PIISA

Piloting Innovative Insurance Solutions for Adaptation

D1.3: Design and Modelling Framework for WP3 Pilots

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1 Executive Summary

The intensifying effects of climate change are leading to more frequent and severe natural disasters across Europe, putting communities at increased risk of extreme weather events. With the number of people living in hazard-prone areas rising, potential losses are expected to grow significantly (IPCC, 2023). Multi-stakeholder collaboration and adaptable products like parametric insurance could bridge local protection gaps and help address some of the adverse effects of climate change.

The Piloting Innovative Insurance Solutions for Adaptation (PIISA) project, funded by Horizon Europe, aims to address these challenges by developing innovative, climate-sensitive insurance products to de-risk and encourage adaptive management practices. The PIISA project is a three-year initiative involving 12 partners from 5 EU countries, including research institutions, meteorological agencies, and insurance experts. It focuses on co-developing climate-resilient insurance portfolios and data-sharing solutions for climate risk and losses.

The purpose of this report is to consolidate findings from PIISA's research, encompassing insurance models, factors influencing uptake of insurance covers, risk modelling, and risk-reduction strategies. It provides both general insights and specific details for each of the five PIISA pilots individually, serving as a comprehensive synthesis document for pilot leaders.- The report summarizes tools and strategies for effective implementation and adaptation and provides practical tools and guidelines to inform pilot design and implementation.

Key findings for the five pilots include:

- Studies focusing on green roof insurances (Pilot 1) explore a widespread underestimation of climate risks, limiting adoption of green roofs across Europe and the U.S. Many in flood-prone areas like Dutch floodplains believe their flood risk is minimal, reducing their willingness to invest in protective measures like green roofs and flood insurance.

- For clay soil shrinkage in urban infrastructure (Pilot 2), findings highlight how demographic factors influence climate insurance uptake. Challenges in insurance coverage were identified to be linked to the operational structure of the French Cat Nat scheme. Different insurance models such as agent-based models, flat premiums, and high-resolution pricing simulate insurance uptake and affordability.

- For the food and agriculture pilot (Pilot 3), insights from Spain's insurance framework highlight that risk aversion and premium subsidies are key drivers of crop insurance uptake, emphasizing the need for affordable, climate-responsive insurance options for small-scale farmers.

- Forest insurances against biotic and abiotic risks (Pilot 4) in Germany, key findings focus on the voluntary climate insurance landscape and its impact on insurance penetration rate, currently at around 40%. The findings also discuss the necessity of partial equilibrium and actuarial models in forest insurance for the integration of adaptation strategies.

- Meanwhile, for forest insurances against wildfire (Pilot 5), studies discuss the increasing insurability challenges for Southern Europe due to longer, more intense wildfire, particularly in Portugal and Greece. Such challenges occur when risks become very severe or recurring, and subsequently become too expensive for both insurers and the insured to partake in without suffering unsustainable losses. Innovative risk-transfer products and adaptive insurance models are recommended to address these pressures.

In addition to pilot-specific insights, this report introduces a Design and Modelling Framework (Section 5) to guide WP3 implementation. This framework outlines best practices for pilot selection, stakeholder engagement, choice and methodology of modelling, data management, and monitoring, evaluation, and communication practices. It is designed to support a robust and replicable approach to piloting insurance innovations under climate uncertainty.

This includes

- Pilot design principles, such as selecting high-risk, data-rich regions, ensuring sufficient spatial scale for robust modelling, and engaging local stakeholders from the outset.

- Modelling and data guidance, recommending scientifically validated, user-friendly, open-source models calibrated with local data, and integration of behavioural, actuarial, and scenario-based methods for credible insurance pricing.

- Adaptation and evaluation tools, including methods to estimate avoided losses, monitor pilot performance, and update models in response to new data or policy shifts.

- Communication and uptake strategies, promoting climate awareness, stakeholder trust, and the usability of outputs through tailored outreach, open-access tools, and policy-relevant formats.

Together, these elements aim to strengthen the scientific, social, and operational foundations of climate risk insurance innovation across the EU.

Keywords

PIISA, climate adaptation, parametric insurance, climate change, risk management, natural disaster risk

Abbreviations and acronyms

Acronym	Description
2DII	2 Degrees Investing Initiative
ADEME	Ecological Transition Agency (Agence de la Transition Ecologique)
AGIF	Integrated Rural Fire Management Agency (Agência para a Gestão Integrada de Fogos Rurais)
BSC	Barcelona Supercomputing Center
CATNAT	Natural Catastrophe (Catastrophe Naturelle)
CCR	Central Reinsurance Fund (Caisse Centrale de Réassurance)
CSS	Clay Shrink-Swell
DRR	Disaster Risk Reduction
FMI	Finnish Meteorological Institute
IbI	Index-based Insurance
LAI	Leaf Area Index
NDVI	Normalized Difference Vegetation Index
NTI	National Treasury Insurance
PIISA	Piloting Innovative Insurance Solutions for Adaptation
PPP	Public-Private Partnership
RGA	Shrinkage and Swelling of Clay Soils
UAV	Unmanned Aerial Vehicle
WTP	Willingness To Pay
WP	Work Package

Table 1: List of Acronyms

2 Introduction

Climate change is intensifying risks across Europe, with extreme weather events and natural disasters becoming more widespread and recurring (IPCC, 2023). Hydrological events (e.g., floods, landslides), and meteorological or climatological phenomena (e.g., storms, droughts, wildfires) are directly influenced by changing climatic conditions and are increasing in both frequency and intensity (Kron et al., 2019).

Future climate risks are expected to escalate due to rising extreme weather events combined with socioeconomic trends like urban expansion and population growth. With more individuals now living in hazard-prone regions, potential losses from climate-related events are projected to grow significantly, leading to substantial direct and indirect societal costs (Botzen et al., 2019).

While risk-reduction strategies such as infrastructure improvements, early warning systems, and land-use planning play a critical role, there remains a residual risk, particularly for extreme events that surpass the protective thresholds of such measures (Botzen, 2013). These growing residual risks highlight the need for innovative de-risking solutions such as insurance to enhance preparedness and resilience.

Insurance mechanisms are uniquely positioned to address climate risks by providing financial coverage for recovery while incentivizing risk-reduction behaviors among policyholders. Through pricing, private insurance often signals the cost of risk, which can in turn encourage households, businesses, and governments to implement adaptive and preventive measures (Botzen & Van Den Bergh, 2009; Kunreuther & Michel-Kerjan, 2013). Measures such as lower premiums for adaptation activities can benefit both parties by enhancing the insurability of hazard risks as well as increasing societal resilience. Furthermore, insurance accelerates recovery by offering timely financial support, which is often more efficient than governmental relief programs, thereby mitigating indirect economic impacts such as business interruptions and consumption shocks (EIOPA, 2023b; Surminski et al., 2016). However, one can notice that the diffusion of climate insurance across Europe is uneven, with many gaps in coverage, which will be discussed in this deliverable.

The Piloting Innovative Insurance Solutions for Adaptation (PIISA) project seeks to advance this goal by researching and developing novel insurance products tailored for Europe's changing risk landscape. PIISA aims to enhance resilience in regions vulnerable to climate-related events by focusing on de-risking mechanisms such as parametric insurance products. This paper synthesizes existing research conducted within the PIISA project, and summarizes insights focusing on insurance models, factors influencing uptake, modelling, and risk mitigation strategies within five pilot contexts: green roofs, urban clay shrink swell, agriculture, and two kinds of forestry risks. This report builds on insights from existing deliverables 1.1 and 1.2, and synthesizes overarching findings and their practical relevance to pilot regions with an implementation focus. These insights are then used to develop a 'Design and Modelling Framework' to guide pilot implementation, providing a set of standardized guidelines and recommendation that the various pilots should follow to enhance their success and eventually to help ensure transferability and upscaling to different contexts.

This deliverable is structured as follows. Section 3 presents the project background, with an overview of Work Package 1 (WP1), and details on each deliverable within WP1: Deliverables 1.1 through 1.4. Section 4 presents key insights from research conducted in WP1 and articulates the relevance for each pilot. Therefore, this section includes general learnings and specific findings across the overarching pilot areas: cities and well-being (green roofs and clay soil shrinkage), food and agriculture, and forestry (wildfire and windthrow), each further examined through the lens of insurance risk modelling. Section 5 outlines the Design and Modelling Framework to be used by pilots in WP3, focusing on pilot design and set-up guidelines, modelling and data specifics, and development and replicability frameworks. Finally, Section 6 concludes.

3 Project context and background

The PIISA project is divided into five interlinked Work Packages (WPs), interacting with each other as shown in Figure 1. This report is linked to WP1, focusing on innovations in insurance solutions.

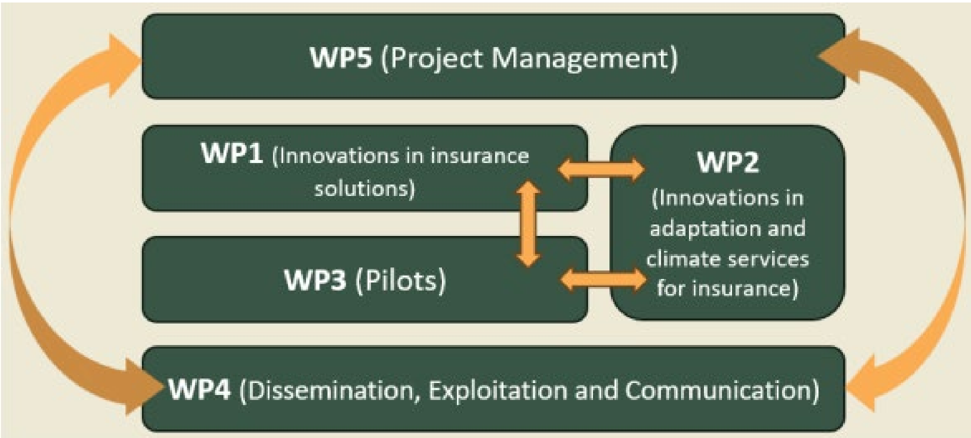

Figure 1: PIISA Work Packages

WP1 is closely linked to the pilot projects undertaken in WP3, with the desk studies and market analysis for innovative insurance solutions directly providing resources and inputs for the pilots. PIISA pilots are organized into 3 themes, namely Cities and Well-being, Food and Agriculture, and Forests and Forestry. These consist of extensive piloting covering at least 3 biogeographical regions, 7 cities, and 7 EU member countries, collectively directly or indirectly impacting 60% of the EU population. An initial overview of the pilots and pilot regions for the first loops of the respective pilots is provided below:

1. Cities and Well Being
    a. Pilot 1: Green Roof Insurance (Netherlands)

    b. Pilot 2: Insurance for Soil Stability Risks (France)
2. Food and Agriculture
    a. Pilot 3: Insurance Services for Agriculture (Spain)
3. Forests
    a. Pilot 4: Forest Insurance against biotic and abiotic risks (Germany)
    b. Pilot 5: Wildfire Insurance for Adaptive Action (Portugal)

The pilots are further broken down into 3 loops, where the first loop is about learning about the insurance and information service potential and identifying gaps and solutions, the second loop widens the concept to new areas to study the applicability, and loop 3 finally explores the wider replicability of the solutions.

3.1 Overview of WP1

WP1 focuses on innovations in insurance and on assessing the role of insurance in accelerating climate adaptation across Europe. It aims to analyse the supply and demand of climate risk insurance, identify barriers to uptake, and focus on the design of innovative insurance products that address emerging risks and opportunities in climate change. WP1 comprises four deliverables, wherein D1.1 and D1.2 are already delivered and D1.3 and D1.4, set to be released together, provide additional insights useful for the implementation and upscaling of pilots in WP3. Each deliverable in this WP contributes to a comprehensive understanding of the insurance landscape in Europe in relation to climate risks and adaptation strategies. The outputs from WP1 are aimed at supporting other WPs and pilots of the PIISA project. Some definitions of technical terms used in the project are outlined below:

No.	Term	Definitions
1	Parametric Insurance	Parametric insurance (also known as Index-based Insurance [IbI]), provides payouts based on predefined parameters or triggers (e.g., rainfall levels or wind speed), regardless of the actual damage. It allows for quicker payouts since no loss assessment is needed, but the payout might not reflect the exact loss. Other advantages include transparent methodologies, and the possibility to assess how much the management of an area impacts the risk and price.
2	Partial Equilibrium Models	Partial equilibrium models analyze specific markets/ sectors (e.g., forestry) without considering the broader economic system, making them effective for assessing market dynamics like supply, demand, and pricing.
3	Actuarial Models	Actuarial models are used to evaluate financial risks by analyzing historical data and forecasting future risks.
4	Catastrophe Models	Models which use computer-assisted calculations to estimate the losses that could be sustained due to a catastrophe event such as natural disasters (hurricanes, earthquakes).

5	Agent-based Models	They are simulations that mimic the behavior and interactions of individual entities, such as consumers, insurers, or policymakers, within a system. Each agent operates based on predefined rules, responding to changes in the environment and other agents' actions.
6	Bootstrapping	Bootstrapping statistics is a form of hypothesis testing that involves resampling a single data set to create a multitude of simulated samples. Those samples are used to calculate standard errors, confidence intervals and for hypothesis testing.
7	Insurtech	The use of technology innovations designed to find cost savings and efficiency from the current insurance model.
8	Protection gap	Describes the difference between economic losses from events and the proportion of this that is covered by insurance. It reflects inadequate insurance coverage, often due to affordability issues, lack of availability, or limited public awareness.
9	Charity Hazard	An individual's tendency not to insure themselves or take other mitigation measures as a result of reliance on expected financial assistance from federal relief programs or donations by other individuals.

Table 2: Definitions of Technical Terms

Deliverable 1.1

Deliverable 1.1 focuses on the potential role of insurance in accelerating climate adaptation in Europe. Methods include a systematic literature search, an AI-powered search, a comprehensive literature review, and a mapping exercise of climate insurance penetration. It assesses the current landscape of insurance for climate risks and climate adaptation, identifying the supply and demand dynamics, barriers to adoption, and potential innovations in insurance. It provides a systematic review of climate-risk insurance systems and the protection gap for hazards such as floods, wildfires, and windstorms. The report highlights differences in insurance penetration across countries and sectors, focusing on barriers to uptake from both demand and supply sides. It identifies innovations like parametric insurance and Insurtech, and emphasizes the importance of public-private partnerships, premium structuring, and multi-actor collaboration for enhancing insurance coverage and promoting climate resilience. For more detailed information, the full report is available on the PIISA website (PIISA, 2024b).

Deliverable 1.2

Deliverable 1.2 studies advancements in climate risk modelling for insurance. Through targeted paper selection by keywords, queries, and screening techniques, it explores the evolution of actuarial and catastrophe modelling techniques for assessing climate-related risks. By undertaking a comprehensive literature review, it provides an overview of the current landscape of climate risk modelling to identify lessons learned and knowledge gaps to be addressed through future research. This deliverable provides insights into effective risk modelling techniques and their implications for insurance product innovation, ensuring that insurers can better respond to climate challenges. Key recommendations include developing forward-looking models, broadening geographical and hazard coverage, and including the commercial sector through public-private insurance mechanisms. For more detailed information, the full report is available on the PIISA website (PIISA, 2024a).

Deliverable 1.3

This current deliverable presents a collaborative design and modelling framework for the pilots in WP3, synthesizing insights from D1.1 and D1.2. It is a result of Tasks 1.1 (Challenges, barriers, and opportunities to reduce the insurance protection gap and accelerate adaptation and resilience building) and 1.2 (Actuarial risk modelling – state-of-the-art, challenges, and innovation potential). It outlines the key areas of focus and study for implementing innovative insurance solutions in pilot regions, emphasizing the importance of tailored approaches to enhance insurance uptake and adaptation efforts within the unique and specific context of each pilot. The remainder of the report synthesises the overarching learnings and takeaways from D1.1 and D1.2 and their relevance to each pilot.

Deliverable 1.4

Deliverable 1.4 is set to be released alongside D1.3 and provides focused market reviews in the WP3 pilot areas and sectors critical to climate adaptation, such as agriculture, forestry, and urban green infrastructure. It is a critical complement to D1.3, as it summarises the current state of insurance markets in the chosen sectors, assessing innovative insurance solutions, and exploring their potential to support climate adaptation efforts across diverse European regions.

4 Key learnings and takeaways from WP1

4.1 General Learnings

D1.1

The purpose of the inventory study in D1.1 (Role and potential of insurance in accelerating climate adaptation in Europe) is to evaluate how insurance can be leveraged for climate adaptation. It presents an overview of insurance concepts, from traditional to innovative models, emphasizing their role in managing risk and compensating for climate-induced damage. The general key learnings are specified as follows:

1. **Traditional insurance mechanisms show limitations and struggle to adapt to climate change.** This is primarily due to increased risks and increasing insurance protection gaps. To address this, the study emphasizes the potential of parametric insurance, which offer faster payouts and better alignment with climate risks like floods, wildfires, and soil shrinkage—insights particularly relevant for Pilot 3 in Spain.
2. **Recent trends in European national insurance schemes, regulatory frameworks, and insurance penetration note differences in climate risk insurance across Europe.** Specifically, insurance penetration rates are generally lower in Eastern Europe compared to Western Europe, driven by diverse regulatory approaches.
3. **Causes of protection gaps and solutions on the demand-side and supply-side** are identified. On the demand side, gaps arise due to low public awareness of climate risks, limited financial capacity, and a lack of trust in existing insurance products. Tools like Pilot 2's Clay Shrink Swell Building Damage Assessor are critical in empowering homeowners to evaluate their risks and insurance needs. On the supply side, insurers face challenges in assessing climate risks due to rising uncertainty, leading to higher premiums or coverage exclusions. Public-private partnerships (PPPs) and incentives for insurers are proposed as solutions to improve coverage availability. This deliverable identified data-sharing frameworks as solution to close these gaps.
4. **The importance of multi-stakeholder partnerships is emphasized, mentioning various stakeholders such as insurers, landowners, and local authorities.** For instance, for Pilot 4 in Germany and Pilot 5 in Portugal, engagement of stakeholders needs to be explored, since these pilots require working closely with local governments and communities to integrate scalable solutions.

D1.2

Deliverable 1.2 synthesizes insights from various climate risk insurance modelling approaches, focusing on lessons applicable across different pilot regions. The findings highlight both the strengths and limitations of existing models and suggest directions for future innovation.

1. **Climate Risk Models:** Majority of forward-looking models show that climate change and socioeconomic developments exacerbate future risks, leading to higher insurance premiums. Models designed to assess high impact, low frequency events, like heatwaves, floods, and hurricane, typically rely on catastrophe modelling, while more frequent events like windstorms and wildfires are better assessed through actuarial models. Furthermore, by integrating hazards, exposures, and vulnerabilities into catastrophe models, insurers can stochastically simulate thousands of scenarios (Botzen, 2021; Jarzabkowski, et al., 2019). Both approaches play critical roles depending on the hazard and the type of risk.

2. **Insurance Pricing and Structures:** Majority of the reviewed studies focused on insurance for households, with insurance models frequently incorporating a consumer decision component. Typically, insurance supply models predominantly concentrated on pricing of

contracts, and often exclude explicit considerations of the insurer as an agent (e.g., Boudreault et al., 2020; Brunette et al., 2015; Sacchelli et al., 2018). If not omitted entirely, a common modelling assumption includes only one representative insurer, an assumption which was also found to hold valid when looking at insurance demand models. Alternatives included modelling an insurance market wherein a public entity provided the insurance instead of a private body (e.g., Crick et al., 2018; Hudson et al., 2019; de Ruig et al. 2023), or through public-private partnerships (PPPs), where the government served as a risk-neutral reinsurer (e.g., Perazzini et al., 2022; Hudson et al., 2019; Aerts and Botzen 2011). Affordability is a critical aspect, as fully risk-based premiums could make insurance inaccessible for lower-income household in high-risk regions. Multi-criteria analyses, such as by Hudson et al. (2019), showed that PPPs could improve affordability by distributing risk and reducing premium costs in vulnerable areas.

3. Gaps in the Research: A key gap in the existing literature is the limited application of forward-looking models incorporating future climate change and socioeconomic scenarios, with less than half of the current models taking such considerations into account. Limited incorporation of multi-hazard approaches, despite their growing relevance due to increasingly interconnected risks is another area for future research.

4. Recommendations for Future Research: Future research should focus on developing forward-looking models, consider using a more refined spatial scale, broaden the geographical and hazard coverage, and include the commercial sector through public-private partnerships. Given the importance to also consider the affordability of insurance, it is also crucial to design insurance schemes that balance affordability and coverage by integrating PPPs, vouchers for high-risk areas, or semi-voluntary insurance schemes tied to financial instruments like mortgages.

4.2 Cities and Well-being

4.2.1 Green Roofs

The green roof insurance pilot, led by IVM Institute for Environmental Studies, aims to investigate how insurance can promote the adoption of nature-based solutions such as green roofs. Green roofs can promote flood mitigation, recreation, and biodiversity benefits. The pilot starts in the Netherlands and partners with Dutch insurer Interpolis to assess the economic viability and environmental impact of green roofs through surveys and cost-benefit analyses. The pilot will also identify incentives to encourage insurance uptake of green roofs, as well as the barriers. The pilot will extend to Finland and Mediterranean regions, evaluating regional differences.

The Netherlands' green roof market is expanding rapidly, driven by dense urbanization and environmental incentives. Cities like Rotterdam and Amsterdam promote green roofs with subsidies and ambitious targets, such as Rotterdam's goal to green 10 million square feet of rooftops by 2030. These initiatives are part of a broader climate strategy for stormwater management, urban cooling, and increased biodiversity, aligning with national goals for resilience and sustainability (Living Roofs, n.d.). Green roofs can play a vital role in enhancing urban resilience to climate risks, particularly for flooding, and insurers can play a crucial role in increasing the implementation of green roofs. For instance, Interpolis offers three types of green roofs to address roof leakages from extreme rainfall, each addressing increased green space, biodiversity, or water storage (PIISA, 2024c).

D1.1 showcases a critical finding that a significant obstacle to the adoption of green roofs is the underestimation of exposure to climate and natural risks in different regions, having studied both European and American exposures. For instance, Dutch survey respondents living in floodplains often underestimate potential flood levels (Mol, Botzen, Blasch, et al., 2020). This trend is significant for the Netherlands, where green roofs could be instrumental in mitigating urban flooding, yet many residents may not fully recognize the severity of flood risks. Moreover, approximately one third of British households responded to surveys saying that they are not exposed to risk of flooding while they live in flood prone areas (J. E. Lamond et al., 2009), and fewer than half of the households in Italy that have previously experienced severe flooding believed similar events will occur in the future. Additionally, there is a tendency for individuals to discount their own personal risk compared to the perceived risk to the broader community (Scolobig, et al., 2012). The evidence of underestimation of risk from the US is also highlighted. A survey conducted among affluent, well-educated households in the U.S., studying '100-year levees', revealed that over 60% perceived their flood risk as low or non-existent, and more than 80% expressed minimal concern about flooding. Despite their education and financial status, only 20% had purchased flood insurance, as many believed the levee offered complete protection. The authors concluded that these households misunderstood the true flood risk, commonly overestimating the likelihood of floods while underestimating the potential damage (Ludy & Kondolf, 2012).

Risk perception has a significant impact on the willingness to pay (WTP) for flood insurance. Botzen and Van Den Bergh (2012) found that Dutch households' WTP was 25% lower for individuals believing their risk was below average and 41% lower for those who thought they wouldn't suffer damages. Similarly, a study by Seifert et al. (2013) showed that individuals in Germany and the Netherlands who perceived a higher likelihood of flooding and greater damage were more willing to insure themselves. However, there is insufficient research available to confirm a consistent link between risk perception and flood insurance uptake. Risk perception is influenced by several factors like homeownership, where homeowners tend to show higher levels of threat appraisal, likely due to the value of their property (Roder et al., 2019). Age also affects perception (Botzen et al., 2009a), with older individuals, particularly those with higher education, generally exhibiting lower levels of perceived risk. These factors shape how people evaluate their vulnerability to climate risks. Addressing this perception gap could help improve adaptation measures in urban areas, such as green roofs, by increasing awareness and subsequently WTP for protective measures.

Insurance Risk Modelling

Moving towards the modelling of insurance products, D1.2 studies insurance supply models and the links with the pricing of climate risk insurance contracts, which can inform green roofs and other adaptation initiatives. An example of such a model is showcased by Aerts and Botzen (2011), who use catastrophe models to calculate flood premiums in the Netherlands based on regional expected annual damage and housing data, considering several socioeconomic and climate change scenarios. Through this methodology, they found a significant increase in insurance premiums over time due to climate change and socioeconomic developments, as well as the complication of long-term insurance contracts due to future uncertainties. Other insurance supply models focus on providing spatially specific premium calculations at a household level (Boudreault et al., 2020). Models at this resolution could help mitigate adverse selection and encourage adaptation by reflecting area-specific risks more accurately. However, purely risk-based premiums may become unaffordable in high-risk urban areas, potentially influencing location decisions of residents (Botzen, 2021). To improve adaptation, premiums should balance risk accuracy with affordability to enhance uptake in high-risk areas and support initiatives such as green roof installations. Public-private insurance models could also help make risk-based premiums more affordable and, in turn, drive greater urban resilience.

4.2.2 Clay Shrink Swell Building Damage Assessor

Pilot 2, addressing gaps in insurance cover for soil stability risks, is led by 2 Degrees Investing Initiative (2DII). It focuses on mitigating risks associated with clay soil shrinkage and swelling, which can destabilize homes and lead to structural damage. Starting in Lyon, the project aims to develop a methodology and an online tool to educate homeowners about the financial risks associated with inadequate insurance cover for property damage caused by clay shrink swell events. The tool will empower users to assess their insurance coverage and advocate for better protection. The tool developed in this pilot will be enhanced by engaging insurance companies, consumer NGOs, and other stakeholders, especially those involved in the various WP3 pilots.

The clay shrink swell phenomenon occurs in clay-rich soils that shrink during dry spells and swell when rehydrated, often leading to structural damage in buildings. Insurers face rising claims, which are handled through the national Cat Nat (natural catastrophe or catastrophe naturelle) scheme in France, which covers drought-related damages, but only in officially declared disaster zones. Recent initiatives by France Insurers (France Assureurs) and Central Reinsurance Fund (CCR), such as “Initiative Sécheresse” (Drought Initiative), are developing preventative and resilience measures including soil stabilization techniques, to address these impacts in collaboration with Mission Risques Naturels and the Ecological Transition Agency (ADEME), particularly in high-risk areas (Cerema, n.d.; CCR, 2023).

Under France's Cat Nat scheme, clay shrink-swell (CSS) damage qualified as a natural event catastrophe only if 3% of the affected area is mapped as containing shrinkable clay, and the event is linked to exceptional drought conditions, as defined based on the Soil Wetness Index (SWI) (Bathélmy et al., 2024). These strict conditions prove challenging when assessing CSS events, especially given the variable and gradual impacts of CSS. Historically, approximately 50% of CSS-related requests for official disaster recognition under the Cat Nat scheme have been rejected over the past nine years (Cour des Comptes, 2022). This dependency on official recognition and the lengthy process of qualification can increase vulnerability of homeowners, delay compensation, and limit proactive adaptation efforts.

D1.1 findings highlight that factors such as education, age, and property ownership influence the adoption of climate insurance- beyond France's mandatory home insurance coverage that largely includes natural hazard protection. Older and well-educated individuals are generally more likely to purchase insurance policies (Atreya et al., 2015). However, some studies (e.g. Menapace et al., 2016) suggest that higher education does not always lead to higher uptake, possibly due to lack of complete understanding of technical policy terms that remains despite education, hindering uptake. Home ownership also plays a significant role, as home and business owners are more inclined to purchase climate insurance due to their legal responsibility to protect their properties. In France, for example, the attribution of responsibility is particularly relevant. According to Cornia et al. (2016), there is a prevalent belief in countries like France that the authorities should ensure the safety of citizens, with these public expectations for government-led protection reducing the perceived need for additional climate risk insurance.

Insurance Risk Modelling

Pilot 2 focuses on addressing insurance gaps for soil stability risks including CSS damage. High-resolution insurance pricing models, such as those by Boudreault et al. (2020), offer relevant insights, as they calculate premiums at a household level, and could accurately reflect localized risks such as CSS. This detailed approach provides an accurate reflection of localized risks, thereby promoting adaptation efforts. However, affordability concerns arise in high-risk areas, which could influence homeowner decisions on insurance and relocation (Botzen, 2021).

Agent-based models, as explored by de Ruig et al. (2022, 2023), further simulate household decisions on insurance uptake. These models incorporate risk-based premiums, household budgets, and deductibles through a subjective expected utility function. Potential relocation decisions are also taken into account, allowing for a more dynamic assessment of market and consumer interactions, showcased in studies by Dubbelboer et al. (2017), Jenkins et al. (2017), and Crick et al. (2018), where households are mandated to take flood insurance but can influence their premium by moving to another location or undertaking Disaster Risk Reduction (DRR) measures. In Tanaka et al. (2022), households decide whether to move or not based on a utility function that considers flood risk reflected by the insurance premium. All these studies modelled the interactions between households and the housing market, focusing on insurance, and de Ruig et al. (2022, 2023) showed that modelling interactions between consumers and the insurance market leads to useful insights about insurance uptake and affordability. Such models can predict how CSS risks, coupled with financial constraints, impact market dynamics and homeowner behaviour, supporting the development of tools to empower homeowners to evaluate risks and insurance needs.

4.3 Food and Agriculture

This pilot, led by Barcelona Supercomputing Centre (BSC), seeks to co-develop a demand-driven, index-based insurance (IbI) solution tailored to farmers' needs, with practical viability for insurance providers. Working closely with a farmer association in the Mediterranean region, the pilot aims to identify local agricultural needs and showcase IbI's benefits within the sector. Additionally, insurers will be supported in designing IbI products, particularly in the context of the Boreal region, by providing indicators related to weather phenomena that impact crop production. The pilot will further explore the potential for scaling these solutions across the EU.

Agricultural insurance supports climate risk adaptation by providing a safety net for European farmers, helping to stabilize income despite challenges such as adverse weather and market fluctuations. Under the EU's Common Agricultural Policy (CAP), farmers can access subsidized insurance and mutual funds, particularly for crop insurance, which is widespread in countries like France, Spain, and Italy. These insurance frameworks are tailored to local conditions and reinforce food security, supporting both sustainable agriculture and resilient rural economies (Bielza et al., 2008). Spain's agricultural sector is vital to its economy and environmental sustainability, generating close to €140 billion in revenue and employing over 440,000 people. This sector represents a major part of rural development, stabilizing local economies, preserving ecosystems, and sustaining nearly half of Spain's land use (ENESA, 2019).

For Pilot 3, several important insights emerge from past studies on Spain's insurance framework. Spain's insurance framework for natural disaster risk is shaped by the Consorcio de Compensación de Seguros (CCS), a public-private partnership (PPP) that closely resembles the French model. Established in 1941 during Spain's post-Civil War reconstruction, the CCS provides coverage for extraordinary and uninsurable risks that private insurers typically do not cover (McAneney et al., 2016). Funded independently through a mandatory surcharge across many policy types, this structure allows CCS to bridge public and private interests effectively, while ensuring that risks beyond market mechanisms are adequately addressed (Jarzabkowski et al., 2018). In Spain's agricultural sector, risk aversion influences the insurance demand, with highly risk-averse farmers willing to pay higher premiums for drought index insurance (Gómez-Limón & Granado-Díaz, 2023). Another key factor influencing crop insurance demand in Spain is the presence of premium subsidies, which Garrido and Zilbermann (2008) identify as the primary driver. However, these subsidies come with specific requirements, such as a mandatory deductible of at least 30% (Liesivaara & Myyrä, 2017), potentially impacting farmers' purchasing decisions.

Another important consideration in the agricultural insurance landscape is the "charity hazard" effect. According to Liesivaara and Myyrä (2017), state aid, especially for crops with low expected indemnity, can diminish the farmers' willingness to pay for high deductibles. However, this state support does not significantly impact the overall demand for insurance or affect premium levels. This suggests that while public assistance may ease certain financial burdens, it does not replace the broader perceived value of insurance coverage among farmers. Demographic factors, such as age, ownership status, and tenancy arrangements impact risk management approaches. Meraner and Finger (2019) identified a nonlinear relationship between farmers' age and their chosen risk management methods. Younger farmers generally favour on-farm strategies within agriculture, middle-aged farmers are more inclined toward off-farm strategies such as crop insurance and other financial risk-transfer tools, and older farmers tend to prefer on-farm, non-agricultural activities as a means of diversifying and managing risk. Ownership status, specifically the proportion of rented land, influences risk management practices. Meraner and Finger (2019) found that farmers who rent a larger portion of their land are more likely to adopt off-farm risk management solutions compared to those who primarily own their land and prefer non-agricultural risk management strategies. This suggests that tenancy could be a significant predictor for farmers' openness to adopting innovative financial instruments such as index insurance.

However, scaling index-based insurance (IbI) products could be hindered by some notable challenges. Binswanger-Mkhize (2012) argued that these products might fail to address affordability concerns among small-scale farmers or appeal to wealthier farmers who may prefer self-insurance. Additionally, without subsidies, IbI tends to have low penetration rates due to high costs (Surminski, 2014), which discourages uptake, particularly in lower-income regions. Therefore, some studies highlight the need for accessible and affordable insurance options to broaden adoption, especially among smaller-scale farmers.

For crop damage assessment from extreme weather events, such as windstorms, we observe advances in remote sensing technology, including the use of drone and satellite imagery. Furlanetto et al. (2023) demonstrated that unmanned aerial vehicles (UAVs) and Sentinel-2 sensors could accurately estimate hail damage in maize crops by using Leaf Area Index (LAI) and Normalized Difference Vegetation Index (NDVI)-based parametric methods. This approach offers a reliable, efficient way to quantify crop loss, significantly enhancing risk management capabilities for agricultural producers.

This pilot aims to extend the analyses to the broader Mediterranean region. In terms of risk behaviour, research specific to the Mediterranean agricultural sector reveals a strong link between risk aversion and crop insurance uptake. Studies such as one done by Menapace et al. (2016), consistently show that Italian farmers with higher levels of risk aversion are more inclined to purchase crop insurance. Similarly, Gómez-Limón and Granado-Díaz (2023) found that Spanish farmers who are more risk-averse exhibit a higher WTP for drought index insurance. These findings suggest that insurance products could be more effectively marketed toward more risk-averse farmers in risk-prone regions within Mediterranean region.

Insurance Risk Modelling

D1.2 delves into the modelling and hazard level analysis for index insurance products. The study found that while hazards such as flooding, hurricanes, and earthquakes are mostly estimated via catastrophe modelling, an area in which partial equilibrium applications prove useful is when the effect of insurance on (agri) businesses is considered. Many papers focused on hazards which would affect farmers, such as earthquakes (Perazzini et al., 2022), droughts (Birghila et al., 2022), hurricanes, and natural disasters more broadly (Kalfin et al., 2022).

While much of the existing literature emphasizes perils such as hurricanes, which are more common in non-EU context, the probabilistic techniques and vulnerability assessments developed for these hazards offer transferable methods. In particular, approaches that quantify exposure, adaptation scenarios, and asset vulnerability can be adapted to model drought risks in EU farming systems. These methodologies can help inform the development of an actuarially sound, data-driven drought insurance scheme for farmers. For instance, climate hazard and risk models have been developed for hurricanes (Bloemendaal et al., 2020; Vickery et al., 2006; and Emanuel et al., 2006). Probabilistic scenarios for hurricanes, based on historical tracks with certain parameters that determine the intensity and probability of occurrence, first developed by Apivatanagul et al. (2011), were widely applied in studies (Guo et al., 2022; Kesete et al., 2014, Peng et al. 2014). Kunreuther et al. (2013) similarly used hurricane scenarios but developed by a climate-catastrophe modelling approach. There is a heavier focus on residential buildings in hurricane insurance models, when compared with those looking at flooding, making the approach less land-based and more focused on the buildings themselves.

Many studies also evaluated vulnerability under different adaptation standards, categorizing exposure by building class, asset, or building value. Some studies focused on adaptation measures financed by agribusinesses (Barreal et al., 2014; Birghila et al., 2022; Brunette et al., 2017), with some papers modelling agricultural insurance, of which two studies specifically focused on crop insurance (Birghila et al., 2022; Islam et al., 2022).

4.4 Forests

4.4.1 German Forests: Biotic and Abiotic risks

Pilot 4, Forest Insurance Against Biotic and Abiotic Risks, led by AXA Climate, aims to explore and enhance forest insurance solutions to compensate for financial losses caused by climate events while promoting risk reduction measures. In collaboration with AXA Germany and forest owner Forst Arco-Zinneberg, both parametric and indemnity insurance models will be tested for different perils. The pilot will gather feedback through surveys and experiments, with plans to scale the approach to Finland, aiming to bolster long-term forest resilience across Europe.

Germany's forestry sector spans 11.4 million hectares, with significant private, municipal, and state ownership, and employs sustainable management practices like regulated reforestation, natural regeneration, and forest thinning. Growing stock is high, averaging 358 cubic meters per hectare, making Germany one of Europe's leaders in sustainable forestry resources (Federal Ministry of Food and Agriculture [BMEL], 2023).

For Pilot 4, several studies highlight the current state and challenges of climate and hazard insurance in Germany and other European contexts. When studying the European forest climate, windstorms are the primary forest risk, responsible for 50% of forest loss between 1950 to 2019, which is supported by data from the pilot region, showcasing that windstorms affected 7-51% of forest volumes (PIISA, 2024d). Wildfires, accounting for 25% of forest loss, prove a significant secondary risk, explored further in Section 4.4.2, and while other biotic risks such as bark beetle infestations are a critical threat, they are not an immediate focus due to limited data and insurance options (Ibid).

In Germany, the penetration of private climate insurance for windstorm risks stands at about 40% as illustrated by Figure 2. Though this uptake rate may seem low, it is comparatively high within the European context, where market-based and non-mandatory insurance systems generally exhibit low uptake (EIOPA, 2023a). Germany's insurance system operates on a voluntary basis without mandatory coverage requirements against natural hazards. However, regions frequently affected by natural disasters, such as large-scale floods, display relatively higher insurance penetration rates, reaching up to 50% in countries such as Germany and the Czech Republic.

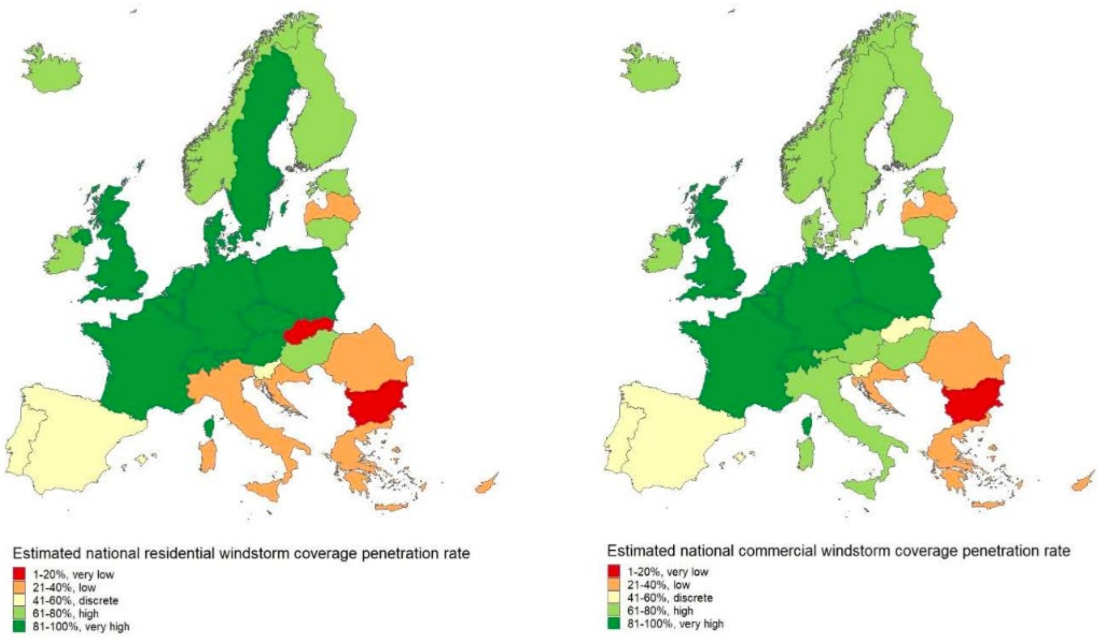

Figure 2: Windstorm insurance penetration rates (left: households, right: businesses) (PIISA, 2024b)

For instance, in northern and Atlantic European countries, windstorm hazard insurance in forests sees higher adoption rates compared to southern and eastern regions. This pattern is influenced by geographical exposure to severe winds and the inclusion of wind risk (EIOPA, 2023a). The strategic bundling of windstorm coverage within property insurance has proven effective in ensuring coverage in regions more vulnerable to wind damage. For example, Denmark has established windstorm reforestations funds. Managed by the Storm Council, these funds are subject to specific eligibility requirements, including that affected areas must have full insurance coverage against windfall, the damaged area must constitute at least one-sixtieth of the total managed forest area, and the forest must fall under public environmental protection measures (European Commission, 2017). This structured approach to windstorm recovery provides a model for mitigating the financial impact of severe weather on natural resources while promoting proactive environmental management.

Insurance Risk Modelling

D1.2 emphasizes the role of actuarial models, which leverage historical data, for estimating frequently occurring hazards like windstorms or wildfires. El-Adaway (2012) found that actuarial models enhanced with bootstrapping increase observational data for windstorm insurance by generating multiple scenarios from historical records; in this application, three datasets of 5,000 observations were created from 2,000 actual windstorm observations.

Partial equilibrium models are also effective in assessing adaptation efforts within forest insurance. Brunette et al. (2017) analysed forest-related damages, and the effect forest insurance can have on the implementation of adaptation efforts by examining the marginal cost and benefit of insurance in different situations, showing that the inclusion of adaptation efforts in forest insurance contracts can be beneficial in promoting adaptation efforts, particularly when adaptation efforts are unobservable to insurers. When examining the effect of insurance on the NPV of forest investments, looking at the equilibrium between marginal risk reduction costs and benefits, Barreal et al. (2014) found that insurance plays a larger role in increasing the NPV of forest investments when restoration costs are included in the policy itself.

Windstorm and wildfire insurance models both target forestry through historical data analysis, with empirical models like those by Brunette et al. (2015) and Loisel et al. (2020), where the latter examined vulnerability based on tree age and structural characteristics like diameter and height. Such models show that older trees are more vulnerable to windstorm damage, with damage likelihood increasing as trees grow taller and wider, underscoring the need for forestry-specific risk management approaches in insurance. Other studies that focused on insurance for forestry were Pinheiro & Ribeiro (2013), and Sacchelli et al. (2018).

4.4.2 Portugal Forests: Wildfire

This pilot, Wildfire Insurance for Adaptive Measures, led by AXA Climate, addresses wildfire risks in Portugal, one of Europe's most fire-prone regions. In collaboration with the Integrated Rural Fire Management Agency of Portugal (AGIF), the goal is to develop innovative wildfire insurance models that incentivize adaptation measures like constructing fire breaks and reducing forest biomass. The pilot focuses on enhancing resilience at both the household and forest management levels. Current wildfire models and adaptation scenarios will be analyzed to reduce wildfire frequency and intensity, with plans to scale the results across other European regions.

Portugal’s forestry sector, representing 2.5% of the national GDP, is critical to the economy and biodiversity (ClimateChangePost, n.d.)., with 35% of land covered by forests predominantly consisting of cork oak, pine, and eucalyptus. Cork oak forests cover about 720,000 hectares, maritime pine 714,000 hectares, and eucalyptus 844,000 hectares, each offering significant economic value due to high international demand (Cruz et al., 2021).

D1.1 discusses the projection of climate change in Southern Europe that is expected to impact the insurability of natural hazards significantly, particularly in Portugal. Both Portugal and Greece are forecasted to experience longer and more intense wildfire seasons over the coming decades, alongside an increased risk of floods (OECD, 2021). This escalating climate exposure suggests that, without shifts in premium structures, large areas in these countries could become increasingly uninsurable by mid-century as risk-based pricing becomes less feasible and affordable for high-risk zones (Tesselaar et al., 2022). This trend calls for innovative insurance approaches and risk-transfer products, especially in regions where climate-related risks are intensifying. However, these countries often lack mandated state interventions. In contrast, as Figure 3 suggests, Nordic countries, including Denmark, Finland, Iceland, Norway, and Sweden, exhibit much higher insurance penetration rates despite relatively lower wildfire risks. Iceland's National Treasury Insurance (NTI), for example, provides specific coverage against volcanic eruptions rather than wildfire, but the prevalence of hazard-specific insurance suggests that standardized insurance mandates can help increase climate resilience (Holzheu & Turner, 2018).

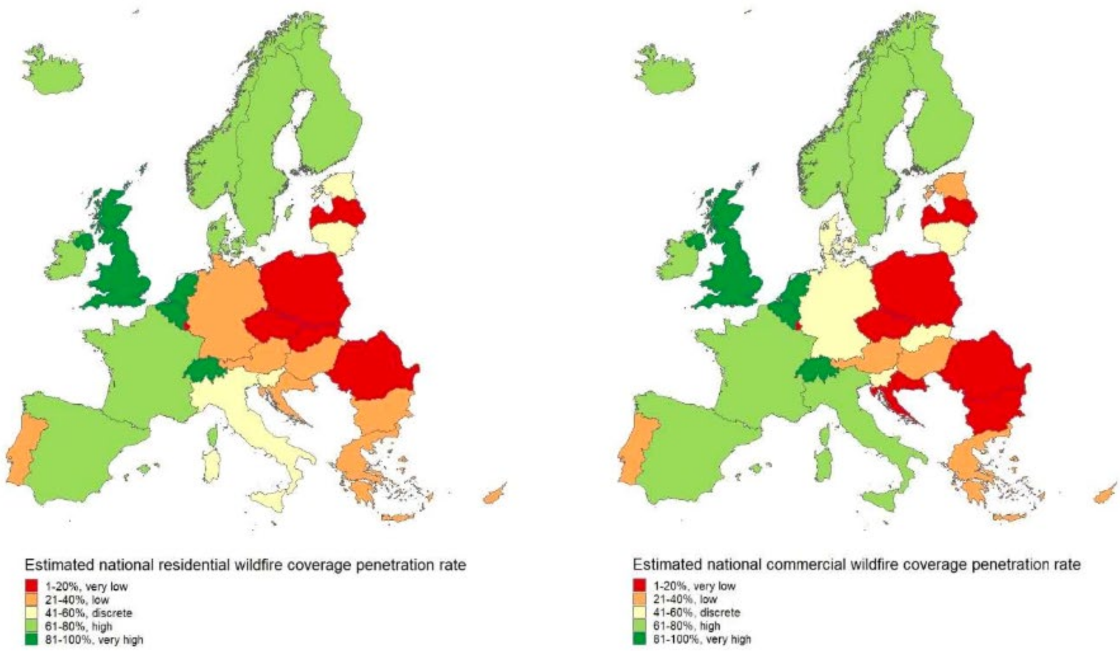

Figure 3: Wildfire insurance penetration rates (left: households, right: businesses) (PIISA, 2024b)

One promising innovation for expanding climate and hazard insurance coverage is through bundling approaches, which can encourage broader adoption. Bundling strategies can take two main forms: combining multiple climate risks into one insurance policy or attaching climate-risk coverage to other relevant insurance or financial products. In the first approach, bundling allows insurers to offer comprehensive protection under a single policy that covers several types of climate-related risks (Holzheu & Turner, 2018). In the second approach, climate insurance may be linked to other products, such as attaching wildfire or flood coverage to general homeowners' or life insurance policies or embedding it in credit products like mortgages and making this mandatory for property buyers. These bundling strategies present a valuable framework for increasing insurance adoption and ensuring financial protections for residents in high-risk areas (Kousky & Kunreuther, 2017).

Insurance Risk Modelling

D1.2 suggests that actuarial models, which use historical data, are well-suited for frequently occurring climate hazards like wildfires. Agent-based models are also useful and can lead to useful insights about insurance uptake and affordability through interactions between the insurance market and consumers (de Ruig et al., 2022 & 2023). They are suitable for integrating climate change and socioeconomic development scenarios into the models, with Sacchelli et al. (2018) showcasing some examples of models that use risk-based premiums for wildfires. Various studies highlight that risk-based premiums, paired with policies addressing affordability, could incentivize adaptation among high-risk communities. An example of this is seen by Hudson et al., 2016, who showed that correctly incentivizing adaptation through insurance can result in a lower household flood risk by 12% in Germany and 24% in France.

Most existing wildfire insurance frameworks against wildfires or storms generally do not account for adaptation (but see Barreal et al, 2014); however, adaptation measures against these hazards do exist (Manocha & Babovic, 2017; Paveglio et al., 2018). The idea of exploiting insurance as a tool to encourage adaptation has been explored across papers and hazard types (e.g., Brunette et al., 2017; Hudson et al., 2016; Jenkins et al., 2017; Peng et al., 2014), and researchers advocate for insurance frameworks that promote adaptation through mandated or incentivized measures, especially in wildfire-prone forestry sectors. Pinheiro & Ribeiro (2013) and Tesselaar et al. (2020) suggested that mandatory uptake of insurance can lead to higher resilience.

For wildfires, the hazard is usually determined as a probability per area based on historical wildfire occurrences. Wildfire risk models, often focused on forestry, can assess hazards by calculating burn probabilities across forested areas, with Pinheiro & Ribeiro (2013) using the expected annual average burned area per municipality based on historical fire occurrences and the annual average burned area. Modelling forest vulnerability often incorporates forest age as a proxy for wildfire susceptibility, with another study making use of empirical vulnerability functions based on the age class of the trees and the probability of destruction (Brunette et al., 2015). Vulnerability can also be translated for the forestry sector as a forest management parameter, with this parameter taken as a proxy for the preventative measures undertaken, and inversely related to the risk (Barreal et al., 2014). Exposure input data for many models is often related to forest stand value, with studies typically relating this value to the age of the forest stand (Barreal et al., 2014; Brunette et al., 2015, 2017; Sacchelli et al., 2018). Other studies that focused on wildfire insurance for forestry were Filippi et al. (2009), and Thompson et al. (2015).

5 Design and Modelling Framework for WP3 Pilots

This section summarizes key insights derived from WP1 and presents the core design and modelling framework to guide the implementation and evaluation of pilots under WP3. It provides structured, replicable guidelines to support the development of the innovative insurance solutions being explored to respond to climate adaptation needs across diverse geographies and sectors. It serves both as a methodological foundation as well as a set of operational guidelines to ensure scientific robustness, local relevance, and policy utility in developing climate risk insurance solutions.

5.1 Pilot Design Principles

To ensure consistency and scalability across WP3 pilots, all project partners are encouraged to follow the following guidelines:

- Selection of Pilot Regions:
  - Within chosen countries, select regions with high historical risk exposure, prioritizing areas with recorded hazard events and associated socio-economic losses.
  - For projects that include the testing of adaptation strategies into insurance products (e.g. forestry and green roof pilots), prioritize a region where existing adaptation measures or community-led initiatives are already planned or in place. This enables better calibration and validation of the models by providing real-world data on intervention performance, thereby offering a practical basis for calculated avoided losses or resilience gains.
  - Benchmark against existing insurance products: For the pilots related to developing or deploying insurance products, choose regions where existing insurance solutions are in place to enable benchmarking, identify market gaps, and ensure innovations cater to real market needs.
  - Minimum scale for model validity: For agricultural and forestry pilots, prioritize pilot regions where natural resource management areas (e.g. forest plots, agricultural land) are of sufficient size to allow for statistically robust modelling and to reduce risks of overfitting during calibration (e.g. >1000 hectares needed for forest plots).

- Co-creation with local stakeholders:
  - Engage relevant public authorities, community representatives, insurers, and technical experts from the onset to tailor solutions to contextual risks and needs, and to support the relevance, legitimacy, and long-term impact of the pilot.
  - Encourage the co-creation of knowledge and outputs by integrating local knowledge and needs into project design and decision-making processes.

- Ecosystem-specific relevance: Adapt the pilot intervention (such as green roofs, forest management practices such as fire breaks, where applicable) to reflect environmental, economic, and socio-political constraints in the pilot area. This ensures that solutions are ecologically appropriate, socially accepted, and economically feasible. Interventions that align with local capacities and constraints are more likely to be adopted, maintained, and scaled, thereby increasing both their effectiveness and long-term sustainability.

- Data Feasibility Assessment: Ensure early verification of data availability and quality to support robust modelling and risk quantification.

- Scalability and Replicability:

    - Design pilots with potential scalability in mind, considering the possibility of extending coverage models across regions and countries.
    - Use results of the market analysis (D1.1 and D1.4) as a stepwise entry point, prioritizing pilots in areas and regions with the highest insurance gaps and climate risks.

5.2 Modelling and Data Guidelines

Each pilot must be underpinned by scientifically credible and transparent modelling exercises. The following practices should be employed:

Models:

- Selection and performance criteria of risk models:
    - Scientifically robust and validated in similar geographic contexts – based on a comprehensive literature review. This helps ensure the model is reliable and credible, reducing the risk of applying inaccurate or irrelevant methods to local conditions.
    - User-friendly for local partners and decision-makers –outputs (e.g. indices, maps) should be easier to explain and interpret, which would increase the likelihood of local uptake and practical use.
    - Favor open-source models and data to facilitate transparency, replicability, and scaling of results in other EU regions.
    - Consider the use of forward-looking models that simulate future hazard trajectories, not just past events.

- Hazard Models:
    - Employ models that incorporate detailed geographic (spatial) and time-based (temporal) data, to simulate the dynamics of hazards like wildfires, droughts, or windstorms with high accuracy.

- Model Calibration and Validation:
    - Calibrate models using local or regional historical event data (e.g. to study fire intensity and spread, drought duration) and associated damage data to fine-tune model parameters for more accurate predictions.
    - Quantify expected damage or loss based on hazard scenarios, exposure datasets, and vulnerability curves. For example, crop simulation models maybe be used for agriculture, and engineering-based or agent-based models may be more

appropriate for urban and forest systems. This would allow for clear risk pricing and insurance product design by linking hazards to real-world impacts across sectors (agriculture, forestry, urban).
    - Use agent-based models alongside risk models to explore behavioural aspects such as insurance uptake and affordability, especially in high-risk or low-trust regions. This would help capture human behaviour and decision-making under uncertainty—key to designing insurance products that are not only technically sound but also socially accepted and economically viable.
    - Validate model outputs with independent datasets or expert judgment to ensure accuracy and robustness.
    - Perform sensitivity analysis to understand the influence of key input variables in the risk model.

- Adaptation Effectiveness Estimation: Where data permits and within the project scope (e.g. for the green roof and forestry pilots), scenario models with and without the intervention should be included (e.g. fire breaks, green roofs) to estimate the avoided loss or resilience gain attributable to the proposed measure.

- Insurance Design Modelling:
    - Integrate actuarial analysis (use of statistical techniques such as loss exceedance curves, frequency/severity distribution, and return periods) to ensure that insurance pricing is grounded in empirical risk data and statistical rigor. This helps in more accurate premium estimations, and applying these techniques to parametric or indemnity models helps match coverage to real-world risk levels and supports fair, transparent, and affordable insurance design.
    - Consider probabilistic approaches to account for climate uncertainty and exposure variability.
    - Competitiveness: Ensure pricing strategies reflect uncertainty in future hazard frequency and exposure, and model insurance affordability alongside pricing by recommending strategies such as semi-voluntary schemes (e.g. tied to mortgages), subsidies for high-risk areas, and PPP-based premium mechanisms for the end-users.
    - High-resolution models offer greater accuracy in risk assessment but can lead to higher premiums in high-risk areas; pricing strategies should therefore carefully balance precision with affordability to ensure broad insurance uptake.
    - Combine insurance with remote-sensing technology for damage evaluation, for example for assessing crop damages.

- Feedback and Uncertainty Loops: Build iterative loops to refine models and incorporate feedback from PIISA project partners, and local and external stakeholders as an ongoing process as pilot data becomes available.

Data:

- Data Quality and Coverage:
  - Use high-quality, consistent data across time and space, covering key layers such as hazard intensity, exposure assets (e.g., crops, buildings), and vulnerability factors.
  - High resolution spatial outputs should be designed where feasible by integrating detailed environmental data such as wind gust speeds, topography, forest stand structure, or crop coordination maps to improve predictive accuracy.
  - Where empirical data is limited, apply bootstrapping or stochastic modelling to generate synthetic but statistically representative datasets.

- Data Transparency and Management:
  - Document data sources, processing steps, assumptions, and limitations for transparency in the project reports to enhance reproducibility and credibility.
  - Conduct data gap analyses and apply imputation or uncertainty quantification where needed or possible.

5.3 Development and Replicability

Following the modelling phase, additional factors to take into account include:

- Monitoring, Evaluation, and Learning:
  - Implement a monitoring and evaluation framework to assess progress, performance, and impact of pilot activities.
  - Regularly review model performance and update assumptions or parameters based on new data or feedback.
  - Document and analyse lessons learned, including limitations and opportunities for improvement.
  - Include policy responsiveness: Update models and insurance parameters in response to changes in regulatory frameworks or government programs that affect risk-sharing or coverage incentives.
  - Knowledge-sharing for transferability: Capture and structure lessons from pilots in a format that supports replication (e.g. toolkits, open-access publications).
  - Engage local stakeholders in this phase to ensure feedback from affected communities and implementers is captured. Their insights improve the legitimacy, usability, and acceptance of project outputs.

- Bridging Perception Gaps:
  - Pilots should focus on building awareness of communities of climatic risks and parametric insurance solutions. Raising awareness is essential because low risk perception often leads to limited insurance uptake. Without understanding the

increasing frequency and severity of climate hazards — and how parametric insurance can provide timely financial support — communities are less likely to see the value in such solutions.
    - Pilot outputs should aim to reduce perception gaps on climate risks and insurance benefits by integrating tailored climate services: Combining insurance with locally relevant climate services (e.g., forecasts, early warnings, risk maps) helps communities better understand their exposure and how insurance can provide resilience. This informed engagement improves trust and increases the likelihood of adoption.

- Communication and Dissemination
    - Share intermediate results and insights with stakeholders throughout the pilot to foster trust and collaboration.
    - Use accessible communication formats: Convert complex modelling outputs into user-friendly formats – such as interactive maps, mobile dashboard, applications, or infographics – for operational stakeholders, and further into briefs and blog posts to increase awareness and ensure usability by non-experts.
    - Promote replication and scaling-up by publishing open-access tools, scientific papers, and case studies.
    - Tailor outreach and feedback mechanisms to local languages, norms, and institutions to build trust and maximize adoption wherever feasible.

6 Conclusion

This deliverable has explored numerous insights into pilot regions, examining challenges related to climate insurance, and focusing on strategies for targeting specific risks such as clay shrink swell, wildfires, and droughts, while highlighting various advanced climate risk modelling solutions for various risks and hazards. It also provides an analysis of gaps in existing frameworks, including affordability barriers, protection gaps, and the need for improved integration of forward-looking climate scenarios into models, and emphasizes the need for innovative insurance models that focus on enhancing risk assessment, insurance uptake, and adaptation strategies.

Each pilot region's unique risks and objectives can be informed and iterated based on the findings of WP1. Overall, WP1's insights provide a foundation for the implementation and scalability of pilots in WP3, focusing on actionable strategies such as the modelling of localized risks. The newly introduced Design and Modelling Framework offer structured, actionable guidelines for the selection pilot regions, engaging relevant stakeholders, choosing appropriate models, ensuring data quality, and embedding monitoring, learning, and communication strategies into WP3 pilots. These guidelines enhance the scientific credibility, contextual relevance, and policy impact of the pilots—ensuring that interventions are not only evidence-based but also actionable, scalable, and aligned with stakeholder needs. These findings outline a roadmap for future work, emphasizing the need to leverage WP1 insights for pilot leaders to refine methodologies, ensuring robust, region-specific adaptation strategies.

It is important to acknowledge that in practice, WP1 and WP3 evolved somewhat in parallel, and thus not all guidelines and insights from WP1 could be incorporated from the outset of pilot design. This framework is thus even more relevant for Loops 2 and 3, where learnings from earlier stages can be integrated more systematically, ensuring stronger alignment between modelling and on-the-ground needs.

To further improve knowledge transfer and learnings across work packages, WP1 and WP4 will play a critical coordination role, facilitating interviews with pilot leaders and project partners to assess the usability of this framework. This will also help feedback into the framework by studying key lessons from WP3 execution. These insights will contribute not only to internal feedback loops but also to the broader dissemination and scaling of effective climate insurance strategies.

This report is delivered as a complement to D1.4, which provides regional and sectoral focused market reviews, which would be imperative for pilot leaders to further scale the projects. Next steps involve tailoring the pilots based on these reviews, and engaging relevant stakeholders to upscale and replicate solutions, contributing to innovative insurance models for a more climate-resilient Europe.

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