most studies to date have focused predominantly on the physical science of hazards, with limited attention to the role of vulnerability in translating the hazard into impacts—the social, economic, political, and historical conditions that shape who is affected and how. The COMPASS project aims to develop a harmonised framework for climate and impact attribution, with a particular focus on compound and sequential extremes. In this context, the role of vulnerability factors in determining the nature and scale of impacts is even more critical as one hazard may influence vulnerability and modify the impact of a second hazard. While COMPASS is developing approaches to quantitative vulnerability modeling, there remains a significant gap, and many questions, around the inclusion of qualitative vulnerability analysis.

This guidance note, deliverable 3.2, aims to address that gap by providing practical directions to researchers on qualitatively assessing vulnerability and non-climatic compounding factors in attribution research. Developed through a review of literature and 16 expert interviews, the report synthesizes current practices, identifies key challenges, and outlines actionable approaches for integrating vulnerability more meaningfully into EEA. It contributes to the COMPASS objective of developing a scalable and flexible methodology for translating hazards to societal impacts in order to conduct impact attribution studies. While this document discusses both quantitative and qualitative approaches, it is the integration of the two that may add the most value for researchers.

Key findings and recommendations include:

- Vulnerability is central to understanding disaster impacts. Without it, attribution studies risk reinforcing hazard-centric narratives that obscure structural drivers of harm such as poverty, inequality, weak governance, and systemic marginalization.
- Qualitative and mixed-method approaches are essential to extend impact attribution to data-scarce regions. These methods allow researchers to capture lived experiences, root causes, and context-specific drivers of vulnerability, particularly in places where social datasets have gaps, do not exist, or are inaccessible (e.g. conflict-affected areas).
- The use case for EEA studies needs to be clearly defined. Vulnerability integration must be designed from the outset, aligned with the intended use—whether for informing recovery, shaping adaptation strategies, or informing policy discussions.
- Compound events often have compounding impacts that require systems thinking. Multiple, interacting hazards demand tools that can track how vulnerabilities evolve over time and across sectors. Simple additive models are insufficient.
- Collaboration with local actors enhances relevance and legitimacy of attribution studies. Co-producing knowledge with communities, practitioners, and local researchers ensures assessments are grounded, inclusive, and policy relevant.

The report outlines a range of methodological options—quantitative, qualitative, and integrative—highlighting when and how each option can be used. It emphasizes that no single method is universally applicable; instead, researchers must choose approaches that reflect the complexity of risk and the realities of those most affected. Within COMPASS, this guidance note will serve as a starting point for determining which vulnerability assessment methodology is more appropriate for each Use Case addressed in COMPASS work package 4.

Ultimately, by embedding vulnerability into attribution science, we move closer to the goal of making climate evidence more actionable, equitable, and meaningful for real-world decisions.

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1 Introduction

Extreme event attribution (EEA) studies have historically quantified the contribution of human emissions to the probability and intensity of observed extreme weather events (Faranda et al., 2022; Trenberth et al., 2015). A further subset of EEA studies are impact attribution studies, which focus on attributing a particular impact of the extreme weather event to climate change. These studies implicitly include aspects of vulnerability and exposure as key factors resulting in impacts such as deaths, displacement, infrastructure damage, agricultural disruptions, or insurance costs (Clarke et al., 2022; Perkins-Kirkpatrick et al., 2022)

The science of extreme event attribution fulfills a scientific curiosity on how and why the frequency and intensity of extreme weather events has changed over time, but it also has an arguably more important and larger potential to inform societal questions (*Attribution of Extreme Weather Events in the Context of Climate Change*, 2016). The National Academy of Sciences argues that event attribution studies could be “a tool for informing choices about assessing and managing risk and guiding adaptation strategies” (*Attribution of Extreme Weather Events in the Context of Climate Change*, 2016). However, societal questions are often complex and require us to understand aspects of vulnerability, especially social vulnerability, that are difficult to measure or are seldom measured systematically and routinely. EEA studies largely leave out critical components of risk, including the degree of exposure, the level of vulnerability, and existing response measures or coping strategies that determine the level of impact (Perkins-Kirkpatrick et al., 2024; Simpson et al., 2023). By integrating exposure, vulnerability, and response dimensions, a more nuanced and contextualized understanding of the changing drivers of risk related to extreme weather events can be developed. This has the potential to provide more salient and actionable information to inform risk management and adaptation options.

The integration of a vulnerability component into attribution is one of the biggest challenges in the EEA community. Methodologies are still being developed and rely heavily on the availability of quantitative data, which can be a severe limitation, especially in data-sparse regions of the world (Fezzigna et al., 2025). Vulnerability is also a complex and debated concept with a multitude of theoretical frameworks and approaches used to understand and assess. To mitigate the limitations of quantitative data scarcity, as well as to reflect the complexity and nuance of vulnerability, qualitative and mixed-methods approaches could be implemented to characterise the vulnerability and exposure of people in areas impacted by extreme weather events.

This deliverable, D3.2, provides an overview and assessment of approaches to including qualitative vulnerability assessments in EEA and impact attribution. As vulnerability assessment is a key element of impact attribution, and in particular of attribution of compounding and cascading extremes, the deliverable contributes directly to the aim of work package (WP) 3 to develop a methodology for impact attribution that incorporates socio-economic drivers. The deliverable documents existing approaches to vulnerability assessment with a focus on qualitative approaches as well as approaches being developed through WP4 Use Cases and so complements and supports the specific objective of WP3 to develop qualitative vulnerability methods for the impact framework;

In chapter 2, the report starts by introducing the risk framing approach that establishes the importance to vulnerability in EEA. In chapter 3 we outline the methods used to develop this report. In chapter 4 we synthesize the results of expert key informant interviews to answer key questions on integrating vulnerability into EEA. In chapter 5 we build on this by outlining example of quantitative, qualitative and mixed method approaches to assessing vulnerability. Finally in chapter 6 we synthesize guidance on when to use which approach.

The COMPASS Project

The COMPOund extremes Attribution of climate change: towardS an operational Service ([COMPASS](#)) project focuses on building new, impact-centered attribution methods to better describe how extreme weather events and their impacts may unfold under different future climate and socio-economic scenarios. COMPASS achieves this through a range of data and analysis developments, tested on real-world use cases.

2 Risk Framing in Extreme Event and Impact Attribution

The Intergovernmental Panel on Climate Change (IPCC) describes risk as the intersection of hazard, exposure, vulnerability, and response, where risk represents the potential for impacts to unfold (Rawshan Ara Begum et al., 2022).

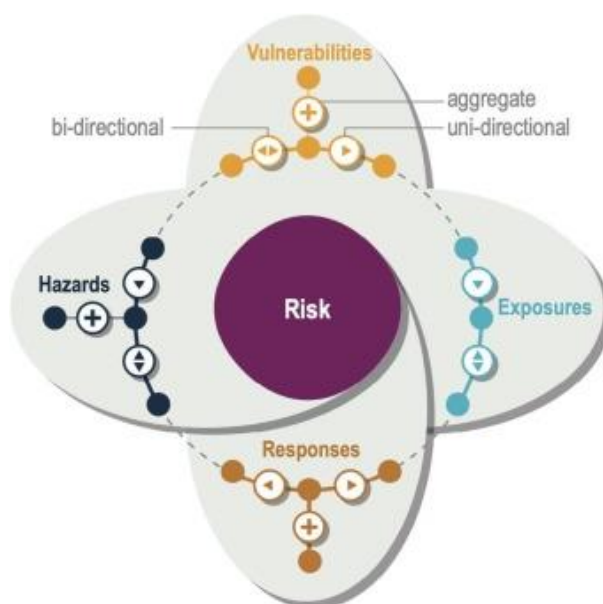


Figure 1. IPCC risk propeller diagram adapted from Aara Bergum et al (2022). This example illustrates how four dimensions of risk can aggregate or compound with each other or other determinants of risk to affect climate change impacts

Hazards refer to physical climate events or hazards (e.g. floods and droughts) and are studied using climate observations and models. However, these datasets have shortcomings in regions with limited meteorological infrastructure, such as countries with lower development or those affected by conflict, and they include inherent uncertainties (Dosio et al., 2019; Maidment et al., 2015).

Exposure describes who or what is located in hazard-prone areas (e.g. people, infrastructure, or assets). For example, flood exposure is sometimes quantified as the number of people who would be affected by flooding in an area. Exposure typically scales with the magnitude or scale of the hazard and so can either be quantified against set magnitudes such as a 1-in-100 year magnitude event, or quantified for a particular observed or simulated event.

Vulnerability is the propensity or predisposition to be adversely affected when exposed to a hazard (IPCC, 2023). Vulnerability can be as significant a driver impacts as exposure and the hazard itself (Simpson et al., 2021). Vulnerability is usually applied as a relative measure to describe differences in relative vulnerability between sub-groups or spatial areas. Assessing vulnerability is often done using indicators that are

quantifiable proxy measures of vulnerability and aggregated at a regional or national level (Chen et al., 2015; Martínez, 2012). Common indicators include household income, literacy rate, average levels of education, and age and gender demographics. Indicators are often combined in a single aggregate indicator where each factor is given a particular weight indicating its relative contribution to total vulnerability (e.g. Notre Dame Global Adaptation Index ND-GAIN (Chen et al., 2015) and the Human Development Index (Martínez, 2012). However, quantifying vulnerability in this way requires making assumptions about how different aspects of vulnerability contribute to potential impacts. These assumptions result in vulnerability indices that may capture significant uncertainties which are seldom quantified or described beyond recognition of data limitations (Ayanlade et al., 2023). Socio-cultural aspects, and attributes such as social capital, gender roles and norms, prejudice and marginalisation and how these factors interact with one another are difficult to capture quantitatively as an index, therefore, context-specific, qualitative assessments an important compliment to quantitative assessments.

Response has emerged as a proposed fourth dimension of risk, referring to how individual, communities, or institutions manage climate risks (Simpson et al., 2021) These responses are often assessed qualitatively and can include both positive and negative coping strategies such as migration or seeking alternative livelihoods. Increasing hazard intensity can overwhelm response options while political instability can render them ineffective. Inadequate responses may worsen vulnerability and contribute to maladaptation (Eriksen et al., 2021; Schipper et al., 2021). Including response as a component of risk is a reflection of the complexity and non-linearity of risk, particularly in the context of extreme events.

While the risk framework's components are conceptually simple, their real-world interactions are complex. Climate extremes often compound with other events or pre-existing vulnerabilities, amplifying risk. For instance, a flood following a prior drought can overwhelm communities still recovering from the drought, highlighting the need to understand how dynamic vulnerability contributes to cascading and interacting risks.

Risk is socially constructed; disasters do not result solely from natural hazards, but from the intersection of those hazards with structural vulnerabilities like poverty, inequality and weak governance (Blaikie et al., 2014). As recent reviews have shown, current risk management strategies often fail to reduce the impacts of subsequent hazard events when they are more extreme than the initial hazard, underlining the need to address the drivers of vulnerability—especially under compounding extremes (Tellman and Eakin, 2022).

COMPASS builds on the foundational IPCC risk framework described above, but goes beyond this to consider cascading and compounding events. COMPASS draws on the conceptual framework compounding extremes described by Zscheischler et al. (2017) which also reflects the non-linear and dynamic nature of risk within these compounding events.

3 Methods

3.1 Literature review

We conducted a literature review on the methodological approaches to quantify vulnerability and exposure in attribution studies. First, a comprehensive search was conducted across multiple academic databases, including Google Scholar, Scopus, and Web of Science, using relevant keywords such as "vulnerability assessment," "exposure quantification," "attribution studies," and "climate change impacts." This was supplemented by reviewing the references of selected articles to identify additional relevant studies. The selection criteria focused on peer-reviewed articles published within the last two decades to ensure the inclusion of contemporary methodologies. After gathering diverse studies, the review involved a systematic categorization of the approaches into qualitative assessments, quantitative models, and mixed-method

frameworks. Each method was evaluated in terms of its strengths and limitations and applicability to different contexts and scales (Brignardello-Petersen et al., 2025).

3.2 Key Informant interviews and thematic analysis

Sixteen key informant interviews (KII) were conducted to gather qualitative insights from experts in the field to enrich the literature review on vulnerability methods in attribution studies (Paprotny et al., 2025; Schoppa et al., 2024). The selection of informants included researchers and policymakers with extensive experience in vulnerability assessment and attribution methodologies. A semi-structured interview guide was developed (see Annex), featuring open-ended questions that explored participants' perspectives on current methods, challenges faced in quantifying vulnerability and exposure, and emerging trends in the field. Interviews were conducted via virtual platforms, ensuring accessibility for participants from diverse geographical locations. Each session was recorded with consent and subsequently transcribed for analysis.

Thematic analysis was employed to interpret the interview data, following a systematic process involving familiarizing the transcripts, coding the data into meaningful categories, and identifying overarching themes (Lochmiller, 2021). This qualitative approach allowed for exploring nuanced understandings and expert opinions that may not be fully captured in the existing literature. The findings from the thematic analysis complemented the literature review.

4 Key insights on integrating vulnerability into attribution

By using the insights from the 16 key informant interviews with researchers and experts working across the intersection of vulnerability and extreme event attribution, we start to answer key questions on vulnerability and EEA studies. The interviews explored how vulnerability is currently understood and applied in attribution studies, the challenges with integrating qualitative and context-specific knowledge, and the methodological trade-offs across different approaches. Rather than presenting a singular “best practice,” the findings reflect a diversity of experiences and perspectives. Together, they highlight not only the practical and epistemological tensions involved in this integration but also emerging opportunities to center vulnerability as a core – rather than peripheral – component of attribution science.

4.1 Is vulnerability important to include in extreme event attribution studies?

Vulnerability is not just a modifier of impacts, but the central reason disasters occur in the first place – often independent of the hazard. Its absence in attribution studies reinforces a hazard-centric narrative that reduces findings to “interesting science” with limited real-world uses. It misses a crucial opportunity for informing real-world narratives and policy around the drivers of impacts during disasters and potential solutions. Including vulnerability helps researchers avoid reductive (climate deterministic, “natural disaster”) framings and fosters a more accurate reflection of not just *what* the hazard did but *how* and *why* the hazard led to harm for specific people or places.

Focusing solely on climate variables risks masking the root causes of harm, including structural inequalities, poor governance, and colonial legacies. By integrating vulnerability, attribution studies can reframe disasters as outcomes of preventable social processes and not inevitable consequences of extreme weather.

However, some of the interviewed experts questioned whether integration is always feasible or even desirable, especially if the approaches used fail to adequately capture vulnerability. A few of the interviewees expressed concerns that vulnerability and attribution studies serve different purposes, operate on different timescales, and risk losing focus if forced together. Indeed, vulnerability challenges dominant norms in

attribution science. It requires interdisciplinary collaboration, the inclusion of an understanding of lived experience, and often confronts political sensitivities and root causes that are systemic and difficult to address. Despite these challenges, the authors of this report and a majority of the interviewees, did consider it is a worthwhile endeavor that significantly improves the societal relevance of attribution science to reflect a more complete, meaningful, and socially grounded reality.

4.2 What should take center stage?

Attribution studies do more than analyze climate data—they shape narratives about why harm occurred, for whom, and what could have been done differently. Key informants cautioned that treating vulnerability as an afterthought or framing it in overly technical or climate-centric terms, obscures the deeper social, political, and historical drivers of disaster. This framing also shapes how the public and policymakers interpret risk. When climate impacts are conveyed only in abstract terms like return periods or global averages, they often seem remote. Grounding attribution in local vulnerability makes the risks tangible and relevant.

Overly technical framings narrow causal explanations and tend to promote infrastructural or technological fixes, sidelining structural, policy, or redistributive solutions. As one interviewee put it, “the technical framing suits political agendas because it avoids meaningful change.” If attribution is to inform just and effective responses, it must reflect on how its own framing shapes political imagination.

Experts emphasized that methodological choices are also epistemological—they determine whose knowledge is valued, what explanations are prioritized, and which solutions are legitimized. Attribution science favors isolating variables and probabilistic reasoning, which can clash with the relational and embedded nature of vulnerability. Rather than reduce social complexity, some argued for centering lived experiences. Vulnerability should not be an “anecdotal” appendix but a core part of the narrative. Doing so improves clarity, relevance, and uptake—especially among decision-makers, who respond more to human impacts than abstract climate signals. This calls for attribution studies that do not only trace climate signals but also explain why harm occurred, who was most affected, and what could have prevented it.

4.3 What is unique about including vulnerability in an attribution study?

EEA studies focus on specific events; therefore, the key difference with vulnerability studies lies in purpose, timing, and framing. The extreme event provides a stress test of how people, policies, systems in a particular location are able to cope or not. This allows for a complimentary analysis that can reveal how vulnerability shaped disaster outcomes, rather than a more generic assessment of vulnerability under “normal conditions”. Further, this can be done for the specific purpose of informing post-disaster recovery efforts or adaptation policy. Several informants warned, however, that there is a risk that vulnerability is reduced to simplified indicators or generalizations that don’t reflect local realities, especially in rapid studies that don’t take the time to include local expertise.

4.4 What are the main gaps and challenges?

As climate impacts become increasingly complex and interconnected, capturing how vulnerabilities evolve and interact across multiple, compounding hazards is an added challenge. Integrating qualitative and quantitative insights on vulnerability can enable attribution studies to provide more nuanced understanding of compounding and cascading risk.

Assessing compounding and dynamic vulnerability is particularly challenging, as interactions between multiple risks remain poorly understood. Insights from experts highlight that current methodologies often fail to

account for the dynamic nature of vulnerability during compound events. Several experts emphasized that vulnerability is not static, it evolves between and during successive events, and this poses major challenges for studies attempting to untangle which hazard or driver caused which impact (Paprotny et al., 2025; Schoppa et al., 2024). Often existing multi-hazard assessments add risks together without analysing how impacts are amplified by compounding events or how vulnerabilities compound over time (Gori et al., 2020; Zscheischler and Fischer, 2020). This can lead to oversimplified narratives and weak policy relevance. There is a lack of agreed-upon frameworks or standards for characterising evolving, interacting vulnerabilities across events or regions. Experts stressed the need for tools that can capture real-time shifts in vulnerability and better model cascading risks. Approaches such as longitudinal community-level studies were proposed as essential to moving beyond linear or single-hazard thinking by providing richer, multi-faceted, evidence of changing vulnerability factors through time.

Data availability and the quality of vulnerability related information vary considerably by region and hazard type. Vulnerability data are often scarce in the Global South, although substantial local knowledge regarding vulnerabilities and impacts exists. Incorporating this local knowledge is critical for context-specific assessments; thus, primary data collection and close collaboration with local researchers and stakeholders are essential. However, some attribution studies are often conducted on rapid timelines that leave little room for new data collection, making it difficult to include rich, ground-level insights. Several informants also pointed out that existing data systems often exclude informal settlements, undocumented populations, or politically sensitive groups, further entrenching blind spots in vulnerability assessments.

Interviewees noted that current attribution frameworks often prioritize quantitative climate data, while social knowledge is treated as secondary or supplementary, if included at all. This reflects an underlying knowledge hierarchy that shapes which forms of expertise are seen as credible, and which are sidelined. Given the diverse nature of vulnerability, applying mixed methods to integrate various data types is recommended by the experts interviewed. No single method universally fits all contexts; the choice of methods should reflect the research question and context of the extreme event attribution study.

Finally, ensuring inclusive and unbiased vulnerability assessments is difficult; local perspectives and marginalized voices may be overlooked. Explicit efforts are necessary to address these biases and include diverse community perspectives in vulnerability analyses. There is also a broader gap between the knowledge prioritized in attribution science (often quantitative, climate-centric) and the social knowledge needed to understand vulnerability. Informants emphasized that bridging this gap will require not just methodological innovation but changes in collaboration, power-sharing, and institutional design. Some also questioned whether there is clarity or consensus about the use cases of vulnerability integration: is it for comparison, explanation, or to justify policy? Without clear purposes, efforts risk being too generic to inform any decisions or processes.

4.5 What are the best practices or key considerations for incorporating qualitative assessments of vulnerability into quantitative attribution statements?

Integrating qualitative vulnerability into quantitative attribution statements requires both methodological flexibility and conceptual clarity. Attribution studies should start by clearly defining the purpose of including vulnerability. For example, some studies may aim to explain observed impacts, while others intend to guide adaptation policy making or rebuilding after a disaster, while still others may simply aim to communicate risk comprehensively. Attribution studies have also been cited as potentially informing mitigation or loss and damage policy discussions. There are a range of potential use cases, and EEA scientists must have clarity on what their goal is in order to choose the vulnerability assessment approach that is best suited to that purpose.

Rather than treating vulnerability as something to add once the hazard has been analyzed, researchers should plan from the beginning to include it. Studies should consider the social, economic, and historical conditions in which the event occurred, and how people's lived experiences shaped the outcomes. For example, EEA studies can build in questions about vulnerability into counterfactuals (e.g. by asking questions like "how would the impacts have been different if the city that was impacted by the cyclone had a flood wall?") or use mixed method approaches such as combining household interviews, policy analysis, and socio-economic data allowing for a fuller picture of how vulnerability shapes disaster outcomes.

Including a disaster/vulnerability lens in the research question can make room in the study to unpack not just what happened but why it did and why people were affected differently. Key informants emphasized that this shift requires more than methodological add-ons; it demands a rethinking of attribution methods, starting with whose knowledge is included, and who defines the questions and outcomes. Co-production with local researchers or affected communities was highlighted as essential to ensure that qualitative insights are meaningful and not extractive or tokenistic.

To bridge qualitative and quantitative analyses, researchers can use tools like structured expert interviews, participatory scenario planning, and counterfactual analysis (e.g. what would outcomes have been under different preparedness conditions?). Translating qualitative insights into semi-quantitative forms – such as Likert-scale scoring from local experts – can help align with the probabilistic framing of attribution science while still capturing context-specific drivers of harm. However, researchers must be transparent about uncertainties and avoid overstating the certainty of vulnerability assessments.

4.6 How do you do this for compound events?

Integrating vulnerability into EEA studies of compound events requires moving beyond single-hazard models and adopting a systems perspective. Compound events – such as heatwaves during droughts, or wildfires followed by a storm – interact with overlapping vulnerabilities that cannot be easily isolated. To account for this, researchers should design studies that trace how vulnerabilities evolve across hazards, sectors, and time. Mixed-method approaches are essential: pairing hazard modelling with KII interviews, institutional analysis, and participatory tools (e.g. impact webs, scenario mapping) helps uncover how social, political, and economic factors shape outcomes when multiple stressors interact.

Key informants emphasized that vulnerability during compound events should not be treated as the sum of multiple risks, but as a dynamic and layered process where one hazard can intensify or reshape vulnerability to the next. This requires attribution studies to ask not just "what happened?" but "what changed in people's ability to cope or adapt between events?"

Since compounding vulnerabilities are dynamic and often non-linear, timing and context are critical. Pre-event vulnerability mapping and collaboration with local actors (e.g. disaster risk reduction (DRR) practitioners, health officials, community networks) can support more accurate real-time integration when compound events unfold. If not feasible, attribution studies could consider conducting phased analyses: starting with rapid attribution analysis, then following up with deeper vulnerability assessments once more data becomes available. Most importantly, researchers should not oversimplify. Vulnerability in compound events is not additive but must be understood as a layered, evolving process shaped by governance, inequality, and exposure.

5 Approaches to integrate vulnerability into attribution research

There is growing recognition of the crucial role that vulnerability plays in influencing the impacts of extreme weather events (Jan Van Oldenborgh et al., 2021; Jézéquel et al., 2024). This section groups methods for integrating vulnerability into extreme event attribution (EEA) into three methodological categories: quantitative, qualitative, and mixed/integrative. Each category is introduced with a brief synthesis of its strengths and limitations, followed by discussion of key tools and examples. Grouping by methodology helps clarify when and why to apply each approach, and supports better alignment with research questions, timelines, and contexts. While not all methods discussed are widely applied in attribution research today, each offers insights on how to capture vulnerability, drawing on both the literature and KIIs to discuss practical pathways to help researchers move beyond hazard-only narratives

Figure 1 below previews the approaches outlined in this chapter, highlighting potential use cases, strengths and limitations.

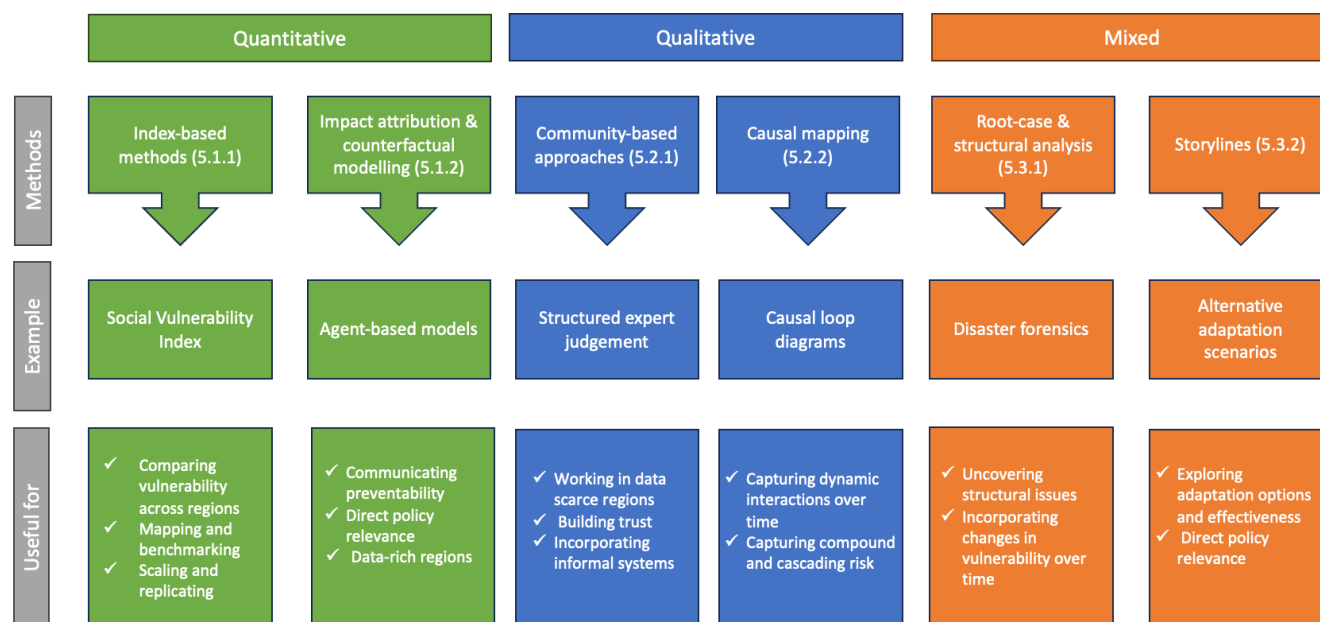


Figure 1: Summary of approaches to vulnerability assessment

5.1 Quantitative Approaches

Quantitative methods offer standardized, replicable ways to assess vulnerability across regions or time periods. These approaches are especially useful in data-rich regions, for rapid assessments, trend analysis, and large-scale comparisons. However, they often miss important local dynamics and social processes, and rely heavily on available datasets that may overlook marginalized or informal populations and systems.

5.1.1 Index-based methods

Composite indices are widely used to quantify vulnerability using socio-economic and demographic variables. These methods distil social, economic, and demographic data into composite indices, offering a standardized lens for comparing vulnerabilities across populations, regions, or time periods. Popular frameworks include the Social Vulnerability Index (SoVI) (Cutter, 2024), and the Livelihood Vulnerability Index (LVI) (Hahn et al., 2009).

SoVI aggregates a range of socio-economic variables like income, education, housing type, and minority status to identify at-risk populations.

Use Cases

After Hurricane Katrina (2005), the SoVI was used to highlight how low-income and minority neighbourhoods in New Orleans experienced disproportionate losses and slower recovery due to long-standing social inequities (Cutter et al., 2007; Finch et al., 2022).

During the 2018 California wildfires, SoVI helped assess evacuation patterns and access to post-disaster assistance, revealing that elderly residents, renters, and low-income groups faced greater evacuation challenges, contributing to higher mortality and longer displacement (Davies et al., 2018).

Spatially comparative indices, such as SoVI, also have limitations, such as missing out on providing the underlying reason why some people suffer more than others. Vulnerability data is often coarse, static, or inconsistently available—especially in informal settlements, politically sensitive regions, or areas with limited data infrastructure. While quantitative indices can support “differentiation” (i.e., identifying why one group was hit harder than another), but not necessarily “explanation” of root causes (e.g., why those vulnerabilities existed in the first place). Experts recommended integrating quantitative indicators within broader frameworks that also include qualitative data, scenario planning, and critical reflection on underlying assumptions and power dynamics.

These tools enable spatial mapping and risk profiling but often fail to capture intra-community differences or root causes of vulnerability. They can reinforce hazard-centric narratives if not contextualized with qualitative insights.

5.1.2 Impact attribution and counterfactual modelling

Impact attribution modeling seeks to quantify how much of the overall impact (e.g. damage costs, crop losses, or mortality) can be traced to changes in anthropogenic climate change and/or vulnerability (Huggel et al., 2016). These approaches rely on a quantitative impact model that may include vulnerability related variables to translate hazard magnitude into impact magnitude. This also enables the use of counterfactuals to estimate disaster impacts under hypothetical scenarios where the hazard, vulnerability, or exposure is altered (Davenport et al., 2021). There is ongoing debate about whether attributing such impacts to climate change is necessary or even feasible for guiding adaptation or compensation; still, it is relevant to briefly introduce the concept here, even though the focus of this report is vulnerability-infused EEA rather impact attribution.

Scenario-Based Impact Modeling (SBIM), for instance, demonstrated how mortality rates during the 2018 European heatwave would have been significantly higher without urban cooling strategies and heat adaptation policies (Harrington and Otto, 2020). Agent-Based Models (ABMs) in flood risk scenarios support similar evaluations, showing that stricter zoning and improved infrastructure could have reduced damages in Hurricane Sandy by 30% (De Ruig et al., 2023), and better insurance uptake and early warnings substantially lowered economic losses in the 2013 Central European floods (Haer et al., 2019). Counterfactual Statistical Modelling (PSM) has been used to assess social disparities in extreme event impacts. Research on European heatwaves showed that heat action plans aligned with reduced mortality (Harrington and Otto, 2020)

Use Case: Attribution of social inequalities related to Hurricane Harvey

Counterfactual statistical modelling was used to evaluate social disparities in the impacts of climate change-attributed flooding during Hurricane Harvey in Harris County, Texas. By integrating climate change attribution with hydrological flood models, researchers estimated flood depths and damages under scenarios with and without climate change influences. This approach revealed that 30 to 50% of flooded properties would not have been inundated without climate change, with low-income and Latina/x/o neighborhoods experiencing disproportionately higher impacts, particularly those outside FEMA’s 100-year floodplain. The methodology combined detailed land-parcel and census tract socio-economic data to highlight how counterfactual modelling can quantify the unequal burden of climate-driven extreme weather events on vulnerable communities, providing insights for targeted policy interventions. (Smiley et al., 2022).

Crop loss assessments in the U.S. Midwest have disentangled climate-induced yield declines from other factors such as farming practices and market forces (Diffenbaugh et al., 2021). Findings suggest that extreme heat and drought played a significant part in reduced maize and soybean yields but that targeted adaptations, such as irrigation and improved crop breeding, helped mitigate some losses (Diffenbaugh et al., 2021), speaking to the potential policy use cases.

These models can powerfully communicate the preventability of harm but depend on data availability, impact modeling, and multiple assumptions resulting in the potential for large uncertainties. For example, this type of approach would be impossible to deploy in large regions of the world where socioeconomic data is not systematically collected.

Several expert interviewees suggested applying counterfactual reasoning more systematically to vulnerability itself, not just to climate or hazard variables. Questions such as “what if early warning systems had reached informal settlements?” “what if the levees had been reinforced before the hurricane hit?” or “what if housing policies had been inclusive?” can help make the preventability of harm visible. These social counterfactuals reveal how outcomes could have been different under alternative political or institutional conditions, reinforcing that vulnerability is not inevitable – but shaped by changeable systems and decisions.

5.2 Qualitative Approaches

Qualitative methods are essential for understanding the deeper, systemic, and contextual drivers of vulnerability. They are well-suited to uncovering root causes, amplifying lived experience, and analyzing complex social processes.

5.2.1 Community-based approaches

These approaches include focus groups, stakeholder interviews, structured expert judgment, and community mapping. These methods center local knowledge and power-sharing but require time, trust-building, and care to avoid extractive or tokenistic engagement. They allow researchers to explore the distribution of risk, adaptive strategies, and coping capacities within communities, contributing to more equitable and actionable extreme event attribution (EEA) studies (Huggel et al., 2016).

Use Cases

In Puerto Rico, structured expert judgement was used to evaluate infrastructure vulnerabilities following Hurricane Maria. Experts from engineering, public health, and disaster response assessed why critical systems failed, while community engagement revealed inequities in post-disaster aid distribution (Marino et

al., 2020). This approach highlighted how colonial governance structures and economic precarity amplified the hurricane's impacts beyond climate-driven hazards.

During the 2011 and 2017 East African droughts empirical knowledge from pastoralist communities was integrated with climate models to assess drought vulnerability. Interviews and historical oral records provided insights into how changes in rainfall patterns, land-use policies, and conflict shaped food insecurity. These findings demonstrated that governance challenges and displacement exacerbated the climate-induced crisis (Maxwell and Hailey, 2021).

In Germany and Belgium, researchers incorporated community perspectives to assess barriers to flood preparedness and response after the Western European floods in 2021. Surveys and focus groups revealed that early warning failures, risk perception gaps, and trust in government institutions influenced flood fatalities. This approach led to recommendations for inclusive adaptation planning, reinforcing that social factors shape climate-attributed disaster impacts (Kreibich et al., 2022).

Participatory methods are critical for capturing the lived experiences of those most affected by extreme events, particularly in underrepresented or marginalized communities. Participatory research not only improves the accuracy and relevance of vulnerability assessments but also builds trust, fosters ownership, and ensures that attribution studies reflect diverse realities. In turn, building trust and ownership, can be fundamental to policy change, underscoring the importance of this method for a particular attribution use case.

5.2.2 Causal mapping

Causal mapping, often implemented through Causal Loop Diagrams (CLDs), is a systems dynamics tool that can be used for visualizing and exploring feedback loops and interconnections between hazards, exposure factors, and drivers of vulnerability. Unlike conceptual frameworks that identify linear combinations of factors, CLDs depict how social, economic, institutional, and environmental variables dynamically interact (Barbrook-Johnson and Penn, 2022; Hanger-Kopp et al., 2024; Haraldsson, 2001). By highlighting reinforcing loops, cascading effects, and potential points of intervention, CLDs are particularly valuable for analyzing compound hazards and multi-risk scenarios. CLDs help trace how vulnerabilities evolve—shaped by factors like social inequities, governance failures, or adaptive responses. These diagrams shift focus from “snapshots” of risk to processes that escalate or reduce vulnerability. However, the insights derived depend critically on whose knowledge is included. Without deliberate efforts to integrate local, Indigenous, or marginalized perspectives, CLDs risk oversimplifying complex realities or reproducing dominant narratives.

Construction of CLDs often relies on participatory approaches, which may include stakeholder workshops, structured interviews, or community validation of draft diagrams (Groundstroem and Juhola, 2021; Jack et al., 2020). When participatory, these methods can ensure context-specific accuracy, foster shared understanding and ownership of findings and raise awareness of structural drivers and policy levers.

In some cases, CLDs are built using qualitative data from interviews or literature (Buzogany et al., 2024) or combined with quantitative tools such as geospatial analysis or simulation models to test assumptions and project future dynamics.

Despite their utility, mapping large systems can be challenging. Effective diagrams require iterative development, careful selection of stakeholders, and strategies to maintain interpretability—such as layering, simplification, or pairing with narrative explanations (Barbrook-Johnson and Penn, 2022; Pregnolato et al., 2024).

Use Case: Participatory CLDs for Urban Flooding in South Asia

A recent study applied participatory CLDs to examine urban flood vulnerability in two South Asian cities (Choudhry et al., 2021). Local government officials, informal settlement residents, and civil society organizations co-developed diagrams that mapped how land tenure insecurity, drainage infrastructure, and political marginalization reinforced flood risk. The process revealed overlooked causal links—such as mistrust between residents and authorities—and identified opportunities for intervention, including tenure reform and co-designed early warning systems.

Ultimately, causal mapping offers a flexible, interdisciplinary lens for unpacking the social production of vulnerability. When used carefully and inclusively, CLDs can inform both attribution studies and policy design by clarifying dynamic risk pathways and revealing leverage points for reducing harm.

5.3 Mixed and Integrative Approaches

Quantitative and qualitative approaches are crucial in analysing vulnerability, exposure, and coping capacity in extreme event attribution studies. Quantitative methods allow for trend identification and hazard-impact quantification. These approaches provide clear metrics for risk analysis but run the risk of oversimplifying social systems by reducing vulnerability to numerical indicators, limiting their effectiveness in, for example, data-poor regions.

Conversely, qualitative approaches offer deep, context-specific insights into the systemic drivers of vulnerability. Through stakeholder consultations and literature reviews, qualitative methods explore how governance, economic structures, and cultural factors shape impacts. These methods capture local realities often overlooked in quantitative modelling but may suffer from limited scalability and reproducibility.

A hybrid, mixed-method approach that integrates both quantitative and qualitative methodologies is increasingly recognized by practitioners as essential for comprehensive attribution studies. Interviewees emphasized that no single method can fully capture vulnerability; instead, combining tools – such as household interviews, policy analysis, satellite data, and participatory scenario planning – provides a more complete understanding of how and why impacts occur.

Mixed methods can yield differing conclusions about “who is most vulnerable,” underscoring the need to clearly communicate methodological assumptions and trade-offs. They also help bridge the mismatch between rapid attribution timelines and the slower, evolving nature of vulnerability. Experts stressed that integrating qualitative insights requires more than tokenism – it demands collaboration with local actors, transparency, and a clear rationale. Semi-quantitative tools like Likert scales or impact pathways can help translate qualitative knowledge. Ultimately, these are not just technical choices but epistemological ones: mixed methods challenge dominant framings and make space for diverse understandings of vulnerability.

Mixed methods combine the breadth of quantitative tools with the depth of qualitative insights, offering a more holistic understanding of vulnerability in EEA. Mixed methods were broadly endorsed as the most robust approach, particularly for complex, compound events where vulnerability evolves over time. Use mixed methods when you need both attribution-level confidence and contextual understanding. For example, combining flood models with local interviews to understand why informal settlements experienced greater losses. Combining satellite data with local interviews or pairing quantitative risk assessments with scenario planning allows researchers to trace both the scale and the story of impact. However, interviewees cautioned that mixing methods is not just a technical fix – it requires intentional design, interdisciplinary collaboration, and transparency about limitation and assumptions. If time is limited, consider phased approaches: start with

a largely quantitative attribution study, then follow up with a qualitative vulnerability analysis. Ultimately, methodological choices should reflect not only the data available, but whose knowledge is being centered, and for what purpose.

While all the tools mentioned in the qualitative and quantitative approach sections could be included into a bespoke mixed or integrative approach, this section highlights suggestions from expert interviewers and a few common approaches and use cases.

Use Case: Rapid Attribution Studies Integrating Vulnerability

The World Weather Attribution (WWA) network conducts operational extreme event attribution in the form of rapid analyses of impactful extreme weather events within weeks of their occurrence. In each WWA study, an explicit section discusses various vulnerability, exposure, and response factors that, alongside the hazard, likely influenced the impacts of the studied weather event.

WWA takes a ‘knowledge-synthesis’ approach, incorporating vulnerability through three components: (1) a synthesis of impacts, categorising affected populations, assets, and systems; (2) a review of peer-reviewed and grey literature on historical changes in vulnerability and exposure, using hazard-specific templates with key vulnerability factors; and (3) key informant interviews with local and topical experts (Van Oldenborgh et al., 2021). These sources are synthesised into an assessment of the key factors that enhanced or reduced the hazard’s impacts (van Oldenborgh et al., 2021).

The rapid approach has limitations including biases towards available literature that can lead to over-representing factors that are more frequently documented or quantifiable, and relying on expert judgement that may introduce additional biases. Despite this, the approach is fit for purpose because it supports WWA’s goal of informing public discussions about extreme weather events soon after they occur and widens the lens of the discussion beyond just changes in the hazard allowing for further research to complement and deepen the findings. For example, a [recent rapid study](#) from the network attributed an extraordinary March heatwave in Central Asia to climate change, with temperatures up to 10C hotter in a warming climate. Importantly, it also highlighted key vulnerabilities in the agricultural sector including reliance on glacier-fed irrigation systems that was reflected in [media reporting](#) about the study.

5.3.1 Root cause and structural analysis

These approaches trace how social, political, and historical forces create and sustain vulnerability.

One widely used framework is the Pressure and Release (PAR) Model, which analyzes the progression of vulnerability from root causes (e.g., unequal power structures, poverty) through dynamic pressures (e.g., lack of training, urbanization) to unsafe conditions (e.g., fragile infrastructure, hazardous locations) (Blaikie et al., 2014; Chanza and Musakwa, 2022).

Another Disaster forensics uses investigative techniques to reconstruct disaster dynamics and identify governance failures or policy gaps (Huggel et al., 2016; Oliver-Smith et al., 2016). An example is the Forensic Investigations of Disasters (FORIN) framework, which examines long-term vulnerabilities, institutional failures, and policy gaps by reconstructing historical disaster events, often employing qualitative and quantitative analysis (Oliver-Smith et al., 2016; Tommasone, 2021). Unlike traditional post-disaster assessments, forensic approaches uncover the systemic failures in governance, land-use planning, environmental degradation, and emergency response (French et al., 2020; McDermott et al., 2022; UNDRR, 2024). For example, forensic studies have shown how poor urban planning and deforestation have exacerbated flood risk in cities, or how institutional neglect has amplified storm surge impacts in coastal areas (Oliver-Smith et al., 2016). By piecing

together data from various sources and time periods, disaster forensics not only explains what happened but why it happened, and what could have been done differently.

Use case: Cyclone Idai and underlying weaknesses

The PAR Model highlighted the role of long-term underdevelopment, weak infrastructure, and poor urban planning to explain why some in Mozambique experienced disproportionate impacts during Cyclone Idai in 2019 (Chanza and Musakwa, 2022).

These approaches are politically sensitive as tracing disaster impacts back to state neglect, land rights, or colonial legacies can provoke institutional resistance and challenge dominant and profitable narratives. They offer a pathway to connect long-standing vulnerability patterns with event impacts, providing a more holistic understanding of risk.

5.3.2 Scenario storylines

Storylines are a family of approaches that compliment probabilistic approaches to climate analysis. Whereas probabilistic approaches aim to assess the probability of an event or change, storylines aim to describe how events could have unfolded or may unfold in the future. As such they typically represent self-consistent unfolding of past or plausible future events or pathways (Shepherd et al., 2018). Storyline approaches directly engage with uncertainties through the construction of multiple storylines representing different assumptions about uncertain elements. For example, if there is uncertainty about the role of sea-level rise in an event, two storylines can be constructed using different assumptions about sea-level change to explore the uncertainty. Broadly speaking, storyline approaches can be divided into physical climate storylines, which focus on how components of the physical climate system interact to result in a particular change or event, and scenario storylines which translate the same ideas into other factors including socio-economics, policy, and vulnerability (Baulenas et al., 2023).

By grounding each storyline in observed and modelled evidence, researchers can integrate quantitative data (e.g., statistics, climate simulations) with qualitative inputs (e.g., interviews, causal maps) (Shepherd, 2019). They can be applied for climate risk assessments that include event cascades crossing multiple disciplinary or geographical borders (van den Hurk et al., 2023). With this integration of different knowledge types, from global to local scale, they allow risk and vulnerability assessment in the absence of purely quantitative information.

Climate storylines have become increasingly broadly applied and relate closely to other concepts such as scenarios, narratives, and impact pathways (Jack et al., 2020; Joosten et al., 2024; Zebisch et al., 2022). A key distinction of storylines is that different storylines are the result of different assumptions. This conditioned approach allows to explicitly illustrate uncertainties. Moreover, storylines allow the exploration of counterfactual futures, revealing how different adaptation measures or vulnerability shifts could alter outcomes (Carlson et al., 2024). As multiple plausible futures are explored, they can be directly employed in the decision-making processes helping to prioritize and optimize interventions to reduce negative impacts (Shepherd, 2019). Furthermore, the plausible futures can be seen as counterfactuals and can be applied for impact attribution studies (Carlson et al., 2024). Non-climate counterfactuals, such as alternative adaptation scenarios, can also be used to explore the role of factors such as improved early warning systems, pre-emptive evacuation and changes in vulnerability.

Use Case: Using Storylines to Explore Coastal Adaptation in Mozambique

Storylines were used to evaluate the effectiveness of different local adaptation strategies against Tropical Cyclone Idai in Beira, Mozambique (Goulart et al., 2025). Four hydrometeorological scenarios described climate change effects on precipitation and sea-level rise, and changes in the timing of the storm relative to tidal cycles. Three different coastal adaptation strategies were tested, no adaptation, hold the line, and integrated strategies. The results indicated that flood impacts were primarily driven by sea level rise, and that the combination of climate change and spring tides in the most impactful for residents in Beira. While none of the adaptation strategies tested fully stops flooding in Beira, the “integrated strategy” is more effective in more extreme scenarios. This approach helps policymakers envision the range of possible future risks, while also exploring the ways in which adaptation options interact with changes in the hazard.

6 Methodological choices: When to use what approach?

Choosing between qualitative, quantitative, or mixed methods depends on the purpose, timeline, and context of the attribution study. Rapid assessments may require readily available quantitative indicators, while deeper explorations of root causes and local dynamics call for qualitative methods such as interviews or participatory mapping. Many informants emphasized that no single method fits all situations; instead, the question should guide the method. In general, quantitative approaches are preferred for comparing outcomes across regions or identifying broad patterns (e.g. demographic risk profiles and spatial exposure). On the other hand, qualitative approaches improve understanding of why certain groups were most affected, especially in contexts with limited data, complex governance issues, or intersecting vulnerabilities. For instance, if the goal is to differentiate why one community was more affected than another, quantitative comparisons may suffice. But if the aim is to explain why those vulnerabilities exist, qualitative approaches are essential to uncover systemic, historical, or political drivers. Studies have shown that different approaches—such as indicator-based indices, qualitative methods, and modelling—highlight different aspects of vulnerability and produce varying results. The choice of method significantly shapes the outcomes and comparability of vulnerability assessments, underscoring the need for methodological transparency and integration (Schlumberger et al., 2025).

Mixed methods were broadly endorsed as the most robust approach, particularly for complex, compound events where vulnerability evolves over time. It is recommended to use mixed methods when you need both attribution-level confidence and contextual understanding. For example, combining flood models with local interviews to understand why informal settlements experienced greater losses. Combining satellite data with local interviews or pairing quantitative risk assessments with scenario planning allows researchers to trace both the scale and the story of impact. However, interviewees cautioned that mixing methods is not just a technical fix – it requires intentional design, interdisciplinary collaboration, and transparency about limitation and assumptions. If time is limited, consider phased approaches: start with a largely quantitative attribution study, then follow up with a qualitative vulnerability analysis. Ultimately, methodological choices should reflect not only the data available, but whose knowledge is being centered, and for what purpose.

6.1 Successful integration of vulnerability and exposure assessment in EEA

For instance, the retrospective analysis of Tropical Cyclones Eta and Iota in Honduras used causal mapping to link socioeconomic vulnerabilities, governance deficits, and climate hazards, showing how these factors compounded risks during the crises (World Bank, 2022). The impacts of the storms were analyzed using causal

mapping to explore the interplay of compounding risks, including climate hazards, violence, urbanization, and governance challenges, using both qualitative and quantitative data sources.

Here, we provide a comparative example of different approaches to characterize vulnerability and exposure in attribution studies. The tables below describe how to map vulnerability and exposure using the sequential tropical storm scenarios from Honduras, specifically Eta and Iota.

Table 1: Selected vulnerability assessment approaches and schematic flow charts illustrating how they are implemented

Approach	Flow chart
Social Vulnerability Index (SOVI)	<pre> graph LR A[Data Collection] --> B{Indicator Selection} B -- NO --> A B -- YES --> C[Index Calculation] C --> D[Mapping Vulnerability] </pre>
Causal Mapping	<pre> graph LR A[Stakeholder Engagement] --> B{Identify Causal Links?} B -- No --> C[Re-engage Stakeholders] C --> B B -- Yes --> D[Develop Causal Map] D --> E{Analyze Vulnerability Pathways?} E -- Yes --> F[Complete Analysis] E -- No --> G[Refine Causal Map] G --> E </pre>

Deliverable 3.2 – Guidance note on qualitatively assessing vulnerability factors in attribution studies

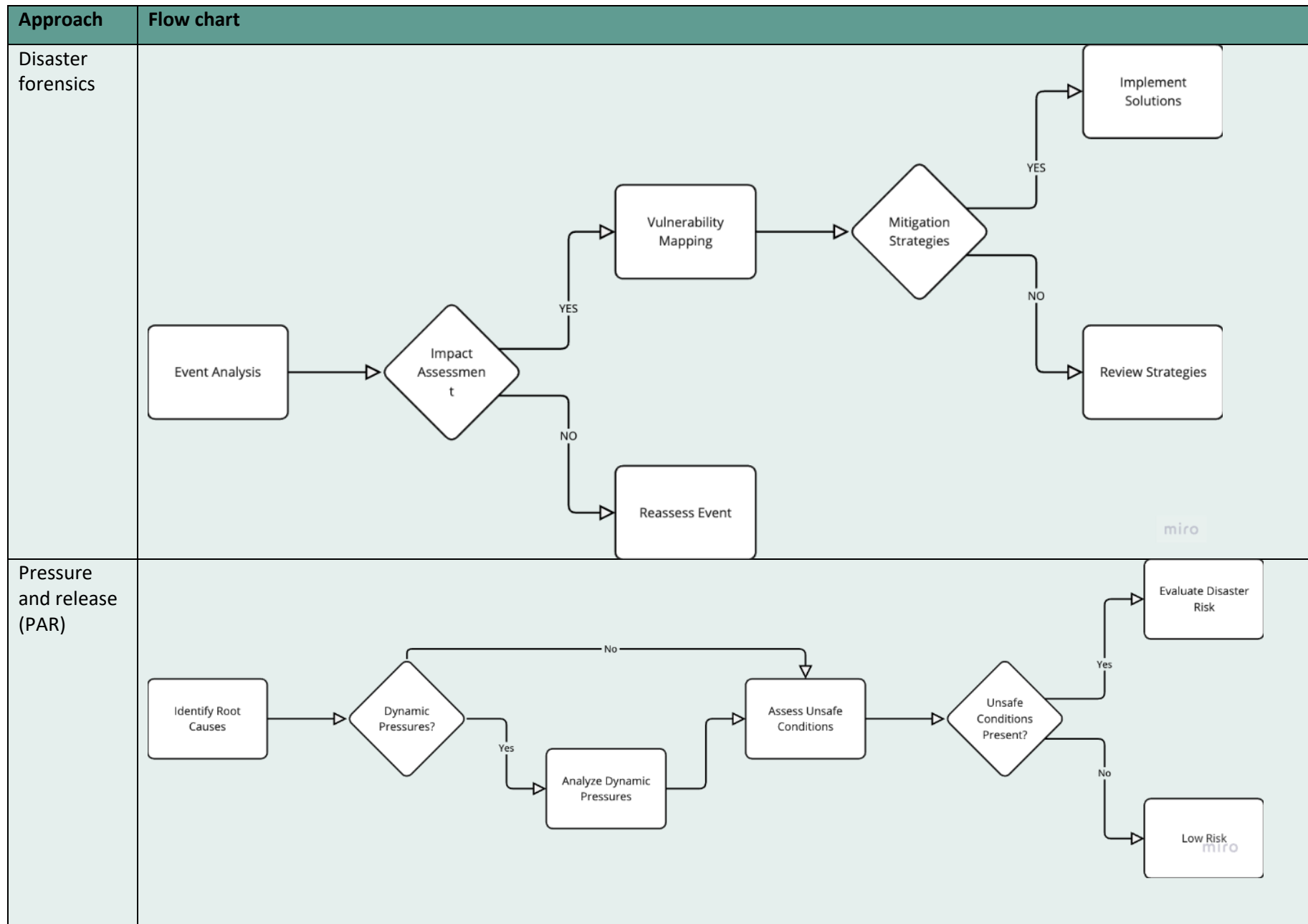


Table 2: Selected vulnerability assessment approaches and comparative characteristics

Approach	Distinct features	Commonalities	Data intensiveness	Effort intensiveness	Applications
Social Vulnerability Index (SOVI)	Quantitative approach that provides a numerical value to represent vulnerability. Utilizes a wide range of indicators to capture different aspects of vulnerability.	Relies on existing data sources. Can be integrated with geographic information systems (GIS) for mapping.	High, as it requires extensive data collection and processing.	Moderate, due to the need for data analysis and index computation.	Identifying vulnerable populations
Causal mapping	Participatory approach that actively involves stakeholders. Provides a visual representation of complex relationships.	Encourages stakeholder collaboration and input. Helps in visualizing complex interconnections.	Moderate, as it relies on stakeholder insights and qualitative data.	High, due to the participatory nature and need for detailed mapping	Visualizing cause-effect relationships
Disaster forensics	Investigative approach that delves into the specifics of past events. Aims to learn from past disasters to improve future responses.	Retrospective analysis helps understand vulnerabilities and impacts. Involves both qualitative and quantitative data.	Moderate to High, depending on the depth of analysis.	High, as it requires detailed investigation and analysis.	Useful for improving disaster preparedness and response strategies.
Pressure and release (PAR)	Focuses on structural and systemic issues that lead to vulnerability. Provides a framework to understand vulnerability as a process.	Emphasizes contextual analysis of vulnerability. Involves qualitative data and stakeholder input.	Moderate, focusing more on qualitative insights.	High, due to the need for comprehensive analysis and stakeholder engagement.	Used to design interventions that address root causes of vulnerability.

In deciding which approach to apply, it is important to:

1. **Define the purpose of the study.** Rapid assessments (e.g. media outreach) usually have very tight timelines, whereas policy or adaptation planning studies may have months of lead time
2. **Assess data availability.** Data availability enables quantitative or combined approaches; low data may require more reliance on qualitative approaches.
3. **Check timeline and resources.** A very short timeline favors leveraging existing quantitative tools (e.g. simple risk models, published statistics) with minimal qualitative work, while longer timelines can support surveys, interviews, or building new models.
4. **Evaluate local expertise.** If community contacts, NGOs, or local researchers are accessible, include them in qualitative focus groups or participatory mapping to ground the study in context. If not, rely on secondary sources or proxies.
5. **Consider event complexity.** Compound events typically require mixed methods such as pairing physical event modeling with qualitative tools (e.g. causal loop diagrams) to capture interacting vulnerabilities

For example, if the purpose of the study is to inform a particular policy decision, then approaches such as counterfactual modelling or storyline approaches that specifically answer policy-relevant questions are appropriate. This approach of course requires the availability of hazard, exposure, and vulnerability data, and therefore is not applicable everywhere, though it is less time-intensive than other approaches.

If you are working in a data-scarce region, the range of approaches narrows but there are still good options available for informing policy. For example, you can use a causal mapping approach to look at vulnerability points within a system (e.g. a city) or a disaster forensics approach that could point out deficiencies in land-use planning that increased flood exposure and vulnerability, for example. These methods present an opportunity for a wider policy discussion than one framed around a particular counterfactual or set of adaptation policies. Further, if you have access to experts or community members and sufficient time, it would be valuable to build in participatory methods that create local buy-in and ownership, and that will strengthen the potential for the research to inform policy. In this way, there is also an opportunity to use multiple approaches that build upon each other.

Alternatively, if the purpose for the research is to simply rapidly communicate the role of climate change in an extreme weather event and point out that human vulnerability factors also modify the extent to which the impacts are felt, methods like the SOVI index may be more appropriate, provided the data exists.

7 Conclusion

Extreme event attribution has evolved significantly over the past decade, offering increasingly sophisticated insights into the changing probabilities and intensities of extreme weather events under climate change. Yet, as this guidance note has explored in depth, focusing solely on the hazard component of risk leaves critical blind spots in understanding why impacts occur, who is affected, and what can be done to reduce harm.

This report has shown that integrating vulnerability into EEA studies is an important methodological challenge. While difficulties remain—such as the lack of standardized data, short timelines for rapid studies, and institutional barriers to interdisciplinary work—there are also a growing number of frameworks, tools, and case studies that illustrate practical pathways forward. This report has identified various promising methods that can be used to integrate vulnerability into attribution studies. However, the most appropriate method will have to be determined on a case-by-case basis. In general, qualitative and quantitative approaches each offer

different strengths, and their careful combination is often necessary to capture the dynamic and context-specific nature of vulnerability, especially in compound and cascading risk scenarios.

Importantly, the inclusion of vulnerability in attribution studies is not a technical add-on—it demands a shift in framing, a broadening of evidence bases, and a rethinking of whose knowledge counts. Co-production with local researchers, communities, and decision-makers is essential to ensure that assessments are not only accurate and reproduceable, but also legitimate, inclusive, and actionable.

We presented a variety of methodological approaches—quantitative, qualitative, and integrative—along with guidance on their appropriate application. In the context of COMPASS, this guidance note offers a foundation for selecting the most suitable vulnerability assessment approach for each Use Case in Work Package 4. By integrating vulnerability considerations into attribution science, we advance toward producing climate evidence that is not only more actionable but also fair and relevant to decision-making in the real world. By moving beyond hazard-centric narratives, attribution scientists can better support a wide range of applications—from disaster recovery to adaptation planning and improved risk communication. Ultimately, integrating vulnerability into attribution science enables more just, relevant, and transformative understandings of climate-related disasters—insights that are urgently needed in a world of deepening climate risk.

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Annex

Experts Interviewed

Expert Name	Job Title	Affiliation	Country	Interview Date
Emmanuel Raju	Director, Copenhagen Centre for Disaster Research	University of Copenhagen	Denmark	19 March
Joyce Kimutai	Researcher	Imperial College London, World Weather Attribution, Kenya Meteo. Dept.	Kenya	18 March
Lisa Thalheimer	Research Scholar	International Institute for Applied Systems Analysis	Europe	18 March
Lisa Schipper	Progressor of Development Geography	The University of Bonn	Germany	13 March
Ilan Kelman	Professor of Disasters and Health	University College London	UK	17 March
Erin Coughlan De Perez	Associate Professor	Tufts University	US	13 March
Kristie Ebi	Professor, Global Health	University of Washington	US	17 March
Marleen de Ruiter	Assistant Professor, Water and Climate Risk	Vrije University Amsterdam	Netherlands	11 March
Richard Jones	Science Fellow	UK Met Office Hadley Centre	UK	17 March
Mike Hulme	Professor of Human Geography	University of Cambridge	UK	20 March
Ana Diez Roux	Professor of epidemiology	Drexel University	US	19 March

Tristian Stolte	PhD Candidate	Vrije University Amsterdam	Netherlands	13 March
Emily Boyd	Professor	Lund University Centre for Sustainability Studies	Sweden	17 March
Ayesha Siddiqi	Associate Professor in Human Geography	University of Cambridge	UK	14 March
Jesse Ribot	Professor	American University	US	20 March
Miqueias Mugge	Academic Research Manager	Brazil Lab, Princeton University	US/Brazil	19 March

Key Informant Interview (KII) Questions

1. Extreme event attribution studies seek to understand the role of human-caused climate change in a particular extreme weather event. In recent years, scientists and other groups have highlighted the importance of including aspects of vulnerability (and exposure) to provide a fuller picture of the factors that contributed to the impacts of the extreme weather event. **Is there anything unique about how vulnerability is integrated into attribution studies? What makes it different from how vulnerability assessments are done for other use cases, if anything?**
2. While attribution science come in different flavours, it generally quantifies the relative contribution of climate change to an extreme weather event, or the change in frequency or intensity due to climate change. However, vulnerability factors are often difficult to fully quantify. **How do we integrate/supplement quantitative attribution statements with qualitative and quantitative vulnerability assessments?**
3. In recent years scientists have increasingly recognised the importance of thinking about compounding and cascading risks. In particular, compound extreme weather events such as heatwaves followed by floods, back-to-back hurricanes, or drought-wildfire interactions, are a new frontier of extreme event attribution. **How does vulnerability shape the impacts of compound extreme weather events?**
4. What are your top 3 recommendations for improving how vulnerability is assessed in attribution studies?
5. Is there anything we haven't covered that you think is important?