



The HuT

Innovative risk transfer and financing for DRR

Deliverable D3.7

DEVELOPED WITHIN

WP3 Governance and Policy,
T3.3 Insurance and risk financing instruments for DRR and local resilience

AUTHORS

Glauco Gallotti (LEITHA); Francesco Lo Conti (LEITHA);
Antonio Santoro (LEITHA); Antonio Tirri (LEITHA); Guido Rianna (CMCC)

Version 0.2

(27 March 2026)



This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement N° 101073957

1. Technical references

Project Acronym	The HuT
Project Title	The Human-Tech Nexus - Building a Safe Haven to cope with Climate Extremes
Project Coordinator	Michele Calvello UNIVERSITA DEGLI STUDI DI SALERNO mcalvello@unisa.it
Project Duration	October 2022 – September 2026 (48 months)

Deliverable No.	D3.7
Dissemination level*	PU
Work Package	WP3 - Governance and Policy
Task	T3.3 – Insurance and risk financing instruments for DRR and local resilience
Lead beneficiary	LEITHA
Contributing beneficiary/ies	CMCC, IIASA

- * PU = Public
 PP = Restricted to other programme participants (including the Commission Services)
 RE = Restricted to a group specified by the consortium (including the Commission Services)
 CO = Confidential, only for members of the consortium (including the Commission Services)



1.1. Document history

Version	Date	Lead contributor	Description
0.1	12.03.2026	Glauco Gallotti, Francesco Lo Conti, Antonio Santoro and Antonio Tirri (LEITHA), Guido Rianna (CMCC)	First draft
0.2	27.03.2026	Michele Calvello (UNISA)	Critical review and proofreading
0.3	30.03.2026	Glauco Gallotti, Francesco Lo Conti, Antonio Santoro and Antonio Tirri (LEITHA), Guido Rianna (CMCC)	Edits for approval
1.0	30.03.2026	Michele Calvello (UNISA)	Final version



2. Table of contents

1. Technical references	2
1.1. Document history	3
2. Table of contents	4
2.1. List of Tables	5
2.2. List of Figures	5
3. Introduction and objectives	6
3.1. Background and rationale	6
3.2. Lessons from D3.6	6
3.3. Insurance-linked securities and catastrophe bonds	6
4. Climate index–based risk transfer for DRR	10
4.1. Rationale for index-based and parametric instruments	10
4.2. Lessons from prototypes and reasons for a climate index-based catastrophe bond	10
5. The European Extreme Events Climate Index	13
5.1. Why an E3CI-based catastrophe bond in D3.7	13
5.2. Aggregating E3CI	15
6. Design of the E3CI-Based catastrophe bond	18
6.1. Deriving a loss model based on E3CI	18
6.1.1. Exposure modelling	18
6.1.2. Derivation of the vulnerability function	19
6.1.3. Transformation of E3CI values into damage ratios	20
6.1.4. Transformation of damage ratios into losses	20
6.2. Spread estimate	22
6.3. Artemis dataset	23
6.4. Cat bond design methodology	26
6.5. Results	29
7. Contribution to DRR and local resilience	36
8. Comparison with alternative financing instruments	37
9. Conclusions and recommendations	38
10. References	39



2.1. List of Tables

Table 1: Example of an Artemis cat bond descriptive sheet.	24
Table 2: Estimated reinsurance needs.	30
Table 3: Indemnity cat bond pricing parameters.	30
Table 4: Parametric cat bond pricing parameters.	31
Table 5: E3CI thresholds adopted for parametric cat bonds.	31

2.2. List of Figures

Figure 1: Insurance financing schema from premium retention to cat bonds (Braun and Kousky, 2021).	7
Figure 2: Cat bond roles and transfer mechanisms (Braun and Kousky, 2021).	8
Figure 3: Comparison of cat bond trigger types (Braun and Kousky, 2021).	9
Figure 4: Aggregated E3CI at the country level (Italy) with spatial median criterion.	16
Figure 5: Aggregated E3CI at the country level (Italy) with POT criterion.	17
Figure 6: Vulnerability function expressing the relationship between E3CI components and the resulting damage ratio values; the function's maximum damage ratio is constrained to 0.7... ..	20
Figure 7: Schematic representation of the E3CI-based loss model.	21
Figure 8: Example of E3CI-based loss model data (Precipitation component, March 1985).	22
Figure 9: Scatterplot of Artemis cat bonds expected losses and relative final spread price.	25
Figure 10: Frequency distribution of selected Artemis cat bonds.	25
Figure 11: Linear fitting of Spread-Expected loss relation based on peril.	26
Figure 12: Schematic representation of the workflow for the development of the Indemnity type Cat Bond.	28
Figure 13: Schematic representation of the workflow for the development of the parametric type Cat Bond.	29
Figure 14: Indemnity Cat Bond results.	33
Figure 15: Parametric Cat Bond (trigger estimated on spatial median aggregation).	34
Figure 16: Parametric Cat Bond (trigger estimated on POT aggregation).	35

3. Introduction and objectives

3.1. Background and rationale

Across Europe, climate- and weather-related disasters are increasing in frequency and severity, amplifying losses for households, firms, and the public sector. Traditional indemnity insurance—while essential—struggles to keep pace with evolving hazards, information gaps, and rising volatility, leaving a persistent insurance protection gap. Within The HuT project, Task 3.3 explores innovative risk transfer and financing solutions to reduce this gap and strengthen **disaster risk reduction** (DRR) and local resilience, emphasizing instruments that deliver rapid, transparent payouts and create incentives for ex-ante risk mitigation. Building on this vision, D3.7 focuses on risk transfer architectures that can scale and integrate with public policies and local governance.

3.2. Lessons from D3.6

Deliverable D3.6 designed and tested two prototype insurance products grounded in bespoke catastrophe (nat cat) modeling and co-developed with Demonstrator 3 – Monti Lattari (landslides) and Demonstrator 8 – Sardinia/Ogliastra (wildfire) stakeholders. These prototypes—a parametric “Landslide First Rescue” product and a Community-Based Catastrophe Insurance (CBCI) “Fire Safe Community” product—validated three pillars for innovation: (i) use of index/trigger thresholds to accelerate claims, (ii) explicit linkages to mitigation actions (e.g., ecological forestry) to earn premium reductions, and (iii) reliance on transparent, localized risk models to price coverage fairly where actuarial loss histories are thin.

The parametric product associated with landslide events illustrated how predefined rainfall thresholds and simplified claims verification can deliver fast emergency liquidity, complementing conventional policies covering damage assessment and reconstruction. The CBCI wildfire concept demonstrated a collective risk approach that can embed incentives for fuel management and community-scale mitigation, while addressing stakeholder concerns around affordability, clarity of terms, and governance. Both prototypes were priced using nat cat models that link hazard, vulnerability, exposure and finance modules; generate stochastic event sets (SES); and derive Aggregate/Occurrence Exceeding Probability (AEP/OEP) curves to inform pure and finite premium rates—providing a methodological foundation for scalable risk transfer solutions.

D3.6 also surfaced implementation realities crucial for subsequent design choices: data availability and quality for triggers; stakeholder trust and clarity in coverage scope; portfolio-level sustainability (mutuality, reinsurance, or capital market support); and alignment with evolving Italian regulatory developments on mandatory catastrophe coverage for businesses. These insights directly shape the D3.7 instrument here proposed.

3.3. Insurance-linked securities and catastrophe bonds

Financial instruments supporting the capital management of insurance products constitute a strategic component for ensuring financial sustainability and enable the possibility to innovate such products—both in terms of market competitiveness and in supporting risk-reduction and mitigation strategies. In the field of natural hazards, financial instruments contribute to the optimisation of the capital required to cover such risks. These instruments can be represented



through different layers of risk transfer, which mainly include reinsurance contracts and other financial instruments, commonly referred to as Insurance-Linked Securities (ILS), mainly represented by catastrophe bonds (cat bonds). Figure 1 illustrates these instruments, highlighting the progressive coverage of different levels of risk.

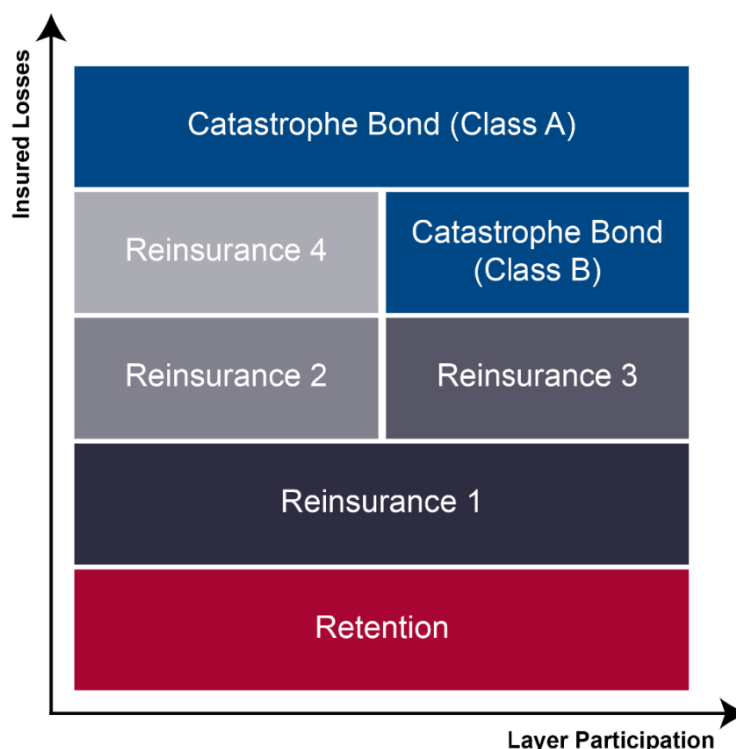


Figure 1: Insurance financing schema from premium retention to cat bonds (Braun and Kousky, 2021).

The figure illustrates a layered risk transfer structure commonly used in insurance and reinsurance programmes for catastrophic events. Insured losses increase along the vertical axis, while the horizontal axis indicates how different instruments participate in covering each loss layer. At the lowest level, the retention represents the portion of losses that the insurer retains and absorbs directly. Once losses exceed this threshold, successive layers of traditional reinsurance are triggered, allowing the insurer to transfer part of the risk to reinsurance companies.

As the magnitude of potential losses increases, additional protection can be provided through catastrophe bonds. These instruments transfer extreme catastrophe risk to capital market investors. In the upper layers, investors absorb losses in exchange for higher returns, but they may lose part or all of their invested capital if predefined catastrophic events occur. This layered structure allows insurers to diversify risk, increase financial resilience, and combine traditional reinsurance capacity with capital market solutions for managing large scale catastrophe exposures.

The financial structure of a catastrophe bond transaction is represented in (Figure 2). The process begins with the sponsor, typically an insurance or reinsurance company, which seeks protection against specific disaster events. A Special Purpose Vehicle (SPV) is constituted to enable the cat

bond transactions. The sponsor pays a premium to the SPV in exchange for coverage. If a predefined catastrophic event occurs, the SPV provides a payout to the sponsor.

Investors purchase the catastrophe bond issued by the SPV by providing the principal. This capital is placed in a secure trust and invested in low risk assets to ensure its availability if a disaster occurs. The investment generates a return, which together with the premium paid by the sponsor is used to pay investors a periodic coupon consisting of premium and interest.

If no disaster occurs during the bond term, the principal held in the trust is returned to investors at maturity. If the specified catastrophic event occurs, part or all of the principal is used to compensate the sponsor for the insured losses. This mechanism enables insurers to transfer extreme catastrophe risk to capital markets while providing investors with access to non traditional risk exposures.

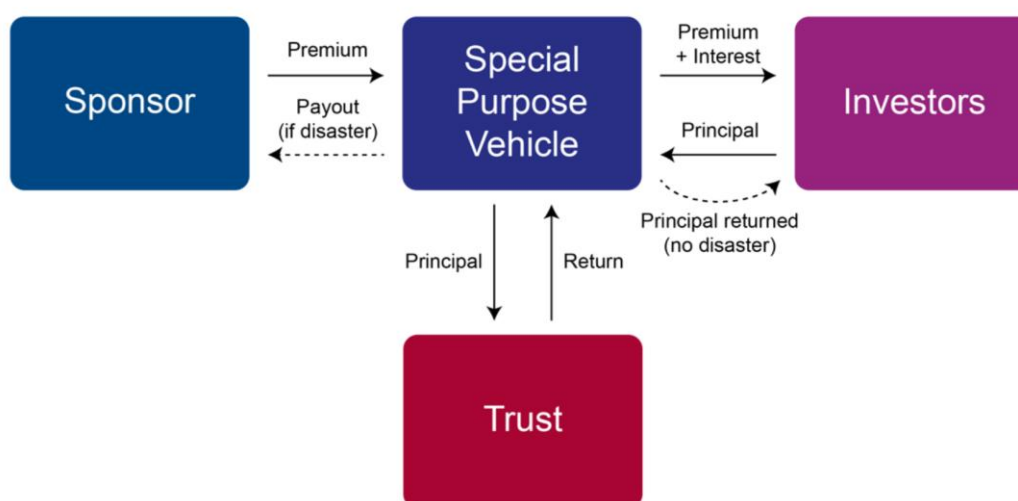


Figure 2: Cat bond roles and transfer mechanisms (Braun and Kousky, 2021).

The events triggering capital transfer may be defined through different mechanisms:

- *indemnity loss*: the event is defined as the insurance loss associated with the covered event type
- *modeled loss*: the event is defined as the modelled estimate of the insurance loss associated with the covered event type
- *industry loss*: the event is defined as the loss of the affected industrial sector
- *parametric*: the event is defined based on the exceedance of a predefined threshold of an index not directly linked to insurance or industry losses.

As highlighted by Braun and Kousky (2021), each of these trigger types presents distinct strengths and weaknesses. The indemnity loss, which is the most widely used, benefits from strong acceptance by regulatory bodies and ensures full correspondence between the cat bond payout and the insurance losses for which the instrument is designed. The disadvantages relate to longer payment times, as payouts depend on the actual loss experience of the covered insurer, and to the lack of transparency regarding the link between these losses and the underlying catastrophic event.

These weaknesses are addressed by parametric cat bonds, as their activation depends on the exceedance of predefined thresholds of an independently computed index. However, this type of instrument tends to face greater regulatory scrutiny and creates a potential mismatch between the cat bond payout and the actual insurance losses, since the latter are not directly tied to the parametric index, even though they are correlated with it (**Errore. L'origine riferimento non è stata trovata.**).



Figure 3: Comparison of cat bond trigger types (Braun and Kousky, 2021).

The main objective of D3.7 consists of analysing the potential for a climate index-based catastrophe bond that is operationally feasible for local and regional authorities (or pooled public sponsors), providing fast and transparent payouts, and encouraging DRR while being scalable and replicable across EU contexts.

D3.7 is well framed in Task 3.3, translating the findings of Deliverable 3.6 and the prototype lessons and modelling capabilities into a market-compatible risk transfer solution that can be adopted by public sponsors and integrated with local DRR strategies. The chapters unfold by first presenting the motivation for adopting climate index-based and parametric risk transfer instruments, drawing on insights from previous prototypes and the rationale developed in earlier project stages. It then introduces the E3CI as a scientifically robust and operationally reliable trigger for a catastrophe bond, explaining its relevance and suitability for the D3.7 framework. The document proceeds to detail the design of the E3CI based cat bond, including the derivation of the loss model, spread estimation, and use of the Artemis dataset, before presenting the resulting performance metrics. Subsequent sections analyse how such an instrument can strengthen disaster risk reduction and local resilience, followed by a comparison with alternative financing solutions. The chapter concludes with recommendations and a policy oriented roadmap for scalable and replicable implementation across The HuT use cases.

4. Climate index–based risk transfer for DRR

4.1. Rationale for index-based and parametric instruments

Traditional indemnity insurance faces structural hurdles under climate change: slow and costly claims adjustment, pricing uncertainty for low frequency/high severity perils, and widening protection gaps—issues already evidenced in The HuT’s prototype work (D3.6). Index-based (parametric) instruments address several of these frictions by tying payouts to objective, observable triggers and thereby accelerating liquidity aftershocks. Economic theory further explains how basis risk—the mismatch between index activation and actual losses—shapes both demand and contract design, with nonmonotonic demand responses under risk aversion and deadweight losses from imperfect index matching (Clarke, 2016).

Recent peer reviewed work has deepened understanding of basis risk mechanics. Quantitative studies show that basis risk is a structural—yet partially manageable—feature of parametric instruments: portfolio diversification reduces basis risk volatility, while geospatial relationships between the insured exposure, triggering station, and hazard footprint are primary determinants of mismatch (Gao et al., 2025). Empirical simulation evidence also confirms that event severity has limited influence on basis risk behaviour, suggesting that even catastrophic events do not inherently undermine parametric model viability (Gao et al., 2025).

Review and applied literature consistently highlight both advantages—speed, transparency, lower administrative costs—and constraints—basis risk, data requirements, stakeholder trust and understanding (Barnett & Mahul, 2007; Carter et al., 2014). Additional analyses emphasize that parametric tools can enhance climate resilience when paired with reliable environmental data, satellite based indices, and clear communication strategies to mitigate design related coverage gaps (World Economic Forum, 2025). Other applied research on climate adaptation contexts similarly shows that parametric schemes lower transaction costs and can extend coverage to sectors underserved by traditional insurance, such as renewable energy infrastructure and smallholder agriculture (Hyman, 2025).

These insights align with The HuT’s prototypes, where parametric landslide thresholds proved operationally efficient but still required strong data governance and stakeholder engagement to sustain confidence. The literature confirms that parametric solutions are most effective when technical trigger design, spatial calibration, and communication strategies explicitly address basis risk perceptions and user trust—key determinants of uptake and long term viability.

4.2. Lessons from prototypes and reasons for a climate index-based catastrophe bond

Several opportunities and gaps emerge from D3.6:

- *Trigger design.* D3.6 showed that environmental thresholds (e.g., rainfall intensity; wildfire intensity/vegetation states) can be reproducible and geographically explicit, supporting automated or rapid payouts and facilitating communication of “if-then” rules to end-users.



- *Integration with DRR.* The wildfire prototype embedded premium discounts for ecological forestry management, illustrating how index-linked products can reward ex-ante mitigation and not only finance ex-post response.
- *Basis risk persists.* Literature and practice converge that basis risk is the primary adoption barrier; mitigation requires improved indices, spatial aggregation, layering, and multi-trigger designs (Barnett & Mahul, 2007; Carter et al., 2014; recent empirical advances on extreme-tail design).
- *Data quality/availability.* Robust triggers depend on consistent historical records and transparent processing; new “big data” sources (e.g., remote sensing) help but bring measurement bias pitfalls if samples are short relative to spatial coverage.
- *Trust and clarity.* Stakeholder interviews in Sardinia underscored concerns about coverage scope and past claims experiences—reinforcing the need for transparent indices, clear wordings, and governance that users perceive as fair.

In this context, climate index-based triggers can capture compound or cascading extremes (e.g., hot-dry events, prolonged drought preceding wildfire seasons) more effectively than single-hazard, event-specific parameters. The IPCC AR6 assessment documents widespread increases in hot extremes and heavy precipitation and emphasizes compound events—a crucial rationale for indices that integrate information across time/space (Seneviratne et al., 2021). In Europe, this recent work shows growing impacts from concurrent extremes (e.g., drought/heat) and their regional synchronization, strengthening the case for pan-regional, standardized indices to support scalable risk transfer (Seneviratne et al. 2021).

For DRR governance, climate index-based triggers offer three benefits:

1. Pre-agreed contingent finance for public sponsors, enabling stabilizing liquidity while damage assessments proceed.
2. Alignment with climatic stressors, not only isolated events—useful for anticipatory action (e.g., fuel management ahead of peak fire weather).
3. Lower transaction costs and improved replicability across regions—important where local hazard datasets are patchy (as D3.6 observed).

Moving from single-policy prototypes to a capital-markets instrument—a catastrophe bond with a climate-index (E3CI) trigger—leverages parametric principles at regional scale and mobilizes diversified investor capital to complement re/insurance and public budgets. Academic and market literature positions CAT bonds as fully collateralized, transparent risk-transfer vehicles with well-studied trigger choices (indemnity, industry loss, modelled loss, parametric/index) and distinct basis-risk profiles—topics extensively treated in the insurance-linked securities (ILS) canon.

Beyond design mechanics, systemic flood/heat/drought correlations across European regions challenge traditional pooling and justify index-based public risk financing; studies show increasing stress on disaster risk finance with correlated extremes, and recommend risk layering across reduction, retention, and transfer, including capital-market instruments (Jongman, B. et al., 2014).

An E3CI-triggered CAT bond thus provides:

- Rapid, rules-based payouts independent of claim adjustment (parametric logic).
- Transparency and replicability (published, science-based climate extreme metrics).
- Scalability across jurisdictions (consistent methodology, governance, and data standards).



- A platform to embed DRR incentives, e.g., conditioning use-of-proceeds or step-down premiums on mitigation benchmarks—extending the logic piloted in D3.6’s wildfire product.



5. The European Extreme Events Climate Index

The European Extreme Events Climate Index (E3CI; <https://climateindex.eu/>) is a climate-risk monitoring tool designed to quantify, map, and track the frequency and severity of extreme weather-induced events across Europe. Funded by the IFAB Foundation and developed by CMCC Foundation and Leithà, the index leverages the ERA5 reanalysis dataset compute monthly anomalies with respect to long-term climatological baselines (in this case 1981-2010). ERA5 reanalysis dataset is a global atmospheric reanalysis dataset produced by the European Centre for Medium-Range Weather Forecasts.

It provides hourly estimates of a wide range of climate variables by combining numerical weather models with observational data through data assimilation. By translating these anomalies into synthetic indicators for seven major weather-induced perils—extreme maximum and minimum temperatures, extreme precipitation, intense winds, hail, drought, and fire—the E3CI provides a coherent and standardized representation of climate stress at multiple spatial resolutions, from the national scale down to regional and provincial levels (NUTS2 and NUTS3). Conceptually, the index functions as both a diagnostic and prognostic climate service: it offers backward-looking assessments that identify territories experiencing heightened climatic pressures, while simultaneously enabling users to detect emerging trends associated with ongoing climate change. Its construction draws on consolidated science-driven knowledge to produce a monthly snapshot of Europe's extreme-event landscape, providing institutions, insurers, and businesses with an accessible and operational metric for evaluating environmental risk. In this respect, the E3CI has rapidly become an important instrument for climate-impact analysis and for designing strategies of adaptation, resilience, and risk transfer, bridging scientific climate diagnostics with practical decision-making in the public and private sectors.

5.1. Why an E3CI-based catastrophe bond in D3.7

Adopting the E3CI as the activation mechanism aligns financial protection with a scientifically grounded representation of climatic stress. Compared with single-hazard indicators or local thresholds, a climate-index approach can better reflect the multi-dimensional and compound nature of extremes that increasingly drive impacts across Europe, as assessed in IPCC AR6 (Seneviratne et al., 2021).

The credibility of a climate index-based trigger hinges on data quality, methodological transparency, and reproducibility. E3CI-type indices benefit from harmonized European datasets and standardized anomaly definitions—critical properties for parametric instruments where payouts must be verifiable and independent of loss adjustment. The insurance-linked securities literature consistently emphasizes clear trigger definitions, public data provenance, and auditable computation as prerequisites for investor confidence and surveillance of catastrophe bonds, while also discussing the trade-offs among indemnity, modelled-loss, industry-loss, and parametric/index triggers and the centrality of basis-risk management in that choice (Barrieu & Albertini, 2010). Geographical consistency is equally important for sponsors operating at regional or multi-jurisdictional scale. Climate-index triggers built on pan-European datasets reduce sensitivity to uneven local observations and support scalability while preserving comparability of activation conditions. This is especially pertinent as extremes exhibit co-variation across basins and regions, which raises portfolio and fiscal stress; evidence on correlated European flood



losses and implications for disaster-risk finance underscores the need for rules-based, scalable risk transfer that can mobilize diversified capital alongside public budgets (Jongman et al., 2014).

A further motivation for E3CI is the potential to reduce basis risk relative to narrow, single-variable thresholds. By integrating multiple dimensions of climate stress, the index can mitigate mismatches between the trigger signal and realized impacts—a factor that index-insurance theory identifies as crucial for adoption and welfare; hence, trigger architectures that track the hazard landscape more faithfully are preferred, provided they remain transparent and auditable (Clarke, 2016). Within a catastrophe bond, a climate index-based trigger enables a clear mapping from statistically rare climate anomalies to activation thresholds, with flexible spatial aggregation matching the sponsor's risk perimeter. This supports tractable risk modelling and investor communication, since trigger probabilities and expected losses can be parameterized against long-run distributions of climate anomalies, consistent with ILS practice on trigger selection, disclosure, and monitoring. Reviews of ILS also note that well-specified parametric/index triggers improve transparency and payout speed, while their basis risk must be engineered down via spatial aggregation, multi-trigger logic, and layered payout functions (Barrieu & Albertini, 2010; Cummins, 2014).

Finally, a climate index-based approach complements DRR governance. Linking payouts to climatic anomalies rather than observed damage avoids creating incentives to delay mitigation or to rebuild “as before.” At the same time, the predictability of index-based liquidity enables sponsors to pre-commit use-of-proceeds to resilience investments, aligning with Task 3.3's DRR objectives while maintaining capital-markets discipline around trigger definition and disclosure (Barrieu & Albertini, 2010).

D3.7 advances from prototype insurance products to a capital markets solution: a cat bond with a climate index trigger based on the E3CI. This direction is motivated by three factors highlighted in D3.6:

1. the need for rapid, rules-based payouts decoupled from loss adjustment delays
2. the importance of transparent, reproducible indices that resonate with policy and operational users
3. the opportunity to mobilize diversified investor capital to complement insurance/reinsurance capacity and stabilize public finances after extremes. By anchoring the trigger to an evidence-based climate extreme index, the instrument aims to reduce transaction costs, support multi-hazard design, and better connect ex-ante DRR investments with ex-post liquidity.

The analyses carried out for defining and evaluating cat bonds using E3CI data are limited to a selected group of perils considered to have the greatest relevance in terms of insurance impact. These perils include the following:

- Wildfire
- Precipitation
- Wind
- Hail.

E3CI data have been used in two complementary ways: first, to develop a loss-modelling framework in which the E3CI serves as the hazard variable; and second, to construct a national-scale aggregation that provides the reference index evaluated as a parametric cat-bond trigger. The first usage take into account a portfolio distribution, here synthesized proportionally to building density, to estimate a distribution of damage effects. Such loss modelling will be described in



Section **Errore. L'origine riferimento non è stata trovata.**. The aggregation of E3CI at national scale is described in the following subsection.

5.2. Aggregating E3CI

The adoption of E3CI as the index for parametric coverage requires the definition of a clear criterion to determine the trigger conditions. In particular, such criterion should take into account the spatial distribution of both events and the E3CI values. A straightforward approach, for a given area of interest, is to aggregate these variables into a single metric that captures both the occurrence and the magnitude of observed events, and subsequently identify an appropriate threshold to determine which events should trigger the coverage.

The spatial aggregation on the monthly map of a given E3CI component could either be carried out by means of simple spatial statistics, such as mean, median, quantiles, or with more complex criteria to account for both the severity and the frequency of values. In order to evaluate these strategies they have been both implemented. After evaluating several statistics the spatial median has been selected to represent the first approach. The other strategy has been implemented determining the proportion of the area exceeding a threshold value, that has been set to a value of two (hereafter this strategy is identified as POT). Finally, E3CI values are filtered to retain only the months during which each peril is climatologically relevant for Italy. The selected months are as follows:

- wildfire events are considered from June to September (months 6–9)
- precipitation related extremes are considered in January through May and again from September to December (months 1, 2, 3, 4, 5, 9, 10, 11, 12)
- wind related anomalies are considered throughout the entire year (months 1 to 12)
- hail events are considered from April to September (months 4–9).

The time series obtained after applying spatial aggregation and temporal filtering are shown in **Errore. L'origine riferimento non è stata trovata.** and **Errore. L'origine riferimento non è stata trovata.** for the spatial median and the POT criteria, respectively.

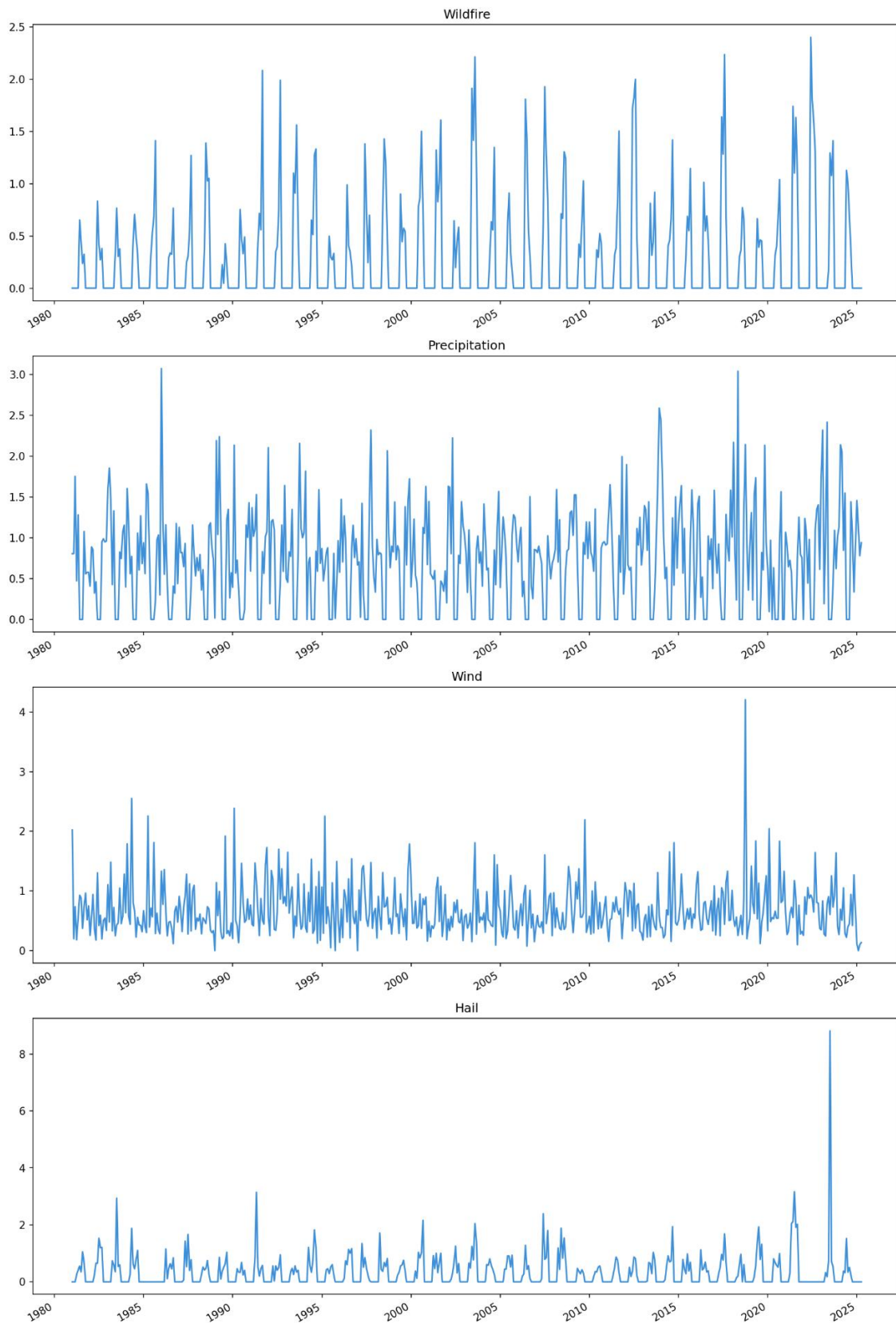


Figure 4: Aggregated E3CI at the country level (Italy) with spatial median criterion.



Figure 5: Aggregated E3CI at the country level (Italy) with POT criterion.



6. Design of the E3CI-Based catastrophe bond

As mentioned above, the analyses conducted in this study focus on exploring the potential of the E3CI as a tool to support the design of cat bonds capable of contributing—through their role as a stabilizing mechanism for insurance activities—to the facilitation or financing of DRR initiatives. In this chapter, the parameter-estimation procedures and the simulation framework adopted to model the functioning of cat bonds associated with the perils represented by each component of the E3CI is described. For each peril, an insurance coverage is assumed over a synthetic portfolio developed to ensure territorial representativeness according to predefined criteria.

The following sections first present the methodology used to construct the E3CI-based loss estimation model, then introduce the pricing framework developed for the associated catastrophe bonds, along with the analyses conducted for both indemnity based and parametric structures. The final sections report the resulting outcomes and provide a comprehensive evaluation.

6.1. Deriving a loss model based on E3CI

The analyses conducted in this study—ranging from the pricing of E3CI-based catastrophe bonds to the design of operational structures—require a procedure capable of translating E3CI values into insurance or financial losses. To support these tasks, a dedicated loss estimation tool was developed. The model follows the standard structure of a catastrophe model, incorporating exposure, hazard, vulnerability, and financial aggregation components as described in the following paragraphs.

6.1.1. Exposure modelling

The first step of the loss modelling framework involves constructing an exposure map aligned with the ERA5/E3CI grid. This is achieved using Global Human Settlement Layer (GHSL; Pesaresi et al., 2024) data, following an approach consistent with that employed in Deliverable 3.6, where GHSL layers were used to reproduce the geographical distribution of buildings across Italy. In this context, GHSL population and built up information serve as proxies for the spatial distribution of insured assets, enabling the creation of a synthetic insurance portfolio that reflects the real concentration of structures across the Italian territory.

To represent this portfolio, a total exposure amount is allocated across the country in proportion to building density or population density derived from GHSL. This produces a spatially explicit synthetic portfolio in which regions with a higher concentration of buildings receive a correspondingly greater share of the total insured value. Once this building density surface is defined, it must be made compatible with the spatial resolution of the hazard data. For this purpose, the GHSL building density map is reprojected and resampled onto the E3CI grid linked with the native resolution of ERA5. This step ensures that the exposure and hazard components operate on the same spatial framework, allowing for direct cell by cell loss calculations. After resampling, the exposure values are normalized so that the resulting map forms a coherent weighting structure. These normalized weights determine how the total portfolio value is distributed across the grid, effectively translating the GHSL derived building density patterns into a consistent exposure map tailored to the ERA5/E3CI spatial structure. This processed exposure map serves as the foundation for all subsequent loss calculations, enabling the model to estimate



financial impacts that are spatially consistent with both the hazard characterization provided by the E3CI and the underlying distribution of built assets across Italy.

6.1.2. Derivation of the vulnerability function

The second component of the loss model concerns the derivation of vulnerability functions, which translate the hazard severity described by the E3CI into expected damage ratios. In line with the objectives of the application, no policy conditions are incorporated into the model. Features such as deductibles, limits, or other technical insurance structures are therefore excluded. As a consequence, the ground up loss is assumed to coincide with the gross loss, and the modelled damage ratio directly represents an uncompromised loss proportion, without adjustments related to policy design.

For each peril represented in the E3CI, a linear vulnerability function is constructed, as shown in Figure 6. The parameters of these functions are derived by exploiting the conceptual structure of the E3CI itself. Since each E3CI component is expressed as a normalized variable relative to the historical baseline for the corresponding month of the year, any E3CI value can be associated with an exceedance probability and, qualitatively, with an indicative level of expected loss. This structure allows the identification of two key thresholds: the value of the E3CI at which the damage ratio first becomes nonzero, and the value at which the maximum damage ratio is attained. Between these two points, damage increases linearly with the magnitude of the E3CI anomaly.

The maximum damage ratio is fixed at 0.7. This moderate upper limit reflects several methodological considerations. First, the spatial aggregation of the model requires accounting for variability in loss occurrence across large grid cells; a cap below 1 better captures the heterogeneity that would be present across real assets. Second, the relationship between E3CI components and the actual insurance coverages found in real portfolios such as property, commercial, agricultural, and automotive is not perfectly direct. Not all extreme E3CI anomalies necessarily correspond to catastrophic physical damages; in many cases, they represent anomalous environmental stress rather than events capable of generating total or near total losses. For these reasons, a maximal damage ratio of 0.7 is deemed both realistic and methodologically appropriate.

The same time filtering, based on selecting a subset of months of the year, that was described for the aggregation of E3CI has been applied here (see Section 5.2). This ensures that vulnerability functions are applied only when the occurrence of an extreme event associated with a given peril is plausible and that the model reflects the seasonal effects on impacts that, in turn, are related to climatic extremes.



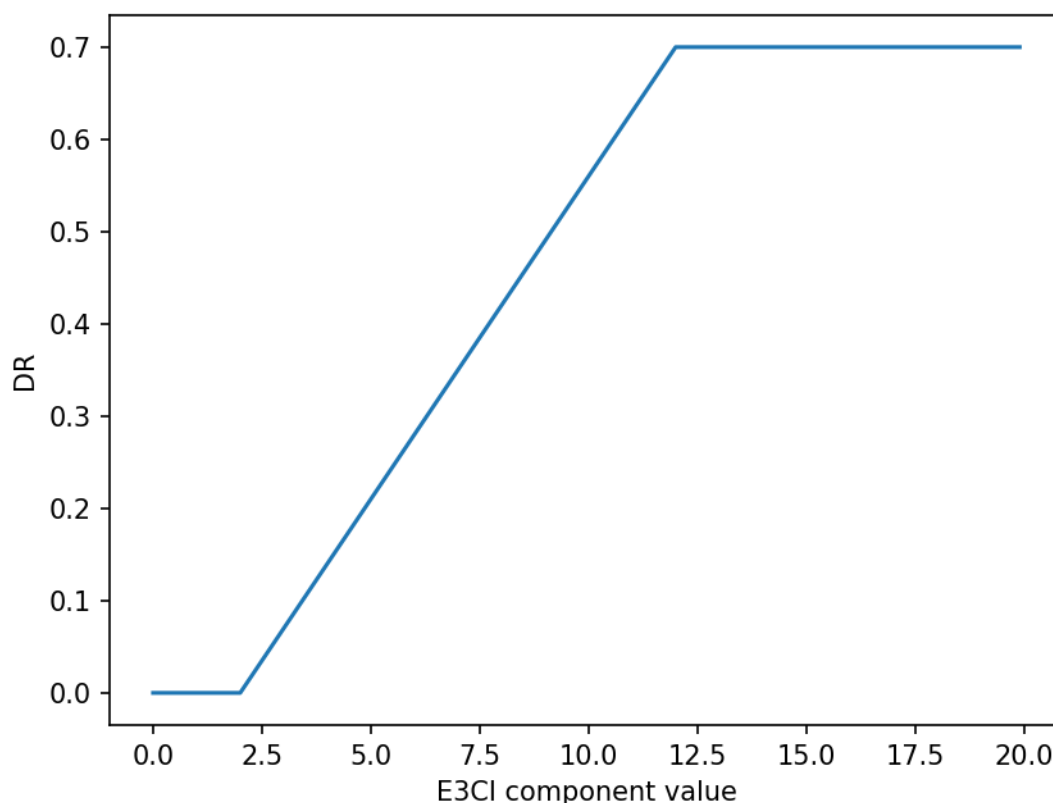


Figure 6: Vulnerability function expressing the relationship between E3CI components and the resulting damage ratio values; the function's maximum damage ratio is constrained to 0.7.

6.1.3. Transformation of E3CI values into damage ratios

The derived vulnerability functions are applied to the E3CI values. This results in monthly maps of damage ratios for each peril represented by the corresponding E3CI component.

6.1.4. Transformation of damage ratios into losses

Damage ratios are multiplied by the exposure map to generate a spatio temporal loss series for each E3CI component. These represent the losses experienced by the modelled insurance portfolio under the E3CI derived hazard conditions. The above-mentioned procedure is summarized in Figure 7 with a data example in Figure 8.

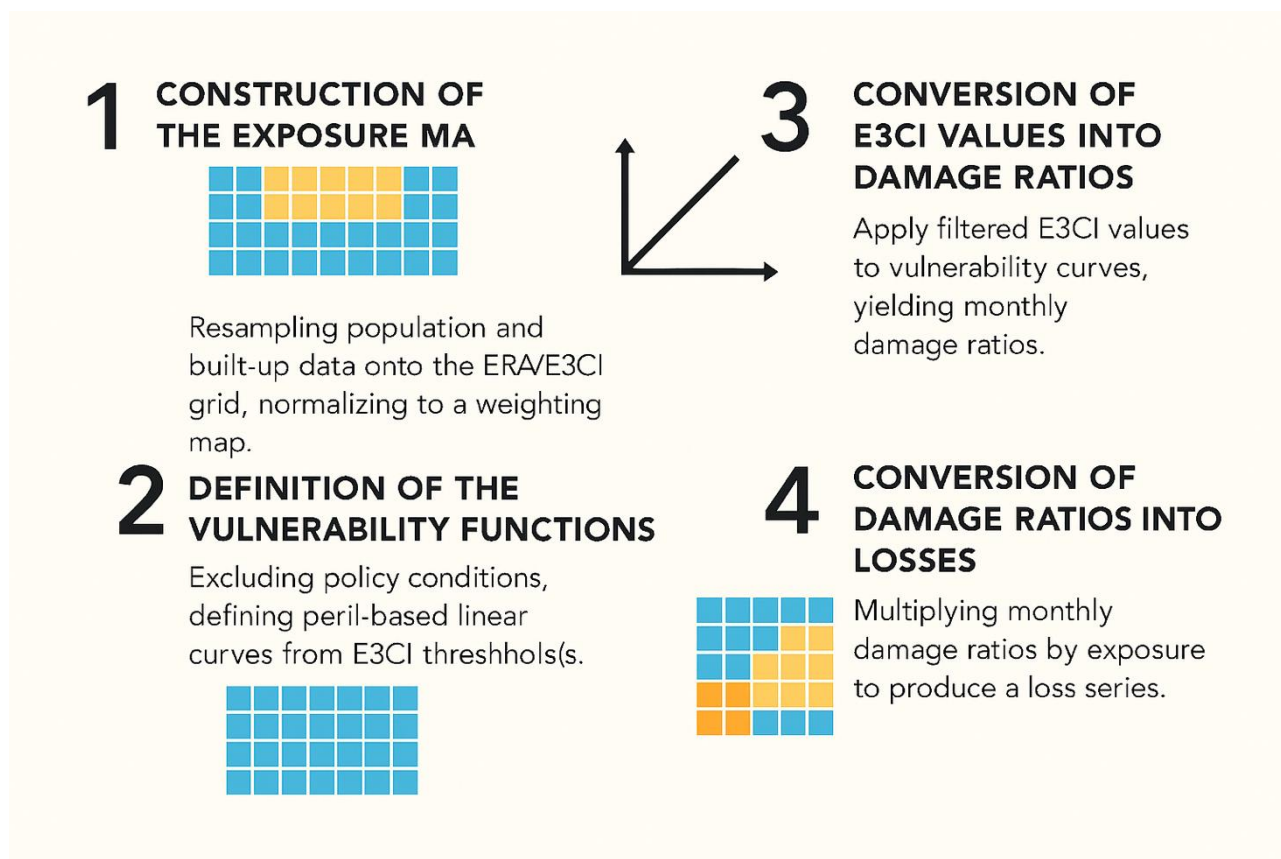


Figure 7: Schematic representation of the E3CI-based loss model.

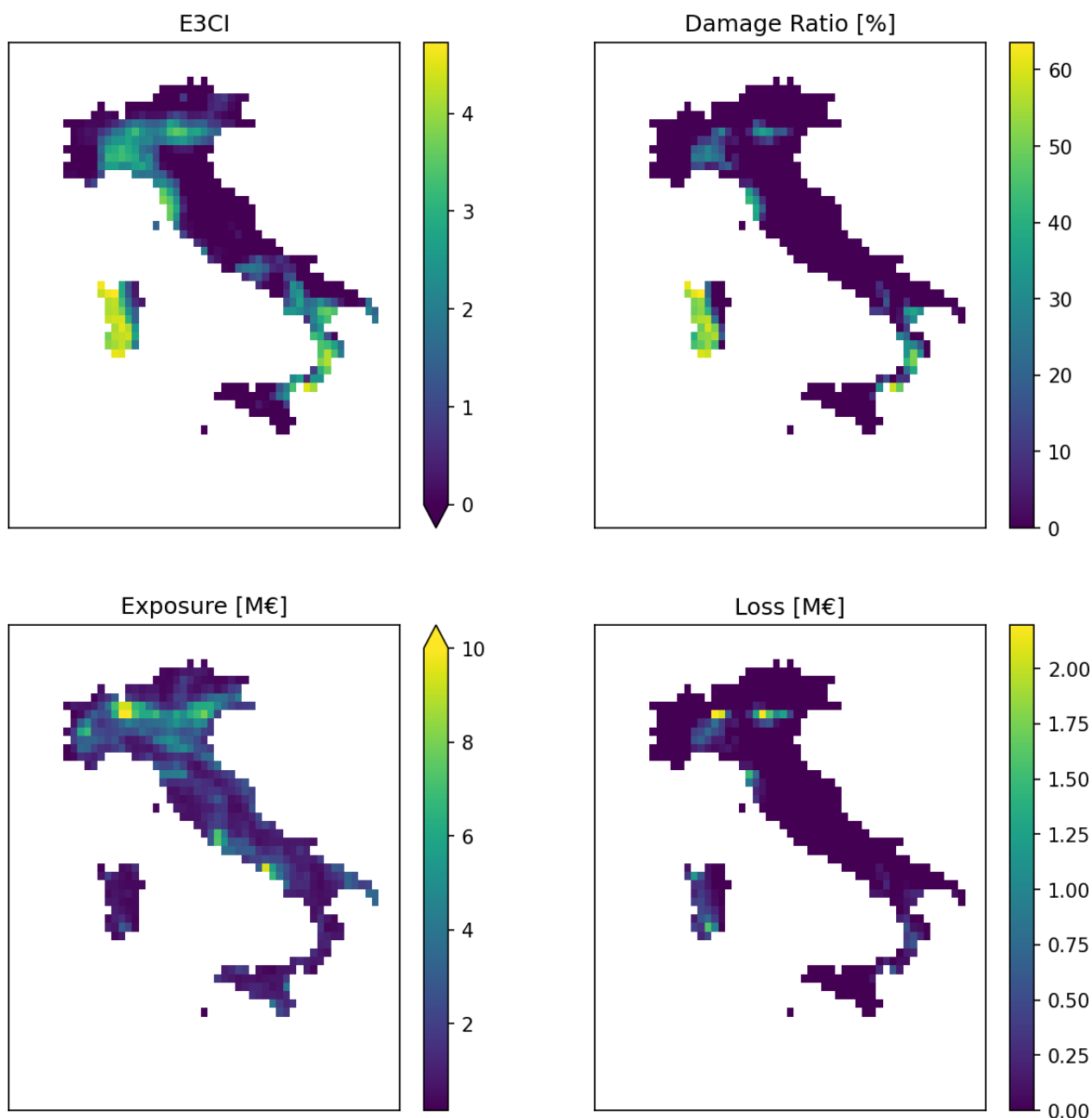


Figure 8: Example of E3CI-based loss model data (Precipitation component, March 1985).

6.2. Spread estimate

The pricing of catastrophe bonds hinges on determining the appropriate spread that investors demand above a risk free benchmark, such as LIBOR or Treasury rates, to compensate for the possibility of severe, low frequency losses. This task sits at the intersection of actuarial modelling and financial engineering. Early studies, such as Lane (2000), modelled spreads using a power function structure inspired by the Cobb–Douglas production function, relating the premium to two core indicators: the Probability of First Loss (PFL) and the Conditional Expected Loss (CEL).

Other foundational contributions relied on stochastic process frameworks, including doubly stochastic Poisson models, to describe the evolution of aggregate losses over time.

Over the years, however, the linear pricing framework has become the most widely adopted approach among practitioners. Introduced prominently by Bodoff and Gan (2009), this method relates the spread directly to the Expected Loss (EL) through a simple linear expression:

$$\text{Spread \%} = \text{Constant \%} + (\text{Loss Multiplier} \times \text{Expected Loss \%})$$

The appeal of this model stems partly from its compliance with Venter's (1991) No Arbitrage Principle, which requires that the price of an entire layer of risk must equal the sum of the prices of its sublayers. Within this structure, the intercept—referred to as the “Constant %”—captures the required return on capital for taking on risk from a particular peril, distinguishing between peak perils such as U.S. hurricanes and diversifying perils that contribute less significantly to portfolio risk. The slope, or “Loss Multiplier,” reflects uncertainty arising from catastrophe model estimation. Because EL is only an estimate derived from simulation, the multiplier is typically greater than one, serving as a margin for potential model error. This formulation also aligns with the widespread industry practice of quoting prices in terms of multiples of expected loss, providing a consistent benchmark across regions, markets, and issuance cycles.

Although the linear model remains dominant, several refinements have been proposed. Lane and Mahul (2008) shifted toward linear regression techniques after finding that CEL did not vary enough between bonds to justify its inclusion in pricing formulas. Mevorach (2018) introduced a log-linear specification, arguing that a functional form of $\ln(\text{Spread}) = \alpha + \beta \ln(\text{EL})$ better captures cross-sectional variation, particularly the amplification effects associated with peril type and regional concentration. Separately, the Wang Transform offers a more actuarially driven alternative, applying a risk-adjusted transformation (often using Student's t- distributions) to the loss distribution to produce a premium consistent with -capital market- risk preferences.

Access to empirical market spreads at which cat bonds are issued provides a valuable means of validating the theoretical models proposed in academic literature. These observations help calibrate spread estimates for the catastrophe bonds developed in this work. In this context, the Artemis platform functions as a primary reference for the ILS industry. It offers detailed historical profiles of cat bond issuances, including information on the sponsor seeking to transfer risk, the underlying peril and geographic exposure, and the structural and financial characteristics of each instrument. This dataset contains the risk parameters typically analysed during pricing, trading, and structuring, and forms a crucial empirical foundation for evaluating how theoretical spread models align with real market behaviour.

6.3. Artemis dataset

To determine the parameters of the linear model used to compute the spread of the cat bonds analysed in this study, an examination of the data available on the Artemis platform (<https://www.artemis.bm/>) was carried out. Artemis collects a wide range of information on Insurance-Linked Securities (ILS), and in particular on cat bonds. Specifically, data from a selection of historical cat bonds listed on Artemis were gathered and analysed. These cat bonds are summarised through descriptive profiles, for which an illustrative sample is provided in Table 1.

Table 1: Example of an Artemis cat bond descriptive sheet.

“Catbond for DRR” – At a glance:

- **Issuer:** The HuT SPV
- **Cedent / sponsor:** Insurance company
- **Placement / structuring agent/s:** broker agencies and bookrunners
- **Risk modelling / calculation agents etc:** Nat-Cat modeling firm
- **Risks / perils covered:** European flood
- **Size:** €100m
- **Trigger type:** Indemnity
- **Ratings:** Rating agency
- **Date of issue:** March 2026

“Catbond for DRR” – Full details:

The insurance company intends to securitize €100 million of collateralized reinsurance through a catastrophe bond for disaster risk reduction (DRR).

The reinsurance coverage will be on an indemnity trigger and per-occurrence basis, covering claims related to floods impacting Italy.

The term of coverage will be across three years, with maturity slated for early April 2029.

The targeted issuance of €100 million of Series 2026-1 Class A notes will cover a €100 million layer of Insurance company's reinsurance tower, attaching at €250 million losses and exhausting at €350 million.

The 2026-1 notes will have an initial attachment probability of 2.02%, an initial expected loss of 2.76%, and are being offered to cat bond investors with coupon guidance in a range from 5.65% to 6.7%.

Update 1:

The pricing has been updated and fixed at the upper end for a spread of 6.7%.

Update 2:

Insurance company secured the targeted €100 millions of earthquake reinsurance with this new cat bond, with the pricing finalised at the top-end of initial guidance, for the 6.7% spread.

An analysis was conducted on a selected subset of cat bonds reported in the Artemis database, with the objective of characterizing the relationship between the expected loss ratio and the corresponding spread. The perils associated with the cat bonds included in the analysis comprise floods, windstorms, and others. A substantial number of these instruments are classified as multi-peril. Figure 9 provides a scatterplot representation of the expected loss ratio and spread values for the analyzed cat bonds. In Figure 10 the spread of the cat bond is represented through a frequency diagram.

For the purposes of subsequent analyses, the coefficients of the linear relationship between expected loss ratio and spread are estimated for the represented perils (Figure 11).

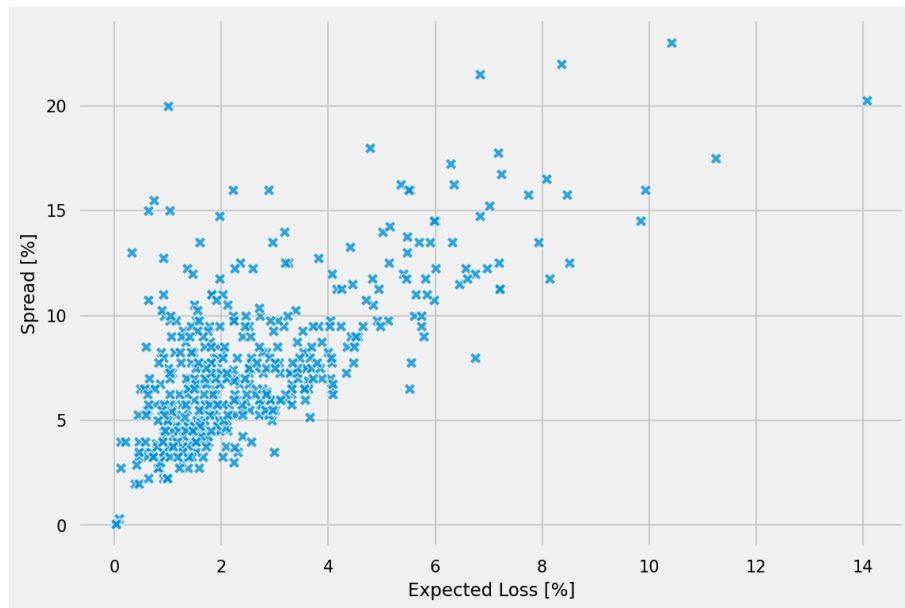


Figure 9: Scatterplot of Artemis cat bonds expected losses and relative final spread price.

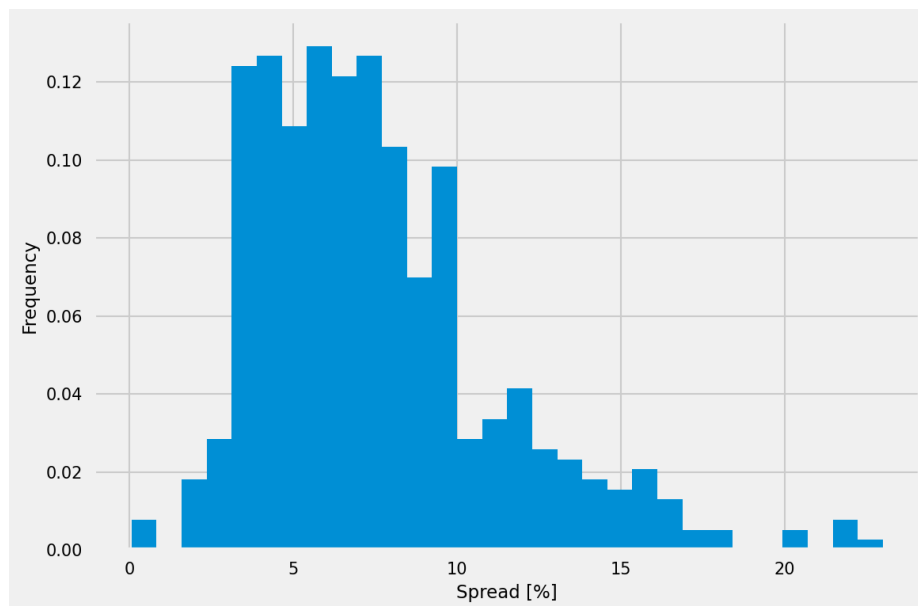


Figure 10: Frequency distribution of selected Artemis cat bonds.

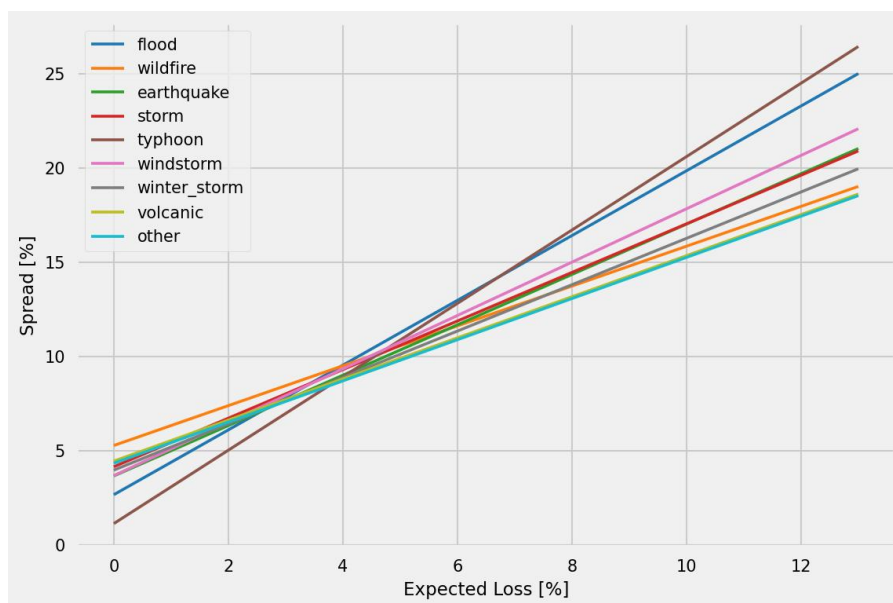


Figure 11: Linear fitting of Spread-Expected loss relation based on peril.

6.4. Cat bond design methodology

Figure 12 describes the modelling and structuring workflow developed for an indemnity type catastrophe bond whose trigger mechanism relies on insurance losses estimated through the hazard–exposure model driven by the E3CI previously described. Even though most of the methodology has been already described, here it is summarized with further implementation details.

The workflow begins with the collection and harmonization of four key input components: GHSL population and built up density, used as a proxy for spatial distribution of the insured exposure; the E3CI index, providing a standardized representation of extreme climate events across Europe; the total insured portfolio value; and a set of vulnerability parameters linking peril intensity to expected damage. These elements feed a probabilistic loss model that transforms E3CI-derived event conditions into simulated indemnity losses for the portfolio.

From this loss distribution, the sponsor's reinsurance needs are evaluated, and an excess of loss (XoL) layer is designed. This layer specifies the attachment point, exhaustion point, and coverage limit that the catastrophe bond is intended to replace. The XoL definition is then used to compute the expected annual loss of the layer ($E[\text{XoL Loss}]$), integrating frequency and severity derived from the E3CI influenced model. This metric is essential for consistent and transparent pricing as it is usually a key descriptor of proposed cat bond and, eventually, drives the market price.

Pricing of the cat bond uses a linear spread model calibrated on market data as described in Section 6.2. The model relates the expected layer loss to the risk spread demanded by investors, combining calibration parameters and the computed $E[\text{XoL Loss}]$. The resulting spread is added to the risk free rate to form the coupon paid to investors under non trigger conditions.

The structural features of the catastrophe bond are then finalized: notional amount, trigger definition based on indemnity losses, payment waterfall, and coupon structure. The complete bond is subsequently simulated over synthetic E3CI scenarios, allowing the evaluation of coupon flows, potential principal losses, and expected investor returns. These simulations generate the final

outputs relevant for both issuer and investors: annual coupon levels, potential reductions due to triggering events, and refund behaviour at maturity.

Overall, this methodology provides a coherent and transparent mechanism to translate climate index driven hazard information into financial risk transfer instruments. It enables the construction of indemnity based cat bonds that remain directly linked to the sponsor's actual loss experience while leveraging standardized climate indicators for modelling consistency and reproducibility.

Likewise, Figure 13 provides an overview of the modelling and structuring workflow developed for a parametric catastrophe bond triggered by exceedances of the E3CI. The reinsurance needs and the spread estimation follow the indemnity cat bond methodology previously exposed. In a parametric structure, however, pricing must also incorporate the relationship between modelled losses and the index based trigger. This is achieved through a quantile mapping procedure that identifies the E3CI threshold corresponding to the probability of incurring losses that fall within the XoL layer. The mapping ensures that the parametric trigger is statistically consistent with the indemnity based reinsurance need, thus reducing mismatch between actual losses and triggered payouts. The resulting E3CI threshold is integrated into the bond's trigger conditions.

Once the trigger threshold, spread, and structural components are defined, the parametric cat bond is simulated across a large set of synthetic E3CI time series. These simulations determine whether the E3CI threshold is exceeded, the payout fraction, and the resulting investor cash flows. The final outputs consist of coupon patterns, expected losses to principal, and the statistical distribution of investor refunds at maturity.

This framework provides a transparent and statistically robust method for parameterizing climate index-based catastrophe bonds. By linking E3CI behaviour to modelled economic losses through a calibrated quantile mapping approach, the workflow ensures trigger consistency, enhances payout reliability, and supports the deployment of climate risk transfer instruments in contexts where rapid, objective, and index-based mechanisms are preferred.

Although both catastrophe bond structures rely on the same E3CI-based loss model to quantify hazard intensity and estimate portfolio losses, the core distinction lies in how these losses are translated into trigger conditions and payouts. In the indemnity cat bond, the modelled losses (here assumed as the insurance losses) directly inform the bond's activation, ensuring that payouts reflect the sponsor's actual financial impact but requiring more complex loss verification and potentially slower settlement. In contrast, the parametric cat bond replaces the loss-based trigger with an E3CI threshold calibrated through quantile mapping, enabling immediate and objective activation based solely on the index. This shift increases transparency and payout speed but introduces potential basis risk, as the parametric trigger may not perfectly match the sponsor's realized losses despite being statistically aligned with the same underlying loss model.

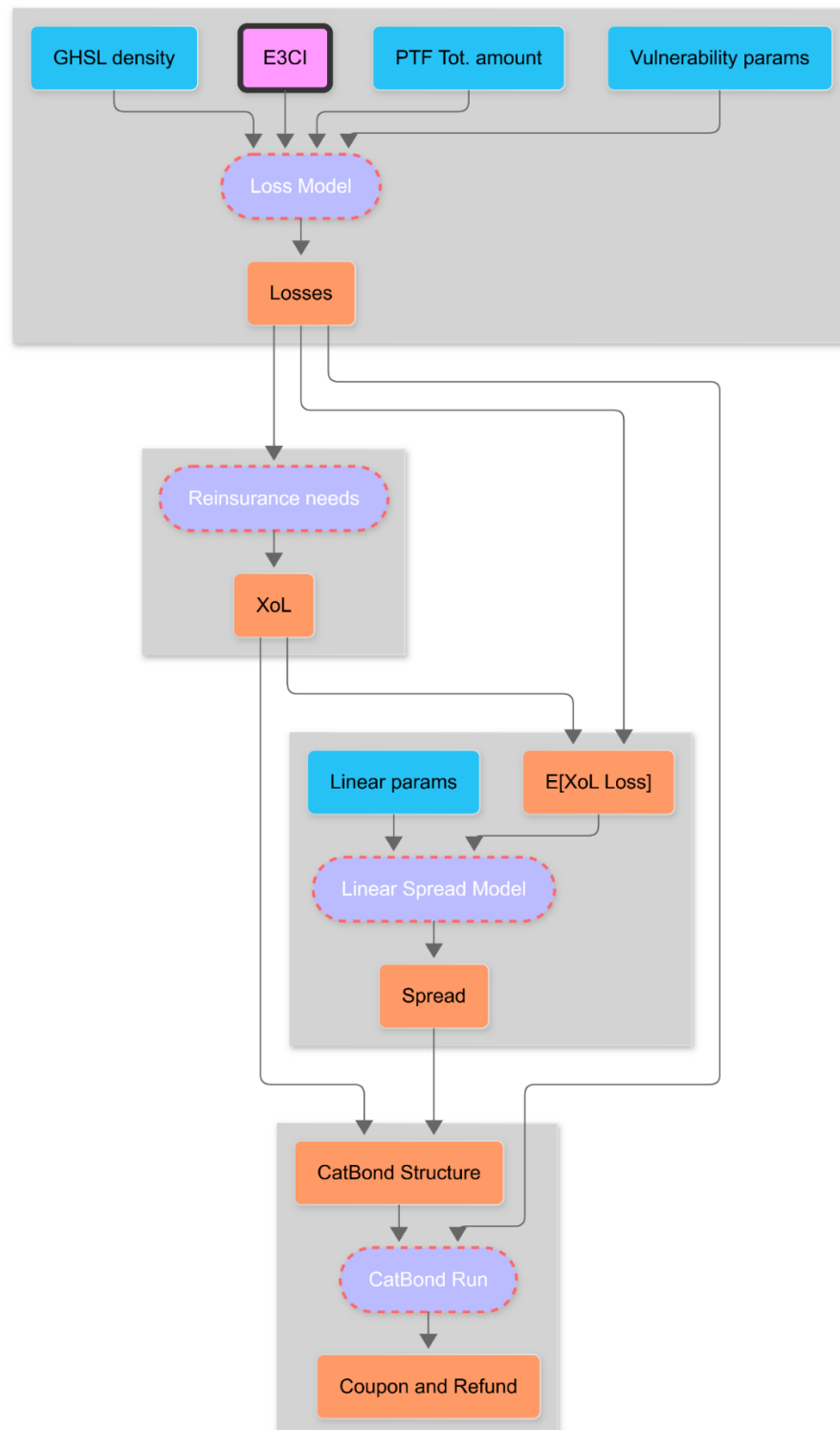


Figure 12: Schematic representation of the workflow for the development of the Indemnity type Cat Bond.

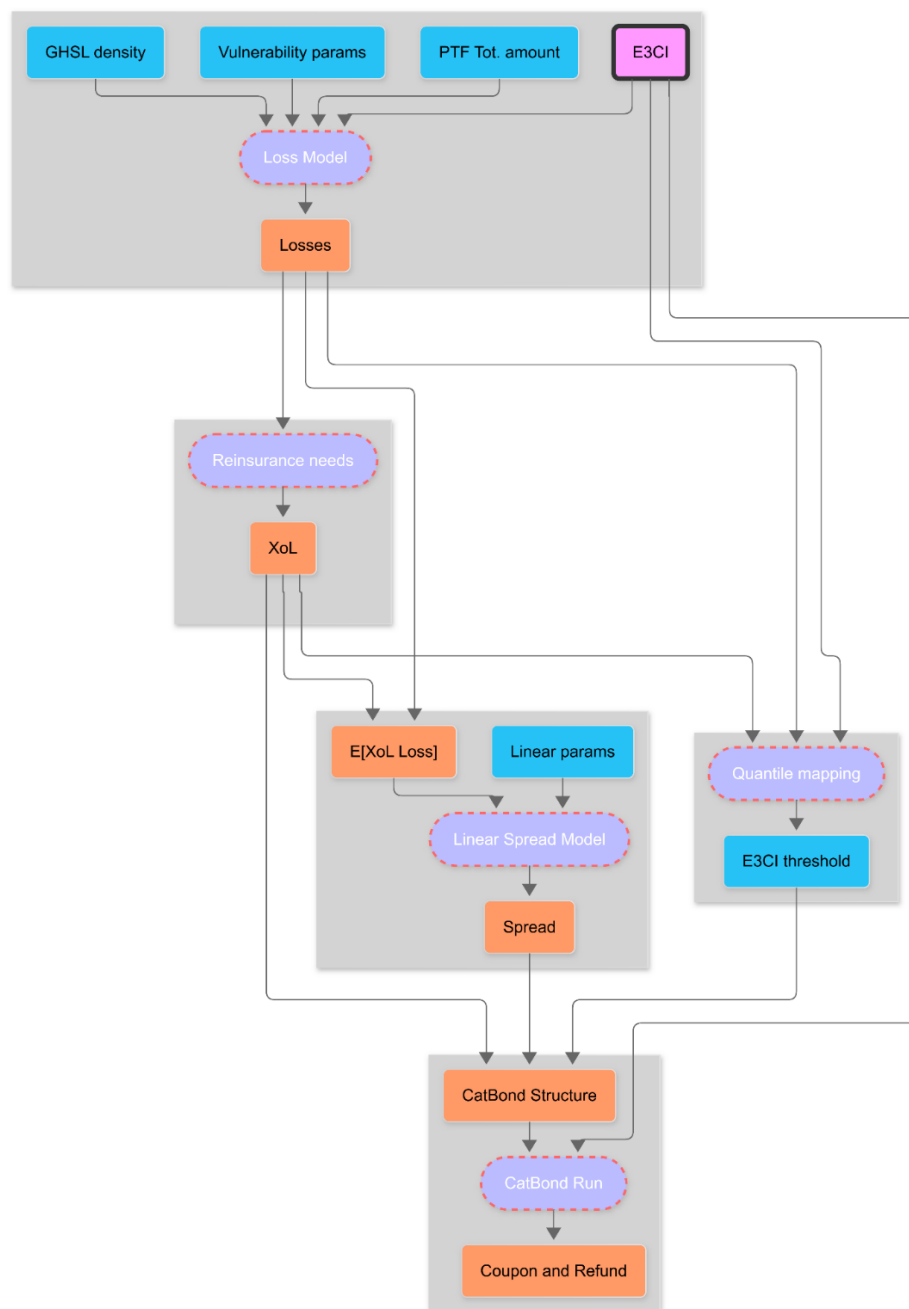


Figure 13: Schematic representation of the workflow for the development of the parametric type Cat Bond.

6.5. Results

For each selected peril, it is assumed that the insurance portfolio is exposed solely to the specified peril, meaning all losses arise exclusively from that single source of risk. A synthetic portfolio is then constructed, following the methodology described in Section 6.1.1, distributing a total exposure of €1 billion across the entire national territory.

For this portfolio, insurance losses are estimated over a baseline period corresponding to 1981–2010. Based on these losses, the reinsurance requirement is determined by computing the priority and capacity of the per occurrence XoL reinsurance treaty designed to cover events falling within a given quantile range of the historical loss distribution. This range has been set equal to 99th–99.9th percentile. It is assumed that such events occur, on average, twice per year. The capacity of the reinsurance coverage—and thus of the cat bond—is defined by multiplying the loss associated with those threshold events by the frequency and by the duration of the **cat-bond** coverage period, that has been set equal to three years. The resulting reinsurance needs are reported in Table 2.

Table 2: Estimated reinsurance needs.

	XoL priority [M€]	XoL limit [M€]	XoL capacity [M€]
Wildfire	30.0	52.0	132.0
Precipitation	28.0	56.0	168.0
Wind	40.0	50.0	60.0
Hail	38.0	65.0	162.0

The expected reinsurance loss is estimated by means of the reinsurance losses computed for the reference period. This expected value is then used to derive the interest-rate component, or spread, by applying the linear model described in Section **Errore. L'origine riferimento non è stata trovata.** The model parameters were calibrated using the historical series of catastrophe bonds from the Artemis database (see **Errore. L'origine riferimento non è stata trovata.**), selecting—per peril—only the relevant cat bonds according to the following mapping:

- wildfire: wildfire
- precipitation: flood, storm
- wind: storm, windstorm, winter storm
- hail: storm, windstorm, winter storm

For the simulation of the parametric catastrophe bond, threshold levels are estimated for the relevant E3CI component aggregated at the national scale, which acts as the index underlying the parametric contract. Once the index and aggregation method are established, the structure of the catastrophe bond is designed to replicate the key features of the corresponding reinsurance contract.

The spread estimation for the indemnity-based cat bond are shown in **Errore. L'origine riferimento non è stata trovata.** Whereas Table 4 reports the values obtained for the parametric cat bond, together with the E3CI threshold levels derived under the different aggregation criteria.

Table 3: Indemnity cat bond pricing parameters.

Expected Loss Rate	Attachment probability	Spread [%]
--------------------	------------------------	------------

Wildfire	0.030817	0.012689	8.55
Precipitation	0.024924	0.012689	7.33
Wind	0.031405	0.012689	8.20
Hail	0.027800	0.012174	7.71

Table 4: Parametric cat bond pricing parameters.

	Expected Loss Rate	Attachment probability	Spread [%]
Wildfire	0.076132	0.012689	13.34
Precipitation	0.076132	0.012689	14.29
Wind	0.076132	0.012689	14.22
Hail	0.073045	0.012174	13.81

As the tables show, the expected loss rates—and consequently the spreads—of the parametric cat bonds are higher than those of the corresponding indemnity cat bonds. This is related to the payment of a fixed amount in the case of the parametric cat bond, equal to the entire range of reinsurance needs estimated for a single event.

The threshold values for the parametric cat bond, derived according to the procedure described above, are reported in Table 5.

Table 5: E3CI thresholds adopted for parametric cat bonds.

	Threshold (median)	Threshold (POT)
Wildfire	1.91	0.29
Precipitation	2.19	0.23
Wind	2.19	0.39
Hail	2.05	0.39

In order to evaluate the feasibility of the proposed cat bonds, simulations are carried out under the assumption that, for each peril, a cat bond is issued at the beginning of every year outside the reference period (as the latter is used exclusively for parameter estimation). The results are summarized in terms of the aggregated technical outcome, defined as the difference between the premium paid by the sponsor (and earned by investors) and the amount absorbed by the events covered by the cat bond—namely, respectively, the insurance losses falling within the reinsurance parameters and the reinsured amount triggered by exceedance of the E3CI thresholds for the

indemnity and parametric cat bond structures, respectively. The corresponding results are presented, in Figure 14, Figure 15, and Figure 16.

The performance patterns of the indemnity cat bonds across different years generally exhibit favorable returns from the investors' perspective, though a deterioration is observed in more recent years. This effect can be attributed to the increased frequency of extreme events, as also reflected in the various components of the E3CI. This suggests that parameter estimation based solely on a historical loss record—even one spanning multiple decades—may be insufficient for this purpose, underscoring the importance of catastrophe-modelling tools and expertise specific to the peril under consideration.

The simulations for the parametric cat bonds are presented both in terms of investor gains and of shortfalls in reimbursement for recorded events, where negative values represent payments triggered by index exceedances that do not correspond to actual extreme events (basis risk). These results are reported for both the median-based and the POT thresholding methods applied to Italian territory.



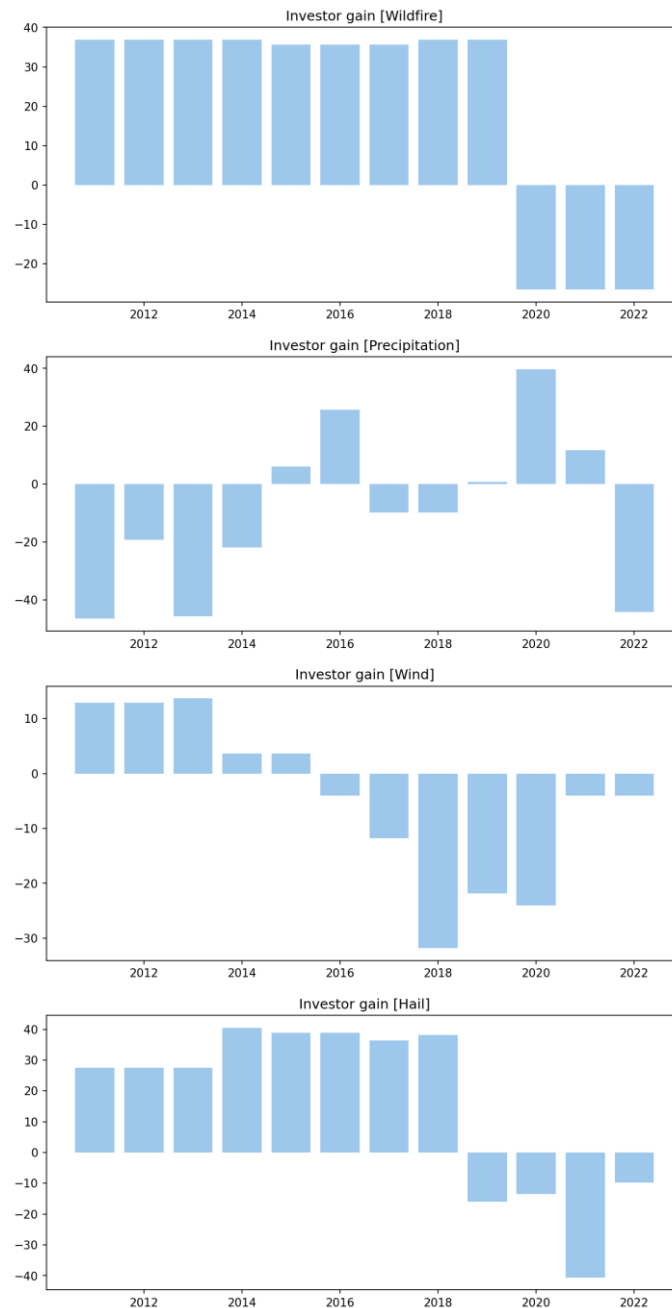


Figure 14: Indemnity Cat Bond results.



Figure 15: Parametric Cat Bond (trigger estimated on spatial median aggregation).



Figure 16: Parametric Cat Bond (trigger estimated on POT aggregation).

The simulations generally indicate positive investor returns, with a few exceptions—most notably the wildfire cat bond when the POT threshold method is applied. Only the hail cat bond shows consistently lower returns in more recent issuance years. The shortfall results reveal both situations in which shortfalls are substantial (as seen for wind and hail in several years) and instances where investors receive large reimbursements despite the absence of actual losses (particularly for wildfire and precipitation under the POT method). Since, in this numerical experiment, insurance losses are simulated directly from the same E3CI components that define the parametric cat bond index, these mismatches arise from the spatial distribution of exposures. This underscores a key limitation of using an index that does not explicitly capture geographic variations in exposure.

7. Contribution to DRR and local resilience

The proposed E3CI-based catastrophe bond offers a structured and forward looking mechanism to strengthen Disaster Risk Reduction (DRR) and enhance local and regional resilience across European territories. Unlike traditional post event financing, the cat bond provides pre agreed, rules based liquidity that is triggered immediately after climate anomalies are detected, enabling authorities to access rapid funding during the crucial early stages of response and recovery. This liquidity stabilizes public finances, reduces pressure on emergency budgets, and ensures continuity of essential services even in the context of largescale climate shocks.

Beyond post event liquidity, the instrument supports anticipatory and preventive approaches. Because activation is tied to climate anomalies rather than documented losses, public sponsors can integrate the bond within early warning systems, linking payouts to predefined resilience actions. This integration allows local and regional governments to allocate resources more efficiently, promoting interventions such as fuel management, drainage maintenance, firebreak construction, urban greening, and civil protection preparedness activities.

The structure of the bond also introduces incentives for ex ante risk reduction. Authorities can condition eligibility, participation, or cost sharing on the adoption of resilience plans, adherence to building codes, or implementation of ecosystem-based measures. Such conditionality aligns financial flows with DRR objectives and encourages long term capacity building. Additionally, because the E3CI aggregates multiple hazards into a consistent framework, it allows for multi hazard governance, helping territories manage compound events—such as drought heat combinations or wind precipitation extremes—that are increasingly relevant under climate change.

Furthermore, the reliance on a transparent, scientifically validated climate index enhances institutional trust and simplifies communication with citizens and stakeholders. The index reduces administrative burden, avoids lengthy claims processes, and points directly to the climatic conditions driving impacts, facilitating evidence-based policy design. Overall, the E3CI based catastrophe bond emerges as a tool that not only mobilizes private capital for public resilience but also strengthens the coherence between ex ante mitigation, ex post financial stability, and long-term climate adaptation objectives.



8. Comparison with alternative financing instruments

Multiple financing instruments are available for managing climate related risks, each with distinct advantages and limitations. The E3CI-based catastrophe bond positions itself as a complement, rather than a substitute, within this broader financial ecosystem.

Compared to parametric insurance, the cat bond provides significantly larger capacity, typically ranging from tens to hundreds of millions of euros, making it suitable for regional or national DRR strategies. While parametric insurance is flexible and well suited for municipal or operational applications, its annual renewal cycle, pricing volatility, and dependence on insurer balance sheet capacity limit its long term predictability. Cat bonds, by contrast, offer multiyear coverage (usually 3–4 years), fully collateralized protection, and elimination of counterparty risk, providing sponsors with greater certainty and budget stability.

Public disaster funds play an important role in stabilizing public finances, yet they face inherent constraints: budget ceilings, slow replenishment, political competition for resources, and susceptibility to post event fiscal stress. A climate index cat bond diversifies funding sources by mobilizing private capital without increasing debt or diverting tax revenue. Moreover, payouts occur without administrative delays often associated with accessing national or EU level disaster funds.

Traditional indemnity reinsurance remains essential for covering high severity losses, but it depends on damage assessments and often excludes slow onset or compound climatic stressors. The E3CI based trigger can capture such stressors more effectively, improving alignment with climate change realities and reducing the risk of liquidity gaps during prolonged events.

The added value of the E3CI based catastrophe bond lies in its transparency, replicability, and scalability. A standardized index allows for consistent trigger design across regions and hazards, lowering transaction costs and supporting cross regional comparability. From a DRR lens, the bond enhances financial preparedness, reduces volatility in public expenditures, and complements both insurance instruments and public funds within a comprehensive risk layering strategy.



9. Conclusions and recommendations

The modelling and simulation results presented in Section 6 highlight both the opportunities and limitations of E3CI based structures. Indemnity cat bonds exhibit generally stable performance and positive expected returns for investors, though recent years show a degradation of outcomes due to the increasing frequency and intensity of climate-related extremes reflected in the E3CI. This confirms that historical loss records alone are insufficient to parameterize long-term public risk-transfer strategies, and reinforces the importance of using climate-conditioned catastrophe-modelling approaches that can explicitly capture non-stationarity in hazard behaviour. Parametric structures, while providing faster activation and enhanced transparency, show higher expected loss rates and more pronounced sensitivity to threshold selection. The observed basis-risk effects—particularly where spatial exposure patterns diverge from the national-level E3CI signal—underscore the need for careful calibration, multi-trigger logic, or hybrid designs to ensure adequate alignment with the underlying loss potential.

From a policy and operational perspective, these findings lead to three strategic recommendations. First, index-based risk-transfer solutions should be embedded within a broader risk-layering strategy that explicitly combines DRR investments, indemnity insurance, and capital-market instruments to address different segments of the loss distribution. Second, sponsors should invest in strengthening climate-data governance and enhancing the spatial resolution, update frequency, and transparency of climate-extreme indicators, ensuring that E3CI-type indices remain robust as foundations for scalable financial protection. Third, public authorities may benefit from further exploration of advanced trigger architectures—such as combining aggregate E3CI signals with exposure-weighted anomaly metrics—to reduce spatial mismatch and improve payout relevance. These refinements would not only mitigate basis risk but also strengthen alignment between climate-index behaviour, modelled portfolio losses, and the operational needs of regional and national DRR systems.

This deliverable demonstrates that an E3CI based catastrophe bond represents a viable and innovative mechanism for strengthening financial resilience to climate extremes in Europe. By leveraging a transparent and scientifically grounded climate index, the proposed instrument aligns trigger design with the physical processes driving impacts, enabling rapid, fair, and predictable payouts. The loss-modelling framework developed in this work confirms that E3CI components can be effectively translated into financial metrics, supporting robust pricing, spread estimation, and evaluation of indemnity-based and parametric structures.

Recommendations for policymakers and practitioners include strengthening climate-data governance, promoting standardized and transparent index methodologies, and embedding resilience conditionality within financial instruments. Public sponsors could consider the E3CI-based cat bond as part of a broader risk-layering strategy, combining DRR investments, insurance, reinsurance, and capital markets. Further research should explore multi-trigger architectures, advanced basis-risk mitigation techniques, and the integration of E3CI-type indices within European Union fiscal and civil-protection frameworks.



10. References

- Barnett, B. J. & Mahul, O. (2007). Weather index insurance for agriculture and rural areas in lower-income countries. *American Journal of Agricultural Economics*, 89(5), pp. 1241–1247. <https://doi.org/10.1111/j.1467-8276.2007.01091.x>
- Barrieu, P. & Albertini, L. (eds.) (2010). *The Handbook of Insurance-Linked Securities*, Wiley, Hoboken, NJ. <https://doi.org/10.1002/9781119206545>
- Braun, A., & Kousky, C. (2021). Catastrophe bonds. Risk Management and Decision Processes Center. Wharton. University of Pennsylvania (2021). <https://impact.wharton.upenn.edu/wp-content/uploads/2023/08/Cat-Bond-Primer-July-2021.pdf>
- Bodoff, N. M., & Gan, Y. (2013). An analysis of the market price of cat bonds. *Variance*, 6(2). <https://www.casact.org/sites/default/files/2021-07/Price-Cat-Bonds-Bodoff-Gan.pdf>
- Carter, M. R., De Janvry, A., Sadoulet, E., & Sarris, A. (2014). Index-based weather insurance for developing countries: A review of evidence and a set of propositions for up-scaling. Carter, M., de Janvry, A., Sadoulet, E & Sarris, A 2021, Determinants of uptake and strategies to improve agricultural insurance in Africa: a review, *Environment and Development Economics*, 26, pp. 605–631.
- Clarke, D. J. (2016). A theory of rational demand for index insurance. *American Economic Journal: Microeconomics*, 8(1), 283-306. <https://doi.org/10.1257/mic.20140103>
- Cummins, J. D. (2012). CAT bonds and other risk-linked securities: Product design and evolution of the market. Available at SSRN 1997467. <https://doi.org/10.2139/ssrn.1997467>
- Gao, H., Yang, S., & Liu, X. (2025). Managing basis risks in weather parametric insurance: a quantitative study of diversification and key influencing factors: H. Gao et al. *The Geneva Papers on Risk and Insurance-Issues and Practice*, 1-28. <https://doi.org/10.1057/s41288-025-00360-5>
- Greatrex, H., Hansen, J., Garvin, S., Diro, R., Blakeley, S., Le Guen, M., Rao, K., & Osgood, D. (2015). Scaling up index insurance for smallholder farmers: Recent evidence and insights, CCAFS Report no. 14, CGIAR.
- Hochrainer-Stigler, S., Mechler, R., Pflug, G., & Williges, K. (2014). Funding public adaptation to climate-related disasters. Estimates for a global fund. *Global Environmental Change*, 25, 87-96. <https://doi.org/10.1016/j.gloenvcha.2014.01.011>
- Hyman, E. L. (2025). Parametric insurance for climate change adaptation, Observer Research Foundation, 14 October 2025.
- Jongman, B., Hochrainer-Stigler, S., Feyen, L., Aerts, J. C., Mechler, R., Botzen, W. W., ... & Ward, P. J. (2014). Increasing stress on disaster-risk finance due to large floods. *Nature Climate Change*, 4(4), 264-268. <https://doi.org/10.1038/nclimate2124>
- Lane, M. N. (2000). Pricing risk transfer transactions1. *ASTIN Bulletin: The Journal of the IAA*, 30(2), 259-293. <https://doi.org/10.2143/ast.30.2.504635>
- Lane, M., & Mahul, O. (2008). Catastrophe risk pricing: an empirical analysis. *World Bank Policy Research Working Paper*, (4765). <https://doi.org/10.1596/1813-9450-4765>
- Mevorach, C. (2018). Modelling Catastrophe Bond Pricing in the Primary Market-A Loglinear Approach. <https://www.sas.rochester.edu/eco/undergraduate/papers/mevorach---catastrophe-bond-pricing,-2018.pdf>



- Pesaresi, M., Schiavina, M., Politis, P., Freire, S., Krasnodębska, K., Uhl, J. H., ... & Kemper, T. (2024). Advances on the Global Human Settlement Layer by joint assessment of Earth Observation and population survey data. *International Journal of Digital Earth*, 17(1), 2390454. <https://www.tandfonline.com/doi/full/10.1080/17538947.2024.2390454>
- Ribeiro, A. F., Russo, A., Gouveia, C. M., & Pires, C. A. (2020). Drought-related hot summers: a joint probability analysis in the Iberian Peninsula. *Weather and Climate Extremes*, 30, 100279. <https://doi.org/10.1016/j.wace.2020.100279>
- 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. *Climate change 2021: The physical science basis: Working group I contribution to the sixth assessment report of the intergovernmental panel on climate change*, 1513-1766. <https://doi.org/10.1017/9781009157896.013>
- Venter, G. G. (1991). Premium calculation implications of reinsurance without arbitrage. *ASTIN Bulletin: The Journal of the IAA*, 21(2), 223-230. <https://doi.org/10.2143/ast.21.2.2005365>
- Vyshkvarkova, E., & Sukhonos, O. (2022). Compound extremes of air temperature and precipitation in Eastern Europe. *Climate*, 10(9), 133. <https://doi.org/10.3390/cli10090133>
- World Economic Forum (2025). What is parametric insurance and how is it building climate resilience? <https://www.weforum.org/stories/2025/01/what-is-parametric-insurance-and-how-is-it-building-climate-resilience/>

