



# PIISA

Piloting Innovative Insurance  
Solutions for Adaptation

## D3.11 Pilots for Cities and well-being

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D3.11 Pilots for Cities and well-being

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## Summary

This document is a result of Task 3.2 which includes two Cities and well-being pilots: Task 3.2.1 ‘Green Roofs’ and Task 3.2.2 ‘Climate adaptation dashboard for financial assessments’ regarding clay shrink swell soils.

The Cities and well-being pilots contribute to the following PIISA Specific Objectives:

- SO5: Localised piloting
- SO6: Activating Climate Resilience Dialogue
- SO8: Enabling insurance market growth

This document summarises development cycles and results for these Cities and well-being pilots and presents feedback from their implementation. It also analyses lessons learned regarding the effectiveness of different mechanisms in incentivising individual adaptation and behavioural changes.

Section 1 provides the context for the Cities and well-being pilots. While much of the focus for climate adaptation in cities is taken up by large infrastructure projects (often driven by public authorities) a significant share of climate risk in cities is concentrated in and around homes. The insurance considerations for implementing small scale, property level measures by homeowners differ significantly from those associated with large infrastructure projects. They require a focus on standard insurance products offered to homeowners and how these can be adapted or improved to support climate resilience. Within the context of the PIISA project as a whole and piloting innovative insurance solutions, the focus of the Cities and well-being pilots explores (a) how insurance innovations and products can incentivise individual homeowners to implement adaptation measures and adopt behaviour changes; and (b) how insurers can develop and supply these insurance innovations and products most effectively.

Section 2 summarises the development cycles and results of the green roof pilot. The pilot addresses what the economic value of green roofs is, what behavioural drivers and institutional conditions shape the adoption of green roofs at household level, and what policy interventions (including insurance products) can contribute to increasing uptake. Loop 1, implemented in the Netherlands, provides the quantitative core of the pilot. It combines a cost–benefit analysis assessing both private and societal value of green roofs at city scale with economic and behavioural experiments testing the effectiveness of different financial incentives. In parallel, stakeholder interviews with insurers, policymakers and technical experts identify barriers and enablers for integrating green roofs into insurance strategies and urban adaptation frameworks. Loops 2 and 3 extend the analysis to Nordic and Mediterranean contexts, respectively, focusing on transferability and regional specificities.

Section 3 summarises the development cycles and results of the clay shrink swell pilot which is focused on the problem of property damage caused by clay shrink swell (**CSS**) events and raising homeowner awareness of the potential financial risks associated with inadequate insurance cover for property damage caused by CSS events. A key output of the pilot was the development of the Clay Shrink Swell Building Damage Assessor (**CSSBDA**) which is a web-based tool to communicate to homeowners various information about the financial (and other) risks they face from inadequate insurance cover. The specification for the CSSBDA was developed during Loop 1 and the website was then developed and pilot tested in the City of Lyon in France during Loop 2 before being replicated at French national



level during Loop 3. At the same time as this replication at French national level, further research was undertaken to analyse the CSS risk level and insurance framework in other countries and geographic regions in the EU.

## Abbreviations and acronyms

Acronym	Description
WP	Work Package
CCS	Insurance Compensation Consortium
CSSBDA	Clay Shrink Swell Building Damage Assessor
CSS	Clay shrink swell
NBS	Nature-based solutions
DCE	Discrete choice experiment
WTP	Willingness to pay
PMT	Protection Motivation Theory
CBA	Cost-Benefit Analysis
NPV	Net Present Value
CBR	Cost-Benefit Ratios
CCR	Caisse Centrale de Réassurance
PPRN	Natural risk prevention plan
SFO	Sustainable Finance Observatory

## 1 Introduction

In Europe, considerable progress has been made in planning for climate adaptation and implementing related policies. However, the recent European Environment Agency review of national climate adaptation actions highlights that implementation of adaptation activities needs to be significantly strengthened (Leitner et al., 2024). Alongside the more recognised barriers to action, there is a need for new and alternative ways to design insurance policies, which could help stimulate climate adaptation activities while addressing affordability and risk-reduction objectives (Ceolotto et al., 2024).

PIISA (Piloting Innovative Insurance Solutions for Adaptation) is a Horizon Europe funded project working to reduce the climate adaptation gap (i.e. the difference between the recognised need for adaptation and the implemented adaptation activities) and the insurance protection gap by developing and piloting new insurance and risk-sharing concepts to address mounting climate risks in Europe.

The PIISA project seeks to extend insurance from purely compensatory, post-damage mechanisms to proactive instruments that incentivise households, firms and public authorities to adopt climate adaptation measures.

Recognising that innovative insurance solutions and risk awareness raising have roles to play in helping EU Member States strengthen their climate adaptation efforts, PIISA has developed and tested a range of insurance related innovations that have been co-created to enable and stimulate households, firms and the public sector to manage climate risks and adapt.

The project has developed new innovative concepts, products and services through a piloting process that includes co-creation with stakeholders and potential users. These pilots focus on three areas: (a) Cities and well-being; (b) Agriculture; and (c) Forests. This document summarises the development work and lessons learned for the Cities and well-being pilots.

Cities are on the frontline of climate change. As concentrations of people, infrastructure and economic activity, urban areas are particularly vulnerable to rising temperatures, more intense rainfall and more frequent extreme weather events (Dodman et al., 2022). Heatwaves are becoming more severe and prolonged, increasing risks to health, productivity and infrastructure (Dodman et al., 2022). At the same time, heavier downpours are overwhelming drainage systems, raising the likelihood of surface water flooding and damage to homes, roads and essential services (UN, 2018).

While climate change mitigation remains essential, climate adaptation has become a central pillar of urban policy and planning. Cities around the world are beginning to redesign streets, infrastructure and public spaces to cope with higher temperatures, manage water more effectively and protect communities from extreme events (Foster et al., 2011; Vollmer et al., 2024).

To date, much of the focus for climate adaptation in cities is taken up by large infrastructure projects - including nature-based solutions (**NBS**) - and often driven by public authorities (Esraz-UI-Zannat et al., 2024; Tran et al., 2024). Such projects require consideration of a wide range of factors including comprehensive and effective stakeholder consultation, ensuring bankability through innovative financing and insurance solutions and establishing the appropriate regulatory and policy environment (Huang & Wang, 2024; Kabisch et al., 2022).

However, climate adaptation is not only a concern for governments and city authorities (Frantzeskaki, 2019). A significant share of climate risk in cities is concentrated in and around homes (Richard &

Kazmierczak, 2011; Botzen et al., 2009; Hegger et al., 2017). Buildings that overheat in summer, are poorly insulated in winter or are vulnerable to flooding can pose serious risks to health, wellbeing and financial security. Homeowners also have a crucial role in climate adaptation by taking practical steps to make their properties more resilient to climate change risks. Measures implemented by homeowners can reduce damage, improve comfort, protect health and often bring additional benefits such as lower energy bills and increased property value.

The insurance considerations for these small scale, property level measures by homeowners differ significantly from those associated with large infrastructure projects. They require a focus on standard insurance products offered to homeowners and how these can be adapted or improved to support climate resilience. This is the focus of the Cities and well-being pilots: exploring (a) how insurance innovations and products can incentivise individual homeowners to implement adaptation measures and adopt behaviour changes; and (b) how insurers can develop and supply these insurance innovations and products most effectively while ensuring that building level adaptation measures should not be developed in isolation from possible collective measures and overall adaptation policy in the city.

Designing appropriate insurance products can serve as leverage to push people to invest in adaptation actions and is therefore an important enabler/incentive for making residential areas more climate resilient.

Within this context, the Cities and well-being pilots focus on different levers of change. The Green Roofs pilot examines how insurers can be encouraged to incentivise small scale adoption of NBS by homeowners by analysing both the factors that influence homeowners to invest in green roofs for their property (effectiveness of incentives, economic valuation etc.), and the barriers and enablers affecting insurers' ability to offer and scale such incentives. The Clay Shrink Swell pilot addresses the issue of low awareness among homeowners of risks related to inadequate insurance cover for property damage caused by clay shrink swell (**CSS**) events. This pilot involved the development of the Clay Shrink Swell Building Damage Assessor (**CSSBDA** and referred to in the Grant Agreement and previous deliverables as the PIISA climate adaptation dashboard), an online tool designed to inform homeowners about their financial risks associated with inadequate insurance cover for property damage caused by CSS events.

This document summarises development cycles and results for the Cities and well-being pilots and presents feedback from their implementation. It also analyses lessons learned regarding the effectiveness of different mechanisms in incentivising individual adaptation and behavioural changes. Section 2 describes the development cycles and results for the Green Roofs pilot, Section 3 covers the Clay Shrink Swell pilot.

## 2 Green roof pilot

### 2.1 Introduction

#### 2.1.1 Motivations and context

The Green Roof Pilot is motivated by the increasing impacts of climate change on the built environment, particularly the increase in pluvial flooding, heat stress and weather-related damages to roofs (hail, wind etc.). Green roofs are increasingly recognised as viable climate adaptation measures that can reduce risk while delivering wider environmental and societal co-benefits (Teotónio et al., 2021). Despite this potential, the large-scale uptake of green roofs remains limited (Brudermann & Sangkakool, 2017; Joshi & Teller, 2021; Vijayaraghavan, 2016).

In the Netherlands, green roofs are more common than in many other European countries - partly due to high levels of urbanisation, a long-standing policy focus on water management in spatial planning and incentive schemes (e.g. municipal subsidies). In other European contexts, green roofs and green roof financing schemes are less common (Brudermann & Sangkakool, 2017; Burszta-Adamiak & Fiałkiewicz, 2019; Davies et al., 2021).

Integrating green roofs and NBS into insurance products is only at its beginning. This pilot is motivated by a precedent, where the Dutch insurance company *Interpolis* initiated a climate adaptation strategy that includes various programs to incentivise Dutch homeowners to adopt prevention measures - including various NBSs, such as green roofs. These programs included information platforms, various services and even a 10% discount offered on the insurance premium to encourage homeowners to install green roofs.

#### 2.1.2 Objectives

The key objectives of the pilot are to understand the economic value of green roofs from both a societal and a private perspective, and to identify the key enablers and barriers that impact their broader uptake. Green roofs provide multiple co-benefits, such as reduced flood damage, improved thermal comfort, biodiversity gains and increased urban amenity (Francis & Jensen, 2017; Netusil et al., 2022; Teotónio et al., 2021). Yet many of these benefits are not directly reflected in market prices, investment decisions or insurance premiums. Additionally, many of their benefits are not directly received by their owners but rather benefit the public at large making it a case of split incentives. This weakens the incentives to invest in green roofs, despite their potential to reduce climate-related risks.

On the one hand, the pilot assesses the costs and benefits of green roofs, including wider societal and environmental benefits, using economic valuation methods. On the other hand, it analyses how different incentive mechanisms and institutional arrangements influence homeowner decisions, insurers' strategies and public-sector involvement. This includes assessing the effectiveness of insurance-based incentives in comparison to subsidies, information provision, and other policy instruments aiming at incentivising their adoption, as well as understanding the behavioural and organisational drivers behind adoption.

Importantly, in the context of this pilot, 'upscaling' has two meanings. First, the pilot aims to support the wider implementation of green roofs in cities by identifying what limits or stimulates their adoption by property owners. Second, it focuses specifically on the upscaling of insurance-related products, services and incentives linked to green roofs and other NBS aiming at residential property. In other words, the pilot aims to provide answers to (a) how can more green roofs be realised in European cities

for climate adaptation?; but also (b) how can the insurance sector play a role in increasing green roof adoption?

Ultimately, the pilot aims to contribute to the development of future viable business cases for scaling up green roofs across Europe. In doing so, it aims at supporting policymakers and insurers in creating the conditions needed for insurers to invest in and incentivise NBS as part of a broader climate adaptation strategy.

## 2.2 Loops and methods

The Green Roof Pilot is structured around three development loops that combine economic valuation with qualitative analysis and stakeholder engagement.

Loop 1 focuses on the economic analysis of green roof insurance (M6–M33). It focuses on the Netherlands and was the core of the economic analysis performed throughout the pilot. The analysis combined economic valuation - through cost-benefit analysis and economic experiments - with an assessment of the enablers and barriers to uptake. Loop 1 continued until the end of the project and provided the main empirical basis for informing the development of future business models.

Loop 2 (M20–M26) focused on the Nordic region. Building on the insights from Loop 1, this loop examined the applicability of insurance-supported green roof strategies in Nordic cities. The emphasis was on qualitative methods, including a webinar and interviews with insurers and policymakers, to assess how local climatic, institutional and market conditions affect costs, benefits, incentives and adoption.

Loop 3 (M27–M33) focused on the Mediterranean region. This final loop further tested the transferability of green roof strategies to Mediterranean cities. A dedicated workshop with policymakers and insurers was organised to assess region-specific barriers and enablers and to identify suitable local sustainable finance mechanisms.

Loop 1 provided the detailed quantitative foundation, while Loops 2 and 3 focused on contextualisation, transferability and the identification of region-specific conditions for scaling up green roofs and insurance-related solutions across Europe.

## 2.3 Synthesis of results

### 2.3.1 Economic analysis of green roofs

The economic valuation formed the quantitative core of the pilot. The approach followed the framework introduced in Deliverable D3.3, where key benefit categories (e.g. flood risk reduction, heat mitigation, biodiversity), cost categories (installation, maintenance, opportunity costs) and incentive mechanisms (insurance incentives, subsidies, information measures) were analysed through a combination of cost–benefit analysis and stated-preference methods.

This section provides a synthesis of the economic analysis of green roofs conducted within the pilot. Detailed descriptions of the methods are not repeated in this deliverable. Instead, this section summarises the methods and focuses on presenting the key insights that are directly relevant for the assessment of green roofs in a societal cost–benefit framework.

Specifically, the section synthesises results from three economic studies: (a) the Discrete Choice Experiment and its embedded informational nudge experiment (see 2.3.2); (b) the Protection

Motivation Theory experiment used to analyse the effectiveness of economic incentives (see Section 2.3.3); and (c) the Cost-Benefit Analysis of green roofs (see Section 2.3.4).

## 2.3.2 Economic study 1: Willingness to pay for green roofs

### Objectives and methods

This section summarises the economic valuation of green roof benefits based on a discrete choice experiment (**DCE**). A detailed description of the methodology is provided in Deliverable D3.3, and the full survey is also the subject of an upcoming peer-reviewed scientific publication. The purpose of this section is to briefly outline the main findings that are directly relevant for the societal cost–benefit analysis presented in this report.

In the DCE, respondents were asked to choose between alternative roof options characterised by different attributes (see Figure 1). These attributes include the presence of a green roof and its associated benefits and co-benefits, as well as a monetary attribute allowing for the estimation of willingness-to-pay (**WTP**). The DCE framework enables the estimation of marginal WTP values for individual green roof benefits by observing trade-offs made by respondents between costs and non-market attributes.

	Green Roof A	Green Roof B	No green Roof
Increase in species richness	Large increase in plant and animal species 	Small increase in plant and animal species 	No increase in plant and animal species 
Contribution to pluvial flood risk reduction	Flood risk reduction 	No flood risk reduction 	No flood risk reduction 
Visibility of Green Roof	Visible 	Not visible 	No green roof 
Indoor cooling during heatwaves	- 1°C 	No indoor cooling 	No indoor cooling 
Roof lifespan	+ 0 yrs (30 yrs) 	+ 30 yrs (60 total) 	+ 0 yrs (30 yrs) 
Annual cost	120€ per year 	30€ per year 	0€ per year 
Which would you choose?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure 1: Example of a choice task used in the DCE. Note: The order of attributes within the choice tasks is randomised between subjects (but kept consistent within-subject)

The primary objective of the DCE is to estimate individuals' willingness to pay for green roofs benefits and co-benefits. These WTP estimates provide monetary values for benefits that are not directly observed in markets, which are then included in the societal CBA.

A secondary objective is to examine how informational nudges influence preferences and WTP for green roofs. Specifically, the experiment tested whether providing information that emphasises either private benefits ('pro-self' framing) or public and societal benefits ('pro-social' framing) (see Figure 2) affects individuals' valuation of green roofs. This analysis provides insights into the potential



effectiveness of information campaigns and other non-monetary policy instruments in stimulating green roof adoption.

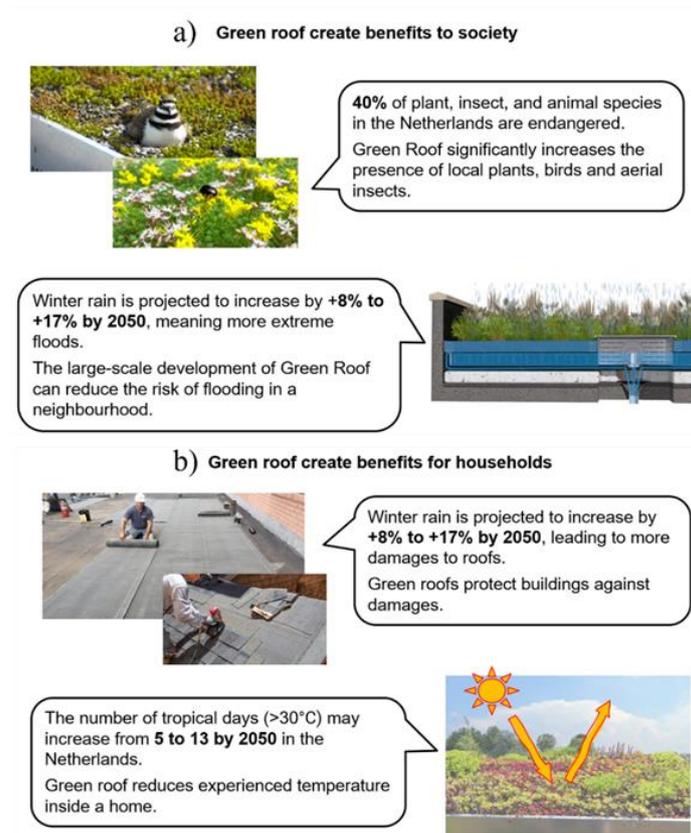


Figure 2: Information nudges presented before the choice tasks. (a) Pro-social treatment focused on the biodiversity and flood risk reduction attributes; (b) Pro-self treatment focused on the lifespan increase and indoor cooling attributes

## Results

Results indicate that respondents exhibit a clear and positive willingness to pay for green roof benefits and co-benefits. Full results are presented in Appendix 1: Willingness to pay estimates for green roofs.

We focus first on the control group, as it serves as the reference case for the cost–benefit analysis. The control group provides estimates that do not incorporate any experimental manipulation and therefore reflect baseline preferences, free from framing toward specific benefits. Within this group, respondents exhibit the highest willingness to pay for biodiversity-related benefits. On average, respondents are willing to pay approximately €103 per year for a green roof that supports a small increase in species richness, and about €153 per year for a larger biodiversity improvement. These values indicate a substantial appreciation of biodiversity outcomes, even in the absence of targeted informational nudges.

Willingness to pay for flood risk reduction is of a similar magnitude, with a mean value of approximately €103 per year in the control group, suggesting a high value for pluvial risk reduction (albeit framed at the neighbourhood scale, once sufficient green roofs are built).

Among the private benefits, indoor cooling also has high WTP, with a mean value of around €72 per year per degrees of cooling during heatwaves. In contrast, the aesthetic-related benefit has a lower

value, with a mean WTP of about €17 per year, indicating that visual improvements alone are unlikely to drive adoption decisions.

Finally, respondents have a positive willingness to pay for an extended roof lifespan, with a mean WTP of approximately €2.8 per additional year, compared to a conventional roof. While small in absolute terms, this value captures a large long-term benefit that contributes to the overall economic case for green roofs when aggregated over time (up to +30 years in comparison to a conventional roof).

The comparison across informational treatments confirms that framing affects stated preferences, with clear differences between pro-social and pro-self framings, depending on the type of benefit considered. These effects, however, are best interpreted as amplifying existing motivations rather than fundamentally changing preference structures, in line with the conclusions of the underlying study.

Under the pro-social framing, willingness to pay for public benefits increases consistently relative to the control group. For biodiversity outcomes, mean WTP rises from €103 to €121 for small species increases and from €153 to €197 for large biodiversity improvements. A similar pattern is observed for flood risk reduction, where mean WTP increases from €103 in the control group to €120 under pro-social framing. These results indicate that making collective and societal benefits more salient strengthens individuals' valuation of green roofs as public-good-providing infrastructure. This suggests that communication strategies emphasising ecosystem services, climate adaptation and societal resilience can effectively raise support for green roofs.

The pro-self framing shows a different pattern. As expected, it tends to strengthen valuation of benefits that are more directly experienced at the household level. The strongest effect is observed for cooling, where mean WTP increases substantially from €72 in the control group to €106 under pro-self framing. Willingness to pay for roof lifespan extension also increases, from €2.8 to €4.6 per additional year, reflecting a stronger focus on long-term private financial benefits. For flood risk reduction, WTP rises further under pro-self treatment to €139, suggesting that framing flood protection as a personally relevant risk can be particularly effective. In contrast, the aesthetic benefit remains low across all treatments, indicating that visual improvements alone are not a major driver of preferences.

Importantly, while framing affects WTP, the relative ranking of benefits remains broadly stable across treatments. Biodiversity and flood risk reduction consistently emerge as the most highly valued attributes. This supports the conclusion that informational nudges reinforce existing values rather than creating new ones.

Overall, the treatment results highlight the potential role of non-monetary policy instruments, such as targeted information campaigns, in complementing financial incentives and insurance-based solutions. The study highlights especially that focusing individuals on their private gains is an effective strategy to increase their WTP for their benefits – as long as there is sufficient trust of citizens in the strategy targeting their neighbourhood and few 'free riding' behaviours. This raised WTP, in turn, can lead to wider adoption rates.

### **2.3.3 Economic study 2: Analysis of economic incentives**

#### **Objectives and methods**

The study investigates how different policy incentives influence household intentions to adopt green roofs in the Netherlands. The same Dutch sample was subjected to this experiment as the DCE presented in the previous section. The central component of the survey is a randomised controlled

policy experiment in which respondents are randomly assigned to one of three treatment groups (see Table 1), each corresponding to a different type of financial incentive:

- municipal subsidies where a share of installation costs is covered;
- insurance premium discounts offering reductions in annual home insurance premiums; and
- insurance deductible discounts lowering the deductible payable when making a damage claim.

Table 1: Incentive types and incentive levels presented to respondents

	Levels				
	0%	25%	50%	75%	100%
Incentive types					
Subsidy	Pay €3,000	Pay €2,250	Pay €1,500	Pay €750	Pay €0
Insurance premium discount	Pay €300/year	Pay €225/year	Pay €150/year	Pay €75/year	Pay €0/year
Insurance deductible discount	Pay €300/claim	Pay €225/claim	Pay €150/claim	Pay €75/claim	Pay €0/claim

Within each treatment group, five levels of financial incentives are presented, ranging from no support to full coverage. These correspond to different absolute monetary values overall. For each scenario, respondents indicate the probability that they would adopt a green roof. This repeated-measures design enables the estimation of adoption probabilities under alternative policy conditions.

In addition to the treatments, the survey in which the experiment is embedded incorporates measures of psychological drivers based on Protection Motivation Theory (**PMT**). These include perceived response costs, perceived efficacy of green roofs in reducing climate risks (flooding, heatwaves and structural damage) and perceived exposure to such risks. Sociodemographic and housing information is also collected to account for heterogeneity in responses.

The data was analysed using a regression analysis suitable for repeated observations per respondent. Each individual provides multiple probability judgments under varying incentive levels, which are modelled using pooled ordinary least squares with cluster-robust standard errors at the individual level. This approach accounts for intra-individual correlation and allows direct estimation of how policy incentives and psychological factors influence stated adoption probabilities. This design provides a basis for counterfactual simulations that quantify how adoption rates would change under different combinations of policy incentives and behavioural factors.

## Results

The main results of this experiment show that municipal subsidies, insurance premium discounts and insurance deductible discounts have distinct effects on household intentions to adopt, and that their effectiveness depends on the incentive level.

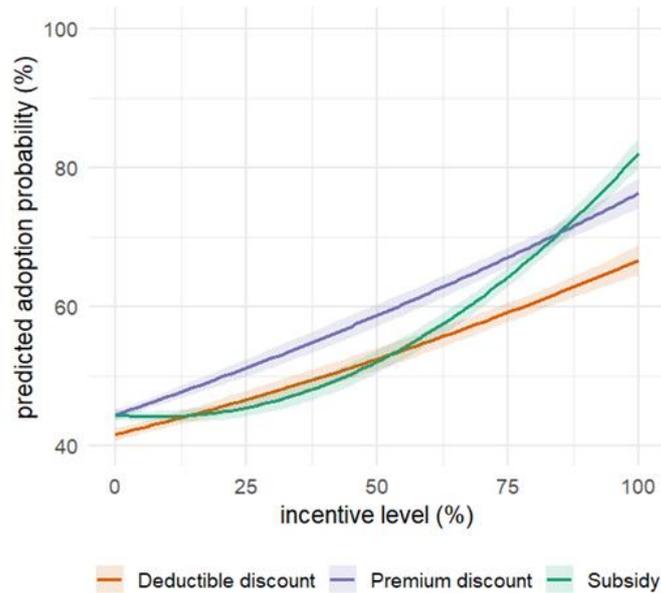


Figure 3: Counterfactual predictions of green roof adoption probabilities under alternative incentive scenarios, showing subsidies, insurance premium discounts and insurance deductible discounts across incentive levels. Buffer areas are 95% confidence intervals

Insurance premium discounts appear as the most effective incentive type up to a certain level (about 50% discount). Uptake rises from approximately 45% to nearly 80% as the discount increases from 0% to 100%, indicating that recurring reductions in annual costs are highly salient to households and effective even at relatively low incentive levels. Above this level of discount (which is highly unlikely to be provided by an insurer), subsidies appear as more effective. Deductible discounts also increase adoption, though more gradually, reflecting their contingent nature and lower immediacy. By contrast, municipal subsidies have a weaker effect at low levels, but adoption accelerates once subsidies reach around 50% or more of the installation costs. This pattern is consistent with a non-linear threshold effect, whereby households respond strongly only once upfront costs are perceived as sufficiently reduced. This echoes the patterns seen in other technology adoption following subsidy schemes (Liu et al., 2020).

These differences are likely linked to the temporal framing and certainty of the incentives. Subsidies lower the initial investment but are one-off transfers, whereas premium discounts provide recurring and predictable financial benefits, making them more tangible over time. Deductible discounts only generate benefits if damage occurs, which reduces their perceived value. At high subsidy levels, however, the rapid uptake highlights the importance of removing upfront financial barriers, especially for households that perceive adoption as costly or burdensome.

Overall, the analysis suggests that insurance-based incentives are more effective at modest levels of support, while large subsidies can trigger strong behavioural responses once a threshold is crossed. Importantly, the high levels of insurance discounts are probably not realistic in the current landscape, while generous subsidies do exist in many municipalities. It does indicate though that the potential

effect of such insurance-based incentives would be comparable to large subsidies. At the same time, the effectiveness of all financial incentives varies across households, with adoption responses shaped by perceived costs, beliefs about effectiveness, and baseline willingness to adopt.

### 2.3.4 Economic study 3: Cost-benefit analysis

The Cost-Benefit Analysis (**CBA**) is designed to evaluate the net economic performance of large-scale green roof adoption in the Netherlands. The analysis combines both biophysical and stated preference valuation methods to capture the multiple benefits and costs associated with green roofs.

#### Scope and data sources

The CBA was carried out for the Netherlands (Loop 1) using two primary sources of data:

- The flood risk modelling of Thijssen (2024) (available as an appendix to this deliverable), performed in parallel to Loop 1, which provides direct physical and economic estimates of avoided pluvial flood damages due to large-scale implementation of green roofs, as well as their cost estimates.
- The DCE results from Deliverable D3.3, which provide yearly stated preference (WTP) values for a range of co-benefits.

These sources allow for a complementary valuation of both use and non-use benefits of green roofs, thus providing a form of sensitivity analysis.

#### Benefits

The following benefits are included in the CBA:

1. **Indoor cooling.** Two increasing levels of indoor cooling were provided in the DCE: a reduction of -1°C or -2°C inside a building during heatwaves. The WTP estimates provided in Table 1 correspond to the WTP per degrees of cooling. However; since indoor cooling may vary dramatically depending on local conditions (building structure, green roof properties, local climate etc.) the most conservative assumption of -1°C was used in the CBA.
2. **Biodiversity.** Biodiversity increase was valued in the DCE, therefore through the angle of stated preferences. It was labelled in the experiment as an 'increase in species richness', to avoid the jargon term of biodiversity. The attribute levels are a qualitative indicator describing either a 'small increase' (small amount of local flora, insects, birds) or a 'large increase' (various species of flora, insects and birds). Considering the high variability and uncertainty regarding the impact of green roofs on biodiversity, the estimates used in the CBA are the most conservative WTP values associated with a 'small increase in species richness.'
3. **Aesthetic value.** In the choice scenario, the option for a visible green roof (either from a home window or from the streets) was provided to respondents, to capture the aesthetic motivation behind green roof adoption by households. It includes two levels 'not visible' - which is common with the status quo alternative - and 'visible.'
4. **Increased roof lifespan.** The lifespan of a green roof cannot be determined with precision, though about 60 years is a standard assumption (Thijssen, 2024). The maximum level in the DCE is 60 years, hence a total of +30 years of added lifespan in comparison to a conventional roof.
5. **Pluvial flood risk reduction.** For this benefit, two alternative valuation methods are used. These two valuation methods were used to run the CBA twice, enabling a form of sensitivity analysis comparing estimates from flood modelling and stated-preference valuation.



- a. Stated preference valuation based on individuals' WTP from the DCE. This attribute is challenging to quantify for a single green roof, since the marginal flood risk reduction benefit of a green roof can be very small at the scale of a catchment or a neighbourhood (Ercolani et al., 2018; Masseroni & Cislighi, 2016) and therefore difficult to communicate in an experimental setting. The design therefore uses a simple binary qualitative attribute: the alternatives can either 'contribute' or 'not contribute' to pluvial flood risk reduction. Notably, the second level defines the status-quo alternative, but it may also appear in green roof alternatives, since some green roofs can have no impact on flood risk reduction at all.
- Flood risk modelling. Biophysical valuation based on avoided damages (from Thijssen, 2024). Since the modelling focuses on *blue-green roofs* - which include an additional water retention layer and can store approximately 80mm of rainwater - an adjustment was required to align these estimates with standard *green roofs*. To ensure comparability, we apply a scaling ratio of 8/3, reflecting the average 30mm storage capacity of conventional green roofs. This adjustment was based on expert judgement and supported by existing municipal subsidy schemes in Amsterdam and Rotterdam, which set a minimum retention threshold of around 30mm for being eligible to a subsidy.

### Cost assumptions

Two main categories of costs are included:

1. Investment costs – covering materials, installation, and design.
2. Maintenance costs – covering periodic upkeep and vegetation care.

Two cost scenarios are made:

- Overlay scenario: installation of a green roof on top of an existing roof structure.
- Replacement scenario: installation that requires replacement or renovation of the existing roof structure.

These scenarios are conceptualised at the scale of the entire city of Amsterdam and represent two stylised cost–benefit extremes. The overlay scenario reflects a lower-cost configuration, while the replacement scenario captures a higher-cost intervention involving structural renovation. In practice, any realistic upscaling pathway would consist of a mix of both situations, depending on building characteristics and renovation cycles. The distinction therefore serves as an analytical abstraction to frame the range of possible cost–benefit outcomes rather than as a prediction of a single implementation pathway.

These scenarios reflect typical cost variations observed in the Dutch context and in comparable European studies. They may however display a slight bias towards the high range due to estimates relying on the [RESILIO project](#), which focused on the case study of Amsterdam, where costs may be higher than the rest of the Netherlands. This would add to a rather conservative Net Present Value (NPV) estimate.

### Analytical parameters

The CBA is conducted for a reference green roof area of 30m<sup>2</sup>. Two different discount rates<sup>4</sup> were used in the analysis over a time horizon of 60 years. When considering the CBA from a societal perspective (i.e. with the full set of costs and benefits) we used the standard discount rate applied in the Netherlands: 2.25%. This rate is based on official guidance applied by institutions such as the [Netherlands Environmental Assessment Agency \(PBL\)](#) and the Netherlands Bureau for Economic Policy Analysis (CPB). When applying the CBA from a private household perspective, that is, accounting only for the costs borne and benefits received by green roof owners, a different discount rate was used. In this case, the mortgage interest rate was adopted, as it reflects the household's opportunity cost of capital and the actual cost of financing the investment. Future private benefits are therefore discounted at a rate that is consistent with the financial decision faced by households. For the Netherlands, this corresponds to average rate of approximately 4.2% for a 60-year time horizon.

The CBA leads to calculating Net Present Values (**NPV**) and Cost-Benefit Ratios (**CBR**). As a reminder: the CBR is the ratio of the discounted value of avoided damages and co-benefits to the discounted total cost of implementation and maintenance. A CBR greater than one indicates that the benefits of the green roof exceed its costs, making the investment economically attractive. The NPV is the sum of the present value of avoided damages and co-benefits minus the sum of the present value of the total cost of implementation and maintenance. A positive NPV indicates that green roofs generate net economic benefits over their lifetimes when discounted to present values.

It is assumed that investment costs are a one-off payment (therefore not subject to discounting) while maintenance costs occur every year (and are therefore discounted in the long run).

Table 2 summarises the inputs used in the CBA. Assumptions rely on a 30m<sup>2</sup> standard green roof, with a capacity of 30mm rainwater storage. The flood risk reduction model is based on yearly damages and damage reductions of green roof scenarios in Amsterdam in euros in the current (cc) and future (FC) climate.

Table 2: Summary of cost and benefit estimates used in the CBA. N.A: Not applicable

Benefit/costs	Estimates (€/per household/yr)		Estimates (€/m <sup>2</sup> )	
	Low	High	Low	High
Indoor cooling (per degrees)	57,61	88,77	1,92	2,96
Aesthetic value	5,37	30,03	0,18	1,00
Increased roof lifespan (per year)	1,95	3,85	0,07	0,13
Biodiversity	83,07	184,75	2,74	4,18
Flood risk reduction (WTP)	85,2	122,74	2,84	4,09
Flood risk reduction (model)	N.A	N.A	1,94	2,02
Investment costs (overlying)	N.A	N.A	195,92	244,79
Investment costs (replacing)	N.A	N.A	298,38	394,07
Maintenance costs (yearly)	N.A	N.A	4,37	5,10

## Results

Results are presented across several tables as follows. Results are shown when considering only private benefits (i.e. indoor cooling, increased roof lifespan and aesthetic improvement) as well as scenarios that include both private and public benefits (private benefits plus biodiversity and flood risk reduction). Low and high bounds are reported, depending on whether lower- or upper-bound estimates are applied to the benefits and cost parameters. In one case ('low'), the lower range of benefits and the higher range of costs were combined – thus leading to the most conservative outlook on green roofs; while in the other case ('high'), high benefits and low costs were combined, leading to a more optimistic outlook. Finally, results are presented using both flood risk reduction valuation methods.



Table 3: Results of the CBA<sup>1</sup>

Private benefits only				
	Overlaying		Replacing	
	Low range	High range	Low range	High range
NPV	-€ 311,30	€ 119,30	-€ 460,58	€ 16,84
CBR	0,33	1,29	0,12	1,03

Public and private benefits				
	Overlaying		Replacing	
	Low range	High range	Low range	High range
NPV	-€ 214,25	€ 290,35	-€ 363,53	€ 187,89
CBR	0,50	1,76	0,37	1,39

Public and private benefits (WTP estimates only)				
	Overlaying		Replacing	
	Low range	High range	Low range	High range
NPV	-€ 159,27	€ 416,85	-€ 308,55	€ 314,39
CBR	0,63	2,09	0,47	1,65

Results indicate that the economic performance of green roofs depends primarily on the scope of benefits included and the assumptions applied to costs and benefits, while the choice of flood risk valuation method plays a comparatively limited role in shaping overall outcomes. As expected, the replacement scenario consistently yields lower NPVs and CBRs than the overlay scenario due to higher upfront investment costs, but the overall pattern of results remains similar across both construction types.

When only private benefits are considered, results are mixed rather than uniformly negative. Under low-range assumptions, NPVs remain negative and CBRs below one in both overlaying and replacing scenarios, indicating that private benefits alone are insufficient to justify investment under conservative conditions. However, under high-range assumptions, NPVs become positive and CBRs exceed one in both scenarios, including roof replacement. This suggests that green roofs can be privately viable where benefits such as energy savings, roof longevity and aesthetic value are sufficiently high, although this viability is sensitive to optimistic assumptions.

Including public benefits substantially strengthens the economic case. In both overlay and replacement scenarios, high-range assumptions lead to clearly positive NPVs and CBRs well above one. Even under low-range assumptions, results improve considerably and move closer to break-even, particularly in the overlay case. This highlights the importance of accounting for societal benefits - such as flood risk

<sup>1</sup> The first two tables present both Net Present Values (NPV) and Cost-Benefit Ratios (CBR) using both valuation methods. The third table uses only benefit estimates from the DCE valuation study and is therefore based only on stated preference study.

reduction and biodiversity - which are not fully internalised by individual homeowners but significantly increase overall welfare gains.

Results based on WTP estimates alone tend to display the same results and show positive outcomes only in high-range scenarios. Overall, both valuation methods match well and paint the same picture of green roof economic value.

The findings point to a mismatch between private and societal incentives. As with many other types of urban NBS; green roofs tend to be economically attractive when public benefits are considered, but much less so from a purely private perspective.

Finally, the CBA was extended to the cases of Loop 2 and Loop 3, using the cases of Finland and Italy, respectively. The methodology for value transfer, assumptions, results and main outputs are presented in an appendix to this report, together with a sensitivity analysis. Overall, these results are in line with the CBA performed for the Netherlands: the overall signs and directions of the NPVs and CBRs are similar.

### 2.3.5 Analysis of green roof insurances enablers and barriers

#### Objectives and methods

Stakeholder interviews constitute the main qualitative component of the pilot and were conducted across all three loops to gather context-specific insights, validate key assumptions and identify barriers and enablers to upscaling green roofs and insurance-related NBS.

Semi-structured interviews were carried out with four main stakeholder categories:

- insurance companies, including insurers directly involved in green roof initiatives (notably in the Netherlands) as well as insurers in Nordic and Mediterranean regions exploring their potential role in urban adaptation;
- urban planning and environmental authorities such as municipal policymakers, water authorities and spatial planners;
- researchers and technical experts specialised in green roofs and urban NBS; and
- other urban stakeholders, including engineering and consulting firms, real-estate developers and homeowners' associations.

Across stakeholder groups, interviews addressed a common set of themes including:

- perceived benefits and costs of green roofs in different climatic and urban contexts;
- institutional, regulatory, financial, technical and behavioural barriers to adoption;
- enabling conditions for scaling up green roofs in general, and insurance-related solutions in particular; and
- the potential role of insurers as climate adaptation actors beyond traditional risk transfer.

Sampling follows a 'snowball' approach drawing on existing PIISA networks, previous research collaborations and participants in related workshops and project activities. A common semi-structured interview guide was used as a basis and adapted to each stakeholder group, ensuring consistency across interviews while allowing respondents to elaborate on context-specific perspectives. Interview material is analysed qualitatively to identify recurring themes, regional differences and sector-specific insights.

A detailed description of the interview design, sampling strategy and analytical framework is provided in Deliverable D3.4.

#### Barriers and enablers to NBS insurances

Across Europe, insurers face substantial numbers of homeowner claims linked to heavy rainfall and storm events. Insurers report a slight increase in both the numbers of claims and the claim rate. They expect this trend to continue and anticipate greater damage in the future. In response to more frequent extreme weather events, most European insurers provide homeowners with advice on how to prevent climate-related damage. This support is generally offered through newsletters and websites, and in some cases free home assessments. However, adaptation measures involving NBS at the household level are rarely implemented.

##### *Barriers to NBS insurances*

Interviews with insurers in the Netherlands, the Boreal region and the Mediterranean highlighted a range of challenges that limit the development of integrating NBS into insurance products for homes (see Appendix 4: Barriers, enablers and incentives of NBS insurance products for European insurers). A key barrier is the lack of a clear business case, largely because data on risk reduction at the scale of an individual home is missing. Other barriers include limited awareness of climate risks and adaptation measures, uncertainty about the appropriate role insurers should play in adaptation, and the costs associated with structural changes to buildings. In addition, region-specific constraints were identified. Insurers in the Boreal region pointed to legislative hurdles and snow load, while in the Mediterranean, wildfire susceptibility and generally low levels of home insurance coverage were noted as barriers.

##### *Enablers to NBS insurances*

Insurers indicated that once these barriers are addressed, they see potential in incorporating informational and financial instruments into insurance products to encourage NBS uptake. Suggested approaches include awareness campaigns, as well as incentives such as deductibles or premium discounts. To make such approaches feasible, insurers emphasised the need for improved data demonstrating how much a single green roof reduced the risk of damage. They also identified several supporting factors that could help remove barriers, including sharing best practices, stronger collaboration with government and the construction sector, and greater awareness of climate risks and adaptation options.

As part of PIISA, a website ([www.greenroofinsurance.com](http://www.greenroofinsurance.com)) was developed to help address the awareness gap among insurers. Delivered through a central interactive platform, the service brings together spatial datasets on climate risks, information on climate adaptation and NBS, and an overview of actions that insurers could take to support adaptation. The website outlines the work carried out within PIISA in an accessible and practical format. The tool therefore strengthens European insurers' understanding of climate risks and adaptation options. More information on the service development can be found in Deliverable 2.3.

##### *Differences across Europe*

The results suggest that scaling and replicating insurance products that stimulate green roof uptake across Europe is possible, but important regional differences should be considered. One key difference is the level of green roof uptake, which varies depending on the presence of supportive measures. A second relates to location-specific factors, as both insurance uptake and climatic conditions differ across Europe. These differences suggest that a country-specific approach to developing NBS insurance products is likely to be more feasible.

## Barriers and enablers to green roof upscaling (insights from interviews with policymakers)

### *Perceived benefits of green roofs*

Stakeholders broadly agree on the multi-functional benefits of green roofs, but their relative importance differs by context. In the Nordic region, stakeholders most frequently cited stormwater management, biodiversity co-benefits and urban aesthetics. However, these benefits are often perceived as diffuse and indirect, particularly at the level of individual buildings, which limits their influence on investment decisions. Thermal benefits are acknowledged but remain contested, especially regarding their magnitude in cold climates and their contribution to energy savings. In the Mediterranean context, interviewees placed stronger emphasis on heat mitigation and thermal comfort, both at roof level and inside buildings, as well as on the creation of usable, accessible spaces. Green roofs are explicitly framed as climate adaptation infrastructure rather than purely environmental add-ons. Policymakers also stressed that many benefits—such as biodiversity enhancement and flood risk reduction—only materialise at scale, when multiple green roofs are clustered within the same neighbourhood or catchment.

### *Barriers to adoption*

Several common barriers to green roof upscaling emerged.

A first major barrier concerns maintenance and long-term performance. In both Nordic and Mediterranean contexts, policymakers reported that uncertainty around maintenance requirements, responsibilities and costs over time generates friction, particularly for private building owners and housing associations. While interviewees in Barcelona noted that maintenance needs tend to decline after the first one to two years, this dynamic is not yet widely understood by the public.

Second, technical and structural concerns limit trust in green roofs. In Nordic cities, roof load capacity, snow accumulation and waterproofing risks are frequently cited. In Mediterranean cities, similar concerns take the form of fear of leakage, difficulty of repairs and strong negative feelings toward biodiversity on roofs (e.g. increased abundance of mosquitoes) which can generate resistance from occupants and facility managers.

Third, policymakers highlighted institutional fragmentation. Responsibilities for water management, urban planning, building regulation and climate adaptation are often spread across departments and governance levels, complicating coordinated action. This fragmentation also limits the systematic monitoring of existing green roofs and the accumulation of performance data.

Finally, public perception and awareness remain limiting factors. In both regions, green roofs are still perceived as experimental, risky, or non-essential, particularly in comparison with more familiar installations such as photovoltaics.

### *Enablers and policy levers*

A first enabler is regulation. In several cases, green roofs are increasingly embedded in planning rules and technical protocols for municipal buildings, with clear performance requirements (e.g. rainwater retention thresholds). Similarly, green roofs are embedded in local stormwater management strategies as viable (albeit complementary) solutions for flood risk management. Several policymakers explicitly compared green roofs to photovoltaics, suggesting that a similar regulatory trajectory, moving from incentives to requirements, could significantly accelerate uptake.

Second, financial incentives and visibility matter. Annual subsidy schemes, design competitions, and flagship public projects were repeatedly cited as effective tools for reducing perceived risk and

increasing social acceptance. Demonstration projects in schools, hospitals and large public buildings were seen as particularly powerful in normalising green roofs and linking them to social benefits.

Third, standardisation and monitoring were highlighted as critical. Both Nordic and Mediterranean stakeholders stressed the need for standardised design guidelines, construction protocols and monitoring frameworks. For example, pilot projects such as Barcelona's TOP SEC explicitly aim to test substrates, vegetation types and construction techniques with systematic monitoring of hydrological, thermal, ecological and social indicators.

Fourth, knowledge brokerage and data platforms emerged as a shared need. Policymakers recognised that neither municipalities nor insurers are well positioned to act alone as data aggregators. Instead, several interviewees suggested the creation of neutral observatories or shared platforms to consolidate performance data, reduce uncertainty, and support evidence-based policymaking.

#### *Knowledge gaps and research needs*

Stakeholders identified several common knowledge gaps to be addressed for green roof upscaling to move forward. These are:

- limited long-term performance data, especially beyond pilot timeframes. This gap is in fact common to many types of green infrastructures and NBS;
- insufficient evidence on maintenance trajectories and lifecycle costs;
- uncertainty regarding biodiversity outcomes and their interaction with social acceptance; and
- limited integration of green roofs into broader risk-prevention and adaptation frameworks.

## **2.4 The way forward: conclusions of the pilot**

### *Current conditions are insufficient to deliver upscaled green roof adoption in Europe*

Market-driven uptake alone is unlikely to deliver green roofs at scale. Even when households value green roofs and recognise their benefits, adoption remains constrained by upfront costs, uncertain private returns and an array of limiting factors. This helps explain the limited diffusion observed in practice and underlines the need for policy intervention.

There is a clear gap between private and societal value provided by green roofs, which limits their voluntary uptake. While green roofs generate societal benefits - particularly for flood risk reduction, biodiversity and climate adaptation - these benefits are only partially captured by individual homeowners. As a result, green roofs are often not economically attractive from a private perspective without additional support.

The role of the insurance industry in supporting green roofs is currently very limited if inexistent but shows potential for expansion. Across Europe, insurers are increasingly aware of climate-related risks and already provide homeowners with advice on damage prevention, mainly through information campaigns, newsletters and online guidance. However, concrete insurance products or incentives linked to NBS at the household level remain rare. Interviews across the Netherlands, Boreal and Mediterranean regions indicate that insurers face significant barriers, most notably the lack of a clear business case and insufficient data on risk reduction at the individual building level. As a result, insurers tend to focus on private, household-level risks and short-term damage prevention rather than on broader societal benefits.

### From fragmented incentives to coordinated action: lessons from the pilot

The different analytical components of the pilot tell a consistent story. The CBA shows strong societal value but limited private viability; the DCE confirms that homeowners are willing to pay substantially high prices for green roof benefits, primarily for private and directly experienced ones; and the behavioural experiments show that informational nudges reinforce, but do not fundamentally change, these preferences. Information framing can increase acceptance and willingness to pay, especially when public benefits are made salient, but such interventions do not substitute for financial incentives. They are best deployed as complements that enhance the effectiveness of economic and insurance-based instruments. Potential actions taken by public authorities can be:

- Establish stable, multi-year subsidy schemes to reduce upfront investment costs for property owners.
- Integrate green roofs into building codes, planning rules and stormwater regulations.
- Develop targeted communication campaigns highlighting mainly private benefits of green roofs.

Insurance-based incentives can act as important enablers, but not as standalone solutions. Premium discounts, advisory services, and facilitated installation can help reduce barriers to adoption, particularly in early stages. However, they are most effective when embedded in a broader policy mix that includes public subsidies, regulatory support, and urban climate adaptation strategies. Potential actions to be taken are:

- Co-pilot insurance-based incentives (e.g. premium discounts or deductibles) in coordination with public subsidy schemes.
- Provide clear guidance on maintenance responsibilities and lifecycle costs for homeowners and housing associations.
- Strengthen collaboration between insurers, municipalities, construction actors, and knowledge institutions.

Finally, building evidence is a key condition for upscaling insurance-related solutions. Insurers require robust, standardised data on the effectiveness of green roofs in reducing climate-related risks at the building and household scale. Linking incentives to measurable outcomes and establishing monitoring frameworks are the way forward to increase insurer engagement and confidence in these solutions. The way forward includes:

- Implementing (long-term) monitored pilot projects that generate building-level performance data. These projects can also raise awareness (and demand) if they are visible within cities.
- Developing standardised monitoring and reporting protocols for green roof performance.
- Creating shared data platforms or observatories at national or EU level.
- Linking subsidies and insurance incentives to verified performance indicators.
- Adapting incentive schemes to regional climatic, regulatory and insurance market conditions.

## 3 Clay shrink swell pilot

### 3.1 Introduction

#### 3.1.1 Motivations and context

The clay shrink swell pilot is focused on the problem of property damage caused by clay shrink swell (**CSS**) events and raising homeowner awareness of the potential financial risks associated with inadequate insurance cover for property damage caused by CSS events. A key output of the pilot was the development of the Clay Shrink Swell Building Damage Assessor (**CSSBDA**) which is a web-based tool to communicate to homeowners various information about the financial (and other) risks they face from inadequate insurance cover. The specification for the CSSBDA was developed during Loop 1 and the website was then developed and pilot tested in the City of Lyon in France during Loop 2 before being replicated at French national level during Loop 3. At the same time as this replication at French national level, further research was undertaken to analyse the utility of developing an equivalent web-based tool in other countries and geographic regions in the EU.

#### The clay shrink swell phenomenon

Clay soil consistency can easily change depending on the soil's water content. When it rains, some clay soils absorb water and dilate just like a sponge. When the water contained in the clay evaporates, then the clay soil shrinks. The drying out of the soil can create both horizontal cracks on the surface and vertical hydromechanical settlement under the weight of the structures (Assemblée Nationale, 2023). Simply put, a CSS event can occur when a drought is followed by heavy rain, occasionally reinforced by snow melt, causing soil to move and change shape significantly in a short period of time.

More specifically, a CSS event can occur if the relevant local factors are present and are combined with the relevant climate factors.<sup>2</sup> For any given geographic location, the local factors can be assumed to remain relatively constant and therefore increasing likelihood of a CSS event occurring is related to climate change and more specifically to the increasing likelihood of relevant weather events such as droughts, heatwaves and rainfall that can potentially trigger a CSS event.

#### Home insurance cover for clay shrink swell in France

CSS events mainly affect single-family homes and are widespread in France. It is estimated that 48% of the national territory is at medium or high risk of this phenomenon and around 10.4 million single-family homes are at medium or high risk, representing 54% of all single-family homes (Sénat, 2023).<sup>3</sup>

When it comes to insurance cover, a national public mechanism called Cat Nat is a compensation scheme for homeowners, companies and local authorities for damage caused by natural disasters such as CSS events. The Cat Nat scheme is based on a dual-guaranteed system:

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<sup>2</sup> Local factors: These include aspects such as the constitution of the soil (it needs to contain clay), the inclination of the area, the hydrological context of the area, surrounding vegetation etc. (British Geological Survey, Undated). As the name indicates, there must be clay in the soil composition. It is estimated that a CSS event can occur if the soil composition is of at least 10% clay (Boivin et al., 2006). Climate factors: Triggering factors of evapotranspiration and precipitation from weather events such as droughts, heatwaves and rainfall can potentially trigger a CSS event in areas where the relevant local factors are present.

<sup>3</sup> Note that more recent analysis and mapping released at the end of 2025 implies an increase in this assessment.

- insurance companies offer insurance policies to cover properties, and they are reinsured by the Caisse Centrale de Réassurance (**CCR**) for payouts when a natural catastrophe has been declared; and
- the CCR benefits from a full government guarantee and in return for this guarantee pays the State around €100 million per year (even if there is no payout).

Natural catastrophe insurance is a mandatory contract clause in home insurance contracts. If a natural catastrophe occurs which is covered by the Cat Nat scheme, the Mayor and then the Prefect must submit an official request to the State to recognise the occurrence of a natural catastrophe through a decree. Once this decree is officially published, the insurer assesses the cost of damage and indemnifies the homeowner and is then reinsured by the CCR. Further detail on this broad framework is shown in Figure 4 below.



Figure 4: Framework for declaring a natural catastrophe and state indemnification (CCR, Undated)

For a CSS event to be recognised as a natural catastrophe under the Cat Nat scheme, two conditions must be met:

- the affected area has at least 3% of its surface mapped as shrinkable clay; and
- the meteorological conditions that have occurred must be identified as being exceptional periods of drought. This label requires the 3-month average of Soil Wetness Index uniforme to be the lowest or second lowest of a 50-year reference associated with the same month (Barthélémy et al., 2024).

#### Potential insurance risks for homeowners

Despite the fact that the insurance position in France may provide better protection for homeowners compared to other Member States (see more on this in Section 3.3.2) there are a number of risks for homeowners associated with the process for recognition of a CSS event under the Cat Nat mechanism.



- **Lack of certainty regarding State recognition of a Cat Nat for CSS events** Over the last nine years, an average of 50% of requests for official recognition of a CSS event as a natural catastrophe under the Cat Nat scheme have been unsuccessful (Cour des Comptes, 2022).
- **Timescale for payouts** The length of time to receive state recognition of a natural catastrophe (and the consequent length of time to receive compensation) is challenging for homeowners as it prolongs their recovery process and adds to their financial burden. And indeed, during the period up to the point of state recognition, the homeowner cannot be certain that there will be state recognition and that they will be compensated for property damage.
- **Failure to adhere to preventive measures** If the property was built without considering the requirements regarding its construction imposed by a natural risk prevention plan (PPRN) or if the preventive work required by a PPRN has not been carried out within five years of the PPRN's implementation, the insurer is not obliged to cover damage caused by a natural catastrophe (Georisque, Undated).

### **Summary of the risks for homeowners associated with property damage caused by a CSS event**

- If a homeowner suffers property damage caused by a CSS event, insurance cover is provided by the typical multi-risk home insurance policy together with the Cat Nat scheme.
- An insurance payout will only take place when the State officially recognises the occurrence of a natural catastrophe under the Cat Nat mechanism.
- Where there has been damage caused by a CSS event but there is no State recognition of a natural catastrophe, there is no insurance payout.
- Even if a natural catastrophe is recognised by the State, there will be no insurance payout if the homeowner has not complied with all preventative measures which are applicable for the property and articulated in the PPRN.
- Even if a natural catastrophe is recognised by the State, the length of time to receive State recognition of a natural catastrophe (and the consequent length of time to receive compensation) is challenging for homeowners as it prolongs their recovery process and adds to their financial burden.

### 3.1.2 Objectives

As demonstrated above, there are potential risks for homeowners in relation to inadequate insurance cover for property damage caused by a CSS event. At the same time, it is estimated that 48% of the national territory in France is at medium or high risk of CSS events occurring (Sénat, 2023). This means that a significant number of French homeowners are at risk. These risks in relation to inadequate insurance cover for property damage caused by a CSS event will be compounded as climate change is expected to increase the likelihood of CSS events occurring in the future.

In this context, the principal objective for the CSSBDA was to educate homeowners about their financial risks associated with inadequate insurance cover for property damage caused by CSS events. The CSSBDA is an online tool to communicate to homeowners various information about the financial (and other) risks they face from inadequate insurance cover.

The CSSBDA therefore has a different mechanism for change compared to other work activities under the PIISA project. Whereas the mechanism for change for these other work activities can be generally understood to focus on assisting the insurance industry, the CSSBDA is focussed on raising homeowner awareness about a particular insurance issue, with the hope that increased homeowner awareness will leverage pressure on the insurance industry to address the issue (e.g. through requesting specific clauses in insurance contracts).

This focus on homeowners as the target audience/constituency means that the parameters which shaped the development process for the CSSBDA were different. Homeowners must be assumed to be non-experts in relation to the technical aspects of climate change, CSS, insurance cover etc. Therefore, communicating to this audience requires transparency, simplicity and clarity. Above all else, the CSSBDA needed to be compelling and easy to use so that homeowners will use it.

In addition, the focus on homeowners as the target audience/constituency means that the CSSBDA will not seek to project beyond the base of evidence. For example, the CSSBDA was not seeking to develop a complex actuarial model of the financial risks for homeowners (as might be appropriate for technical users). Rather, the CSSBDA sought to effectively communicate credible and easily understandable information about the financial risks associated with inadequate insurance cover for property damage caused by CSS events in a way which activates homeowners to address the issue with their insurance providers. This means that the methodology which sits behind the financial risk metrics draws from existing empirical data (rather than a modelling approach).

## 3.2 Loops and methods

As for the Green Roof Pilot, the Clay Shrink Swell Pilot was structured around three development loops.

**Loop 1 (M6-M19)** focussed on developing the preliminary specification for the CSSBDA and articulating the methodology and data to be used in the CSSBDA. This loop commenced with background research on the CSS phenomenon and the insurance position in France and a review of public data sources which could be used in the CSSBDA. This research enabled articulation of various aspects of the user journey/interface which should be embedded in the CSSBDA to effectively communicate to the intended audience of homeowners and development of contracting information used to instruct a third-party web developer to develop the online version of the CSSBDA. A summary of this work is contained in Deliverable 3.5: Preliminary dashboard specification.

**Loop 2 (M19-M25)** focussed on pilot testing the online version of the CSSBDA in the City of Lyon in France. Following submission of Deliverable 3.5, SFO undertook a procurement process to select a

software developer to convert the specification into the online website which forms the CSSBDA. The CSSBDA was then piloted and tested in the City of Lyon. Deliverable 3.6: Lessons learned from testing usage in Lyon, France analyses lessons learnt from pilot testing in the City of Lyon during the period from March to August 2025 which were then integrated into our planning and work activities for replicating the CSSBDA at French national level during Loop 3. This document articulates key lessons from: (a) the procurement and contracting process to select and contract a software developer to convert the specification into the online website which forms the CSSBDA; (b) data work (i.e. cleaning the underlying datasets to make them appropriate for use in the CSSBDA) and working with the software developer to convert the specification into the online website which forms the CSSBDA; (c) pilot testing in the City of Lyon including efforts to publicise the CSSBDA and feedback received from user testing. It also articulates planned changes to the CSSBDA to address feedback received from user testing which were implemented prior to replicating the CSSBDA at national level in France.

**Loop 3 (M25-M33)** consisted of two primary modes of activity: (a) replication of the CSSBDA at national level in France and associated communication activities to publicise the CSSBDA among relevant audience constituencies; and (b) researching the CSS risk level and insurance framework for other countries and geographic regions to analyse whether developing an analogous tool to the CSSBDA might have utility in these other countries or geographic regions.

### 3.3 Synthesis of results

Given that the activities and key lessons from Loop 1 and Loop 2 are already well covered in Deliverable 3.5 and Deliverable 3.6, the following commentary relates to activities and key lessons from Loop 3. It is split according to the two primary modes of activity (a) replication of the CSSBDA at national level in France (see Section 3.3.1); and (b) researching the CSS risk level and insurance framework for other EU countries (see Section 3.3.2).

#### 3.3.1 Replication of CSSBDA at national level in France

Deliverable 3.6 articulates key lessons learned from pilot testing the CSSBDA in the City of Lyon including: (a) analysis of the effectiveness of efforts to publicise the CSSBDA; and (b) planned changes to the CSSBDA to address feedback received from user testing which were implemented prior to replicating the CSSBDA at national level in France.

In terms of publicising the CSSBDA, one of the key lessons learnt during Loop 2 was that PIISA project communication tools had limited utility for publicising the CSSBDA among the intended audience of homeowners in France. Broadly speaking, we concluded that the PIISA website and the surrounding social networks (e.g. LinkedIn) associated with the PIISA project itself or the consortium partners were better suited to professional networks and individuals in their professional capacity rather than individuals in their capacity as homeowners. Using LinkedIn was not the most effective choice for promoting the CSSBDA to our core user base, as LinkedIn primarily attracts professional white-collar workers. This approach risks excluding other important audiences, such as older or retired individuals, or those outside of LinkedIn's typical user base. In addition, as the primary language of the PIISA website and surrounding social networks is English this is a further factor which limits the utility of this apparatus for publicising the CSSBDA to a French audience.

As a result, following integration of the changes to the CSSBDA to address feedback from user testing, we adjusted our communication strategy to more effectively target homeowners in France and refined our messaging to highlight clear value for users. This was achieved through establishing a Facebook profile and implementing a Facebook Ad Campaign.

### Facebook Ad Campaign

Given that the PIISA acronym lacks clarity and attractiveness for an audience of French homeowners, several more accessible and user-oriented alternatives were considered. The final name selected for the Facebook profile was *Le Club de l'Habitat Résilient – Info & Solutions*.

To ensure institutional visibility and credibility, a descriptive subtitle was added to position the Facebook profile as an initiative of the PIISA project, including a reference to the funders as well as the official project logo. The introductory text on the Facebook profile presents PIISA as a European project funded under the Horizon Europe programme, whose objective is to develop innovative insurance solutions to support individuals and cities in adapting to the impacts of climate change. This wording establishes the Facebook profile as a communication channel dedicated to promoting the PIISA project, while explicitly linking the project's objectives to concrete, homeowner-focused concerns. By directly addressing individuals and emphasising practical climate risk awareness, it improves clarity, coherence and accessibility for this audience, while maintaining strong institutional positioning. The text also includes the mandatory reference to Horizon Europe as the funder of the PIISA project.

After creation of the Facebook profile, the Facebook Ad campaign was implemented. The primary objective of the Facebook Ad campaign was targeting relevant audiences within a META campaign designed to drive traffic to the CSSBDA. To that aim the Facebook Ad campaign was structured around two ad sets, each targeting a different audience and messaging approach.

The Facebook Ad campaign relied exclusively on broad audiences, to maximise reach, allow META's algorithm sufficient learning flexibility and avoid overly restrictive targeting before initial performance patterns could be identified. Each ad set targeted users located in France, while testing two distinct audience logics.

- **Ad Set 1 – Homeowners and insurance-oriented audience:** This ad set targeted a more mature and potentially more qualified audience (25+, with a focus on 45-65+), combining interests related to home ownership, real estate acquisition and investment and insurance or risk management. The targeting followed a two-layer logic, requiring users to show both real estate-related and insurance-related interests. The underlying rationale was to reach individuals likely to already own property or be in the process of acquisition, and therefore more receptive to prevention and protection-oriented messaging.
- **Ad Set 2 – Real estate decision-making audience:** This ad set targeted a broader and younger audience (18-65+), including users interested in real estate in a wider sense, such as investment, development, energy efficiency and environmental dimensions of real estate. The objective was to capture users at earlier or more diverse stages of the decision-making process and to assess how a less constrained targeting strategy would perform in terms of traffic generation. Compared to ad set 1, this audience was intentionally more exploratory and heterogeneous.

Each ad set included three visuals with varying text options to identify the most effective combinations for traffic generation. Appendix 6: Creative assets and formats contains more information about the design of these two ad sets.

## Results

Ad set 1, generated a total of 6,654 visits to the CSSBDA. In terms of reach and delivery, the ad set achieved 187,612 impressions (number of times that the ad was displayed on a screen including multiple views by the same user) with 106,159 Facebook profile accounts reached.

From a demographic perspective, results were strongly concentrated among users aged 45+, and particularly 55-64 and 65+ with a majority of female users (66%), compared to 33% male users. These results confirm alignment between the targeted audience logic and engagement patterns.

The most successful ad design of this ad set was the one focusing on homeowner's potential risks before signing to an insurance, which convinced 5,137 people to click on the ad to explore the CSSBDA.

Ad set 2 generated a total of 1,814 visits to the CSSBDA. In terms of reach and delivery, the ad set achieved 107,362 impressions with 70,409 Facebook profile accounts reached.

From a demographic perspective, engagement patterns were again strongly skewed toward older age groups, with most results generated by users aged 45+, and particularly 55–64 and 65+. The gender distribution was more balanced than in ad set 1, with 54% female users and 44% male users.

Overall, ad set 2 confirms that while broader, exploratory audiences can generate traffic, they do so with lower efficiency and weaker message resonance than more targeted homeowner-focused audiences. Informational and awareness-oriented messaging performs better than insurance-check framing, but remains less effective than decision-focused, prevention-oriented narratives observed in ad set 1.

## Google analytics - Results

To assess the traffic to the CSSBDA generated by the Facebook Ad campaign, Google Analytics was used to measure user behaviour and interaction across the CSSBDA.

As of 28 January 2026, Google Analytics had recorded 8,000 *active users*<sup>4</sup>, all of whom were new users, indicating that traffic was almost entirely driven by the Facebook Ad campaign. User activity peaked in late December and early January, with 5,600 active users in the 30 days prior to 28 January 2026. However, despite the high number of active users, the average engagement time suggests low interaction with the content or a potential mismatch between user intent and the landing page experience.

Regarding acquisition channels, user traffic was overwhelmingly dominated by Organic Social (through social media accounts), which generated 8,300 *sessions*<sup>5</sup>, accounting for more than 95% of total traffic. Other channels contributed only marginally:

- Direct<sup>6</sup>: 331 sessions
- Paid Social<sup>7</sup>: 207 sessions

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<sup>4</sup> Active users is the number of people who engaged with the site or app in the specified date range.

<sup>5</sup> A session initiates when a user either opens the app in the foreground or views a page or screen and no session is currently active, for example, their previous session has timed out.

<sup>6</sup> Traffic coming from users who visit your website by entering the URL directly into their browser, or through links from offline documents such as PDFs and Word. (Google support, 2026)

<sup>7</sup> Traffic coming from users who clicked on one of your paid ads on search engine, like a Google Ad.

- Organic Search<sup>8</sup>: 7 sessions

A deeper analysis of CSSBDA usage shows that most page views were concentrated on a single page: 'Home Risk EU | Votre maison...' (9,200 views) and secondary pages recorded between 204 and 370 views, with a significant drop-off beyond the top three pages. This distribution indicates that most users landed on the CSSBDA homepage and had limited exploration of additional content. This behaviour is also reflected in the limited use of the 'Assess your risk' section, where only 95 assessments were completed during the period up to 28 January 2026.

User engagement data and tracked *events*<sup>9</sup> further confirm this pattern. A total of 9,900 page view events and 9,000 session start events were recorded. However, deeper engagement actions were more limited (user engagement beyond 30 seconds: 622, scroll: 461, click: 25). Finally, cohort analysis reveals low user retention. While Week 0 retention stands at 100% by definition, it drops to 0.5% in Week 1 and approaches 0% from Week 3 onward, confirming that users do not return after their initial visit.

### Conclusion

Through the targeted digital outreach strategy associated with the Facebook Ad campaign, the CSSBDA successfully reached thousands of homeowners at very low cost, confirmed the relevance of prevention-oriented messaging, and generated valuable behavioural insights that go beyond traditional research outputs. The Facebook Ad campaign demonstrated that homeowner-focused climate insurance messaging can be delivered at scale and at very low cost, provided that targeting and framing are carefully aligned. The Facebook Ad campaign generated a significant increase in traffic during the analysed period, surpassing 8,000 visits. However, the Google Analytics data indicates weak engagement and poor retention, which are also reflected in the low usage of the evaluation form. The gap between reach and engagement highlights where additional investment would have the greatest marginal impact and suggests that awareness is not the main bottleneck – homeowner activation is.

### 3.3.2 Researching CSS risk level and insurance framework for EU countries

During Loop 1 and Loop 2 it quickly became apparent that a simple extension of the CSSBDA<sup>10</sup> for other countries would not be possible. The principal reasons for this are twofold:

- The CSSBDA draws information from French public databases<sup>11</sup> and relies on French specific climate projections from PIISA project partner Amigo.<sup>12</sup> Replicating the CSSBDA in other countries will require other public databases to be available in the relevant country OR

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<sup>8</sup> search Measures landing pages with associated Search Console and Analytics metrics for your linked Search Console property. (Google support, 2026)

<sup>9</sup> An event allows you to measure a specific interaction or occurrence on your website or app. For example, you can use an event to measure when someone loads a page, clicks a link, or completes a purchase, or to measure system behaviour, such as when an app crashes or an impression is served.

<sup>10</sup> Extension in this context means using the same software configuration as in the current (French) CSSBDA and applying it to different countries or geographic regions.

<sup>11</sup> See Deliverable 3.5 for further information

<sup>12</sup> See Deliverable 3.5 for further information

different methodological assumptions which in turn requires new software development to integrate into an analogous tool to the CSSBDA.<sup>13</sup>

- The CSSBDA synthesises and communicates information about the French Cat Nat mechanism and how this state mechanism working with commercial home insurance cover may leave gaps in insurance cover for French homeowners. This information is French specific and shapes a lot of the user journey and the provision of information in the CSSBDA. However, the insurance framework which applies in other Member States is different and will therefore require a different user journey and provision of information to communicate about the potential risks to homeowners.

Therefore, analysing the applicability of the CSSBDA to homeowners in other countries or geographic regions requires researching the extent to which developing an analogous tool to the CSSBDA might have some utility in these other countries or geographic regions (however the actual development of an analogous tool for another country or geographic region is outside the scope of the PIISA project). To answer this question the research focussed on two principal areas:

- Researching the CSS risk level including: (a) Exposure: identifying regions characterised by high clay soil content; (b) Hazard: identifying regions where hydro-meteorological conditions may potentially cause CSS events to occur and where events may intensify with climate change, and (c) Vulnerability: performing preliminary survey on awareness and potential impacts of CSS events.
- Researching the insurance framework to identify if there is a gap in insurance cover for property damage caused by CSS events and/or other potential risks for homeowners.

#### Researching the CSS risk level

##### ***(a) Exposure: identifying regions characterised by high clay soil content***

To focus research efforts, the following countries were chosen for analysis: Finland, Germany, Italy, Luxembourg and Spain. These countries were selected based on having regions with high clay soil content (exposure) or due to practical considerations such as language accessibility for the researcher team. Nevertheless, the five countries plus France provide a cross-section of the main European biogeographical regions.

##### ***(b) Hazard: identifying regions where hydro-meteorological conditions may potentially cause CSS events to occur and where events may intensify with climate change***

###### *Occurrence of future deep-soil drought over the European continent*

To provide background information for the estimation of damage risks in the future, we studied the occurrence of soil drought at depths of 60–100cm across the European continent. Technical details of the analysis are explained in Appendix 7. In France, it is drought in the 80–100cm layer that appeared to correlate best with building damage caused by CSS events (Barthelemy et al., 2024). However,

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<sup>13</sup> While some countries might centralise natural catastrophe information (decrees, risk maps, claim guidance) others might leave it dispersed across insurers, regulators, consumer bodies or municipal sources. If the country specific website aims to pull together authoritative information in a similar way to the CSSBDA, integrating this information in the country specific website will likely require bespoke software configuration for each country. Different data sources (PDF guidance notes, interactive portals etc.) imply different methods to capture the information such as APIs in some places, web scraping or manual curation in others. In addition, these public information sources may be subject to varying update frequencies and reliability



according to that study the 60–100 cm layer works equally well, and examining such a slightly thicker layer is better in concordance with the typical vertical resolution of the soil component in climate models. In most areas of Europe, the soil invariably becomes wet and swells back to its original volume in winter. Therefore, it is the dry periods in summer and autumn that pose the largest risk of building damage.

*Time-mean changes*

Figure 5 shows the changes in 30-year mean deep soil moisture in June–November from the turn of the millennium to the middle of this century. On average, the soil is becoming drier across Europe. Nevertheless, the intense drying seen in northern Scandinavia and the Kola Peninsula is evidently not veracious in a quantitative sense since it is influenced by the spurious occurrence of permafrost in some models in the historical period. Melting permafrost tends to substantially reduce the total water content of the soil.

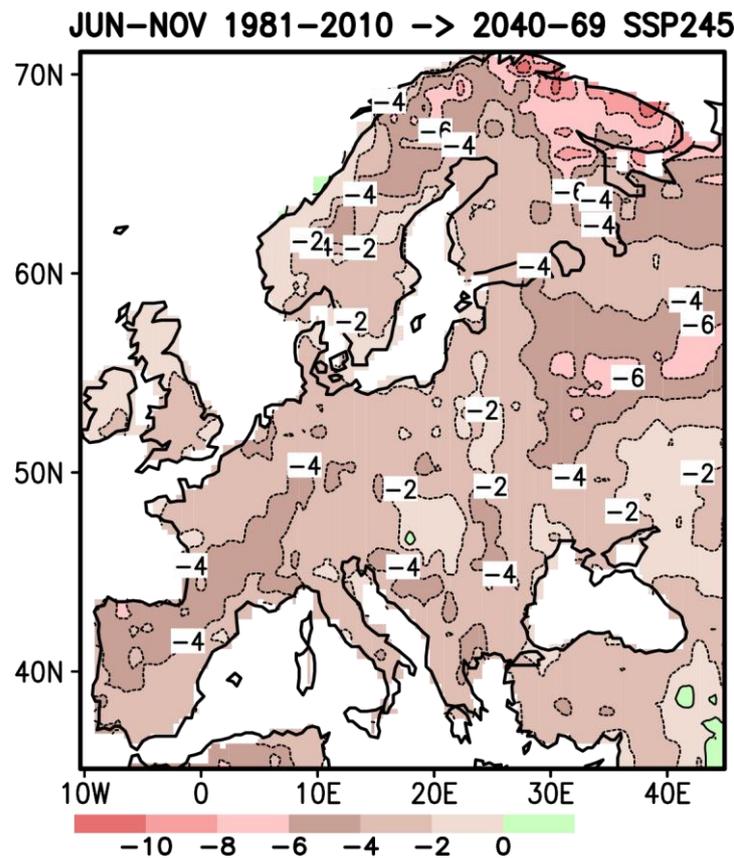


Figure 5: Changes in the mean June–November soil moisture (in %) at depths of 60–100 cm from the period 1981–2010 to 2040–2069 under the SSP2-4.5 scenario; the mean of responses simulated by the 14 climate models listed in Appendix 7

*Occurrence of severe drought episodes in the future*

In this report, the threshold for severe drought is defined as the 4th percentile of the monthly mean values of deep-soil moisture in June–November between 1950 and 1999 (300 time steps in total). This choice is motivated by the fact that in France, a natural catastrophe induced by soil drought can only be declared if the Soil Wetness Index is lower than that occurred twice in the 50-year reference period (Cooke et al., 2024).

Examining the median of simulations by the 14 climate models listed in Appendix 7 reveals that, by the middle of this century, the probability of severe drought occurrence in the six European sub-regions ranges from 9 to 14% (Figure 6). Accordingly, a drought event experienced twice in 50 years in the late 20th century climate is anticipated to occur approximately 5–7 times in 50 years in that time. In other words, the annual probability of a drought episode would roughly triple.

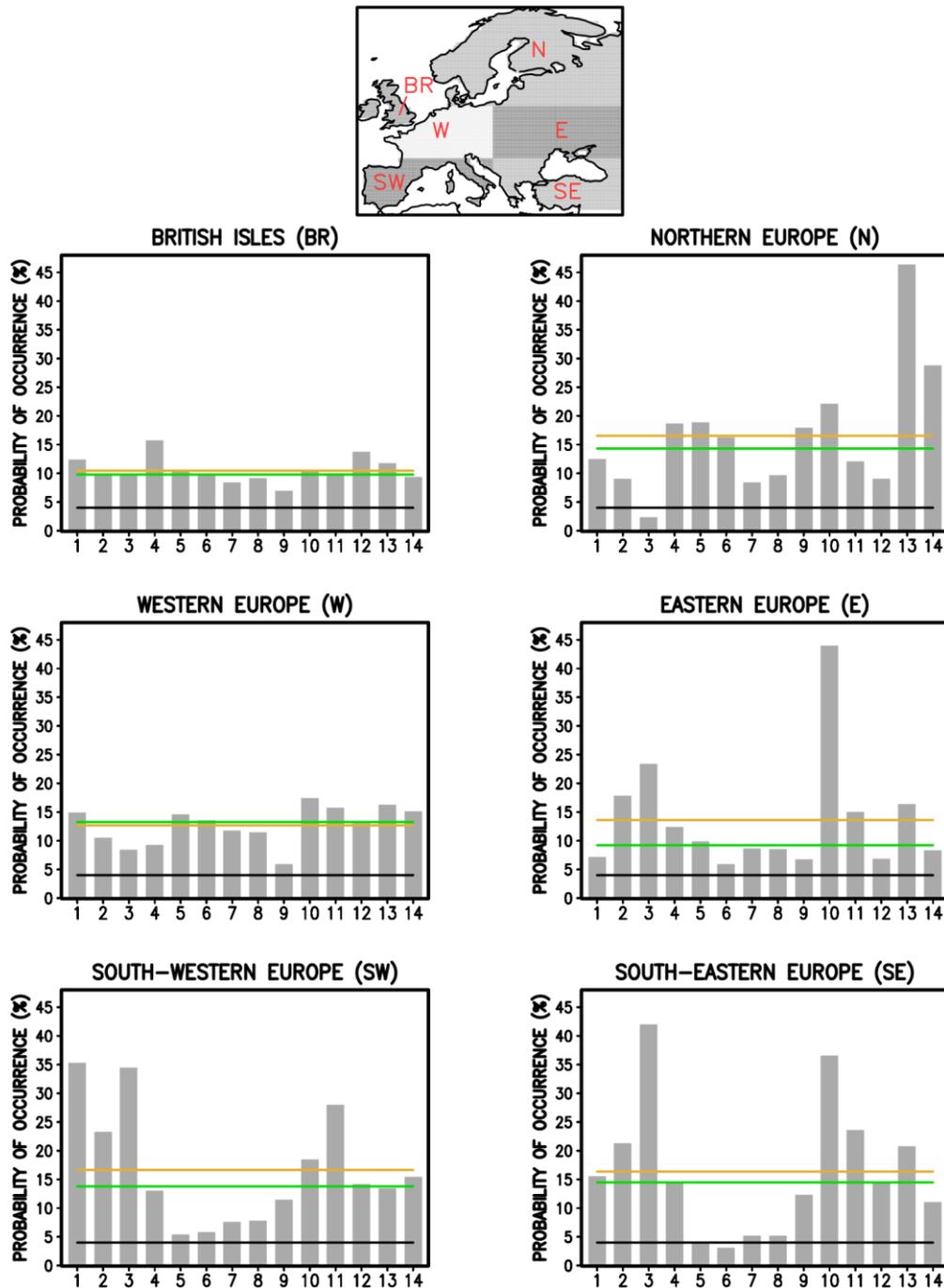


Figure 6: Probabilities (in %) for the monthly mean 60–100 cm soil moisture being lower than the corresponding 4th percentile derived from historical runs for the period 1950–1999; the June–November season in 2040–2069, SSP2-4.5 scenario<sup>14</sup>

Nevertheless, inter-model differences in the response are large. Drought events are certainly projected to become more common in nearly all cases, apart from two exceptions (BCC-CSM2-MR in Northern Europe and UKESM1-0-LL in Southeastern Europe). Conversely, some models project much more

<sup>14</sup> The probabilities are given separately for the 14 climate models listed in Appendix 6 (grey columns) and the six sub-regions depicted in the map at the top. Horizontal black lines denote the nominal baseline probability (4%) and fawn-yellow and green lines the multi-model means and medians.

frequent drought occurrences than others, for example, CNRM-ESM2-1 in Eastern Europe and both ACCESS models in Northern Europe. Accordingly, in these regions the multi-model mean response is distinctly higher than the median (Figure 6).

Germany, Italy, Luxembourg and Spain are located in the western and south-western European sub-regions where the occurrence of drought increases more pronouncedly than in many other sub-regions. Owing to the sparse horizontal resolution of climate models and significant discrepancies among various simulations (Figure 6), it is not feasible to prepare tailored projections for every individual country. Projections for Finland and other high-latitude countries are less reliable than those for central and southern Europe, since in some climate models there is excessively frost in the soil in the historical period. As stated above, such a bias tends to induce a spurious drying trend.

Figure 5 shows that the projected changes in time-mean soil moisture are modest. However, even such minor changes in long-term means tend to lead to substantial responses in the occurrence of severe drought (Vicente-Serrano et al. 2020).

### *Conclusions*

The models almost unanimously agree that, as climate change progresses in Europe, the soil at a depth of 60–100 cm will become drier in summer and autumn. By the middle of this century, drought episodes would occur approximately three times as frequently as in the late 20th century. For example, according to the multi-model median, a drought period similar to that experienced once in 25 years in 1981-2010 would occur in Luxembourg, Italy, Germany and Spain approximately once every 7 years in the mid-21st century. Even so, the responses of the various models do differ substantially from one another, so this estimate is subject to significant modelling uncertainty.

In any case, there is reason to fear that damage to buildings caused by drying-induced soil movements will become more frequent and severe over time virtually everywhere in Europe.

### ***(c) Vulnerability: performing preliminary survey on awareness and potential impacts of CSS events***

The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as ‘the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes’ (IPCC AR4, 2007). Below we present a preliminary assessment of vulnerabilities related to CSS property damage, with a particular focus on awareness levels and the potential impacts of CSS events occurring in the selected countries (i.e. Finland, Germany, Italy, Luxembourg and Spain).

The vulnerability assessment was conducted utilising: (a) web-based searches (e.g. related websites, grey literature and scientific literature); and (b) three stakeholder discussions in Finland (housing or construction experts). In addition, AI-tool (MS Copilot) was used to identify whether relevant national-level strategies related to climate adaptation address clay shrink swell issues.

### *Web-based search*

Based on socioeconomic conditions in 2015, subsidence-related damage to infrastructure accounted for approximately 8% of total drought-related losses in Europe, with higher proportions observed in regions characterised by elastic soils (Naumann et al., 2021). For additional country-specific numbers, see Table 4.

Table 4: Sensitive economic value of buildings and infrastructure in million euros (2015 values) exposed to drought induced soil subsidence. (Based on Naumann et al. (2021)<sup>15</sup>)

	2015 (millions, €)	2100 (millions, €)
Finland	640	2 053
Germany	2 703	7 561
Italy	4 589	13 065
Luxembourg	85	276
Spain	2 873	9 716
EU + UK	23 605	78 252

The economic consequences of drought episodes are often difficult to identify, partly because of the complexity of the underlying mechanisms. In this section clay shrink-swell refers to the soil volume change driven by moisture variation in clay soil, whereas subsidence is the broader phenomenon of ground-surface downward movement. Subsidence processes are characterised by slow kinetics, which complicates the establishment of direct causal links between subsidence events and possible insurance claims; moreover damage may concretize long after the occurrence of drought periods (Charpentier et al., 2022).

Swiss Re (2011) indicates that regions with prior experience of drought already possess the knowledge and risk management tools needed to address soil subsidence, including suitable insurance solutions. Sharing this expertise and applying established approaches in newly affected regions should be a key element of local climate adaptation strategies (Swiss Re, 2011).

Despite the rising financial burden, CSS related property damage costs remain underrepresented in natural hazards and climate risk research as well as in the insurance sector and society in general (Gruslin et al., 2022; Corti et al., 2011; Swiss Re, 2011). Also, vulnerability of buildings has received little attention (Mzungu et al., 2025). Swiss Re (2011) suggests that this underrepresentation is related to the inherent characteristics of soil subsidence as a hazard. Unlike many other hazards, soil subsidence is typically a slow and gradual process. Because vertical ground movements are often limited to only a few millimetres or centimetres, the phenomenon is relatively unspectacular in scale and difficult to observe and visualise.

At the EU-level, the IPCC Sixth Assessment Report (AR6) identifies CSS events as a risk that can affect the stability of buildings and infrastructure and result in substantial damage costs. However, the national adaptation plans or strategies of the in-focus countries<sup>16</sup> do not explicitly address risks related

<sup>15</sup> Exposure by the end of this century is calculated by scaling present sensitive exposure value of each sector according to the projected changes in GDP (Naumann et al., 2021).

<sup>16</sup> Finland ([Kansallinen ilmastonmuutoksen sopeutumisen suunnitelma 2030](#)), Germany ([Deutsche Anpassungsstrategie an den Klimawandel 2024](#)), Italy ([Strategia Nazionale di Adattamento ai Cambiamenti Climatici 2023](#)), Luxembourg (; [Draft Adaptation Plan 2025–2035](#)), and Spain ([Plan Nacional de Adaptación al Cambio Climático 2021–2030](#))

to CSS events.<sup>17</sup> Furthermore, all these documents consider infrastructure and buildings within their adaptation frameworks, but none specifically address the impacts of shrinking and swelling clay soils.

As indicated in the hazard section above, the projected drought episodes show that damage to buildings caused by drying-induced soil movements may become more frequent and severe over time virtually everywhere in Europe. In addition to climate-related risk factors, a building’s susceptibility to damage is influenced by factors such as the construction year (newer buildings might be more resilient to CSS risk) (Swiss Re, 2011), materials, the existence and condition of extensions or attached structures (including drainage and sewer systems) as well as foundation type and depth (Mzungu et al., 2025; Geobear, 2025). Additionally, soil movements are more likely to occur in the vicinity of trees and bushes, as tree roots tend to draw water from the ground (Gruslin et al., 2022; Assadollahi & Nowamooz, 2020).

Radevsky (2001) emphasises that approaches to managing shrink-swell clay soils vary widely across countries and regions, and are shaped by multiple factors including property market conditions, national legal frameworks, insurance policies, the attitude of insurers, the history of the region, the degree of building regulation, the experience and training of construction professionals as well as the homeowner’s sensitivity to structural damage such as cracks in the walls.

Table 5: Country specific information on vulnerability

<p><b>Finland</b></p> <p>Seasonal drying and wetting, together with freeze-thaw cycles, promote cracking of clay soils (Rasa et al., 2009). Geobear (2025b) has developed a subsidence map on their website based on reported damage claims, which shows that most subsidence cases occur in major urban areas such as Helsinki, Turku and Tampere. Large areas in southern and western Finland consist of clay-rich soils, which are sensitive to moisture variations. According to Geobear’s data, more than 75% of their company’s subsidence cases are attributed to the shrink-swell behaviour of clay soils.</p> <p>In Finland, the extreme 9-month drought period in 2002–2003 triggered significant shrink-swell responses in water-rich clay soils, particularly in southern regions of Finland (Silander &amp; Järvinen, 2004). These volumetric changes in soil produced uneven settlements in buildings founded on clay, generating substantial structural stresses, cracking and a reduced tolerance to traffic-induced vibrations. Damage was observed and reported in the Halikko area (southwestern Finland) as well as in the Helsinki Metropolitan Area among others (Silander &amp; Järvinen, 2004).</p> <p>Based on analyses of building and soil data, as well as practical experience, Silander and Järvinen (2004) estimated that the repair costs for damage to detached houses caused by prolonged drought period (such as that experienced in 2002 to 2003) range from €13.5 to €16.2 million in Finland. This estimate assumes that approximately 90,000 houses are built on shrink–swell clay soils in Finland, and that long drought conditions lead to damage requiring repairs in about 0.6% of these buildings (as observed in southwestern Finland). They estimated the average repair cost to be at €25 000 to €30 000 per house.</p>
<p><b>Germany</b></p>

<sup>17</sup> These documents discuss other geohazards and water management issues, including for example erosion, landslides and stormwater management. Italy’s national climate change adaptation strategy refers to subsidence risk.



For Germany Herrera-García et al. (2020) forecast a decline in potential subsidence due to effective groundwater management and population declines. Nevertheless, CSS-related impacts remain evident, as illustrated by the progressive cracking of the Massenheim Evangelical Church in Hessen, where damage has been observed since the 1930s and attributed to CSS processes. Mitigation measures such as micropiles have been proposed to transfer structural loads beneath the active zone of moisture-induced volume change (Lancellotta et al., 2022).

Companies such as Uretex Germany (2026) provide remediation services for infrastructure related damage, including foundation settlement and structural cracking, and recognise the role of moisture variability in soil instability (although these impacts are not explicitly framed within a climate change context on the company's website).

#### Italy

Herrera-García et al. (2020) ranked countries worldwide based on potential subsidence occurrence and associated impacts, accounting for the greatest reported damages. Among the top ten, Italy and the Netherlands were the only European Union countries. According to their analysis between 2010 and 2040, the predicted population exposed to potential subsidence in Italy will be less than 30%. There are number of recognised subsidence hotspots (e.g. Emilia-Romagna and Veneto regions) at fluvial and coastal plains in Italy, which are mostly due to natural compaction of recent geological deposits accelerated by the effect of intense groundwater withdrawals from aquifers, as well as new urbanization (Cigna et al., 2025; Boni et al., 2024).

Cigna et al. (2025) assessed land subsidence-induced deformation and associated structural stress in 15 metropolitan cities in Italy. The results indicate that approximately 1.44 km<sup>2</sup> of the 2665 km<sup>2</sup> of urbanized land within these cities is classified as high risk, due to angular distortions affecting highly vulnerable infrastructure. Furthermore, the study identified more than 2700 buildings with a high probability of having already experienced, or being at risk of developing, structural damage.

Lenardón Sánchez et al. (2024) assess the subsidence-induced risk to urban infrastructure in three major Italian cities by integrating satellite data with urban vulnerability metrics. The study reports spatial variability in subsidence hazard among the investigated cities, with specific areas experiencing significant differential ground deformation that threatens critical infrastructure. Specifically, areas classified as high to very high-risk cover approximately 36.15 km<sup>2</sup> in Rome, 11.44 km<sup>2</sup> in Bologna, and 0.43 km<sup>2</sup> in Florence. Additionally, they find a notable reduction in subsidence rates over time, accompanied by changes in the distribution of hazard zones within the three cities. For this positive development they thank mitigation efforts and highlight the importance of continued monitoring and understanding of land subsidence dynamics.

It should be noted that the primary focus of these studies concerning Italy is on subsidence risk in general, rather than specifically on the shrink-swell behaviour of clay soils and the potential long-term influence of climate change on these processes.

#### Luxembourg

In Luxembourg, CSS risk is particularly pronounced in the southern part of the country, corresponding largely to the Gutland region. The structures most frequently affected by CSS movements are individual residential buildings, especially detached houses founded on shallow continuous footings (Gruslin et al., 2022).



According to the experience of Gruslin et al. (2022) in Luxembourg, CSS risk is often unknown or misunderstood. There is no appropriate legislation or risk maps in Luxembourg related to CSS events. Additionally, the zones of foreseeable geological risks are not defined, and if specialists aware of this risk are not included, the likelihood increases that such risks will be overlooked. Gruslin et al. (2022) point out that CSS cycles ultimately weaken the structures and make lasting repair work impossible.

**Spain**

In Spain, Alonso-Martirena et al. (2015) find that most foundation failures in buildings in the southern Madrid region are associated with expansive clay soils. Complementing these findings, the Baleario company (2025) note on their website that subsidence vulnerability of houses is particularly pronounced in areas characterized by expansive clays, fluvial deposits and poor drainage, including regions such as Murcia, Valencia and several southern municipalities. The company further emphasises that overlooked issues include construction near dry riverbeds, on land with subsidence history, former wells and tree roots.

The Generalitat of Catalonia (2024) identifies land movements, including subsidence, as a significant geological hazard in Catalonia region, second only to river and coastal flooding. On their website, they describe a case study of subsidence and progressive cracking in residential buildings since 1997 in the Granada region in southern Spain. This was followed by systematic surface and subsurface monitoring, which enabled damage prediction, implementation of early-warning systems and the evacuation and relocation of affected residents in 2009. It has been confirmed that the ground continues to move relentlessly and is expected to do so indefinitely (Worldsensing, 2024).

*Stakeholder discussions*

All stakeholder discussions are based on experiences in south and southwestern Finland. Potential impacts of CSS events that came up in the discussions include breakage of main pipelines within buildings, water flow disruptions, structural cracking and separation of buildings. In extreme cases, there can be a collapse although this is a long-term risk rather than an immediate one.

One major factor slowing down construction progress is the complexity and high cost of groundwork in areas with clay soil. A severe challenge is associated with underground sewer systems. In some cases, the buildings themselves remain stable, but the surrounding ground and sewer infrastructure are sinking, leading to long-term structural concerns.

Based on these stakeholder discussions, there is a general lack of sufficient information, particularly regarding the effects of climate change on CSS events. While professionals tend to be aware of the risks and available solutions, the level of understanding is not as good among homeowners.

The respondents indicated that construction practices aim to prevent CSS-induced damage from arising in the first place. These include for example thorough soil surveys before building and strategic piling. New buildings are no longer constructed on wooden piles due to their vulnerability to moisture and changes in clay soil, which can significantly shorten their lifespan. The condition of existing wooden piles is actively monitored, and steel piles are used as a more durable alternative. Additionally, insulation against cold and stormwater management preventing excess water from entering clay soil help managing CSS risk.

### Researching the insurance framework

Across the reviewed countries, insurance cover for property damage caused by CSS events turns on whether CSS is treated as a natural catastrophe covered by a state mechanism, or as a form of ground movement which may potentially be addressed only through private insurance contracts. Alongside France, Spain is the only country that has established some sort of state mechanism. It has a public compensation body (**CCS**) for extraordinary risks, but CSS is generally treated as an ordinary ground movement outside CCS unless linked to an officially recognised phenomenon such as extreme drought. Germany, Finland, Italy and Luxembourg predominantly rely on voluntary private contracting for CSS risk, with standard home/building policies typically excluding soil movement or desiccation-related subsidence unless specifically endorsed. Further detail on the insurance position for each country is set out below.

#### *Finland*

There is no state mechanism for natural catastrophes in Finland.<sup>18</sup> Natural disaster insurance is not extensively governed and property insurance is voluntary and provided by private insurers. Finnish laws and regulations do not extensively govern insurance related to natural disasters, and across insurers the connecting coverage requirement is that the damage must be ‘sudden and unpredictable.’ Consistent with this logic, CSS is not typically named in policies but would be categorised as frost heave/ground movement/subsidence which is not typically covered by property insurance. Specific clauses covering CSS or other ground movement are not available by request in the Finnish market. From a homeowner-risk perspective, this creates a structural exposure: while certain natural catastrophe perils may be insured privately, ground movement (including CSS) is generally excluded.

#### *Germany*

Germany does not operate a centralised or mandatory natural catastrophe insurance scheme. Insurance cover for soil movement risks such as CSS is available only through voluntary, privately negotiated contracts although there is no legal obligation for property owners to purchase insurance against natural hazards. CSS is not automatically recognised as a natural hazard under German law and is typically excluded unless expressly included in policy wording. Even under extended elemental damage insurance, subsidence (‘Erdsenkung’) is defined narrowly and policy terms explicitly exclude dryness/desiccation-driven soil movement which are directly relevant to CSS. While CSS damage may resemble subsidence in its effects, it is generally excluded from cover unless it can be causally linked to a covered geological event as defined in the policy. As a result, there is forward-looking homeowner risk due to the combination of incomplete take-up of natural hazard cover and how the insurance framework covers CSS.

#### *Italy*

There is no general statutory mechanism for compensating damage to private property caused by natural disasters - state intervention is exceptional and discretionary and does not create an enforceable right to indemnity. In the private market, standard Italian home insurance (‘fire and ancillary risks’ policies) typically covers fire/explosion, certain atmospheric events, third party liability and sometimes catastrophic events such as earthquakes and floods. But they typically exclude damage from subsidence, landslides and ground/soil swelling - meaning CSS damage is not automatically covered. Therefore, there appears to be a protection gap for homeowners facing CSS damage under

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<sup>18</sup> While state compensation for exceptional floods existed in the past, this was stopped in 2014 (Finland memo, p. 2).

standard cover. While cover for subsidence/ground movement (including CSS) can be obtained only through private contractual arrangements by requesting additional cover, this would generally involve higher premiums and, in market practice, underwriting requirements such as a geological survey of the insured land. In addition, recent legislation does reference mandatory insurance in certain circumstances but implementation is delayed and lacks clarity, leaving it uncertain whether CSS will fall within scope.

#### *Luxembourg*

Luxembourg has no state compensation mechanism for natural catastrophes and all insurance cover is provided through private insurance contracts. The general market baseline is that CSS is not recognised as a natural catastrophe under Luxembourg law and is not included in standard property insurance policies. However, it may sometimes be added as an optional risk under broader natural catastrophe coverage, subject to negotiation. Market practice is that cover for CSS is rare, but it is possible to request a specific clause, typically on a case-by-case basis and often with higher premiums. From a homeowner perspective, there is a significant coverage gap under standard policies which may widen as CSS increases: because insurance relies on the principle of fortuity/uncertainty, if events become frequent and predictable in high-risk areas they may no longer qualify as insurable risks - leading insurers to refuse cover or impose strict exclusions.

#### *Spain*

Spain combines private insurance contracts with a public compensation mechanism for extraordinary risks through the Insurance Compensation Consortium (**CCS**). However, CSS is not automatically treated as an extraordinary risk covered by the CCS. Furthermore, the CCS regulation expressly excludes losses caused by movement of slopes, landslide, settlement of land or similar phenomena, save for the limited exception where such ground movement is manifestly caused by rainwater that produced an extraordinary flood in the area. Therefore, individual cover is driven by policy wording and exclusions, but standard home insurance policies typically exclude damage caused by CSS phenomena, which are also not recognised as extraordinary risks by CCS. As a result, there is a homeowner protection gap, particularly in high-risk areas – while tailored cover for expansive soils can be negotiated with private insurers, this will be at potentially higher premiums.

Country	State compensation mechanism for natural catastrophes?	Does that state mechanism cover CSS?	Default position in private home insurance regarding CSS	Can a homeowner request specific cover for CSS?	Homeowner insurance cover gap risk if CSS increases?
Finland	No state mechanism for natural catastrophes.	N/A	Property insurance is voluntary/private. Ground movement (including CSS) is generally excluded in Finnish market policies.	Specific clauses for CSS are not available by request.	Yes - exclusion plus projected increase in CSS risk implies widening protection gap.
Germany	No state mechanism for natural catastrophes.	N/A	Insurance cover is via voluntary, privately negotiated contracts. Even with add-ons, subsidence is narrowly defined and desiccation/dryness-related soil movement is excluded.	In principle only via explicit inclusion/wording. Drought/soil contraction damage is typically excluded unless specifically included.	Yes - due to low take-up of natural hazard cover and insurance treatment of CSS.
Italy	No state mechanism for natural catastrophes. State intervention is exceptional and discretionary and no enforceable right to indemnity.	N/A	Standard fire and ancillary risks policies exclude subsidence/soil swelling, so CSS not automatically covered.	Yes – can request additional cover/extension for subsidence/ground movement. Often requires geological survey and higher premiums.	Yes - a clear protection gap absent private tailored cover.
Luxembourg	No state compensation mechanism and all insurance cover is through private insurance contracts.	N/A	CSS not included in standard property policies.	Yes but rare. Possible to request a specific clause on case-by-case, higher premiums.	Yes and may worsen – insurability depends on fortuity; frequent/predictable events may become uninsurable or heavily excluded.
Spain	Yes — CCS (Insurance Compensation Consortium) for extraordinary risks.	Likely no: CSS are not usually an extraordinary risk within CCS. Expressly excludes movement of land save where caused by extraordinary flood.	Coverage is contract-wording driven - if excluded, no obligation to indemnify.	Yes, specific cover can be negotiated with private insurers.	Yes - protection gap because standard policies exclude CSS and CCS does not treat it as extraordinary event.

Table 6: Comparison of key aspects of insurance cover for property damage cause by CSS for Finland, Germany, Italy, Luxembourg and Spain

### 3.4 The way forward – conclusions of the pilot

The principal qualitative conclusions drawn from experience of conducting the pilot are as follows.

#### A clear gap in insurance cover for property damage caused by CSS events

Our review of the insurance treatment of CSS across the target countries reveals a consistent conclusion: property damage from CSS events can sit in a structural cover gap between what are typically defined as insurable sudden events and what are treated as gradual ground movement or a non-qualifying natural catastrophe.

In those countries where there is no state mechanism to provide cover for natural catastrophes and cover is predominantly through private insurance (Germany, Finland, Italy, Luxembourg), CSS is generally positioned within exclusions for subsidence/ground movement or within requirements that insured damage must be sudden and unpredictable. This makes CSS claims hard to fit within standard home policies. Even where optional natural hazard cover exists, CSS is often excluded via narrow definitions or is available only rarely and case-by-case, at higher premiums and sometimes with underwriting hurdles such as geotechnical assessment.

But even for those countries where there is a state mechanism (France and Spain), the existence of the state mechanism does not remove the CSS gap. In France, while the Cat Nat mechanism can cover ground movements linked to drought and rehydration, compensation depends on formal state recognition (interministerial decree) and on claim eligibility conditions that may limit access for homeowners. And while Spain's CCS protects against extraordinary risks, CSS is usually treated as an ordinary ground movement outside of the CCS.

This gap will become more consequential under climate change. As climate projections point toward more intense drought episodes and heavier rainfall events, the physical conditions for CSS damage are likely to become more frequent and severe - expanding both the number of affected properties and the scale of losses. The insurance challenge is compounded by a classic insurability tension: as CSS becomes more predictable in high-risk zones, insurers may view it as less fortuitous and respond by tightening exclusions, raising premiums, or declining coverage - especially in purely contractual regimes.

The result is an increasing risk of systemic underinsurance: homeowners face growing exposure to repair costs, diminished property values and financial risk depending on location and ability to purchase bespoke endorsements. Without policy and market adaptation - clearer coverage definitions, more reliable triggers, and scalable mechanisms to keep premiums affordable - the CSS protection gap is likely to widen as climate pressures intensify. In addition, based on the vulnerability assessment there is a clear need to better understand CSS mechanisms and how climate drivers affect them.

#### Targeting homeowners to create change may be best conceived as a supporting mechanism

Because the homeowner audience is large, diffuse and hard to mobilise at scale, targeting homeowners directly can be valuable but it may not be the most effective primary mechanism for closing the CSS protection gap.

First, the success of the CSSBDA depended heavily on publicity and outreach. Despite the effort to create as simple a layout as possible and the focus on communicating a clear narrative about CSS risk, the real determinant of the success of the CSSBDA was sustained publicity to ensure homeowners were aware of its existence. Indeed, it is hard to know if impact was limited to already-engaged households such as those actively searching after damage occurs, or those with high risk awareness. Homeowner outreach works when it is tightly connected to moments of decision (home purchase,

mortgage origination, policy renewal, renovation permitting) and delivered through channels that already touch homeowners at scale (banks, notaries, municipalities, insurers, builders, real estate platforms).

Second, there is potentially a mismatch between national-scale messaging and the fact that CSS risk is highly localised and spatially uneven risk. A national campaign risks being too generic to prompt action in high-risk zones, while simultaneously feeling irrelevant to low-risk households. A one-size-fits-all approach at national level can dilute urgency and reduce conversion into concrete homeowner behaviours (checking policy wording, requesting endorsements, commissioning soil reports or taking mitigation measures). Effective targeting may require finer geographic resolution (e.g. municipality, postal code etc.) yet national campaigns are typically constrained to broader messaging.

Third, empowering homeowners may be structurally limited. The experience with the CSSBDA in France shows that even where a large number of homeowners access the tool, there are questions around homeowner engagement. Based on the research for target countries, even motivated homeowners may face barriers such as insurance firms not offering CSS endorsements (or where available these increase the premium or require technical documentation such as geotechnical surveys). For renters or apartment owners, agency is even weaker.

Therefore, there is a question as to whether these limitations mean that informing and empowering homeowners through tools like the CSSBDA simply raise awareness without materially shifting outcomes. This indicates homeowner targeting is best seen as a supporting layer in a broader strategy. Given the diffusion and motivation challenges, the highest-leverage approach is often to combine homeowner information with upstream interventions that shape the market: standardised disclosure at sale/lease, insurer product guidance, lender requirements, building-code and retrofit standards etc.

#### Replication of an equivalent CSSBDA in target countries

While a separate website for each country can be way to provide credible, actionable guidance on CSS risk to homeowners, because the insurance frameworks differ across jurisdictions, each site must communicate different information and be structured around different user journeys.

For example, while the CSSBDA needed to communicate information about the risks associated with the Cat Nat mechanism and the requirement for official recognition of a natural catastrophe etc., an Italian site would have to focus on contract exclusions, how to request optional extensions, and what evidence insurers may require. In Spain, the key message relates to when CCS applies versus when the homeowner is entirely in the private-policy domain. And in Germany, the site would have to explain the issues related to narrow subsidence definitions that often exclude CSS movement. This means that a single replicated website structure risks either misleading homeowners or obfuscating key locally specific information under generic content.

This variability significantly affects the appropriate content architecture for any new website. The user journey, content on what measures can be implemented to reduce risks associated with inadequate insurance cover need to be country specific. Each website must package information on what cover exists, what triggers it, what is commonly excluded, and what steps a homeowner can take in a clear and simple narrative appropriate for a homeowner audience.

There is also a practical issue associated with accessing data to inform any country specific website. By way of reminder, the CSSBDA accessed French publicly available information to provide information to the homeowner on the level of CSS risk, typical property prices etc. But the availability of public

information may be uneven across countries, be hosted/provided by different public institutions and published in different formats. While some countries might centralise natural catastrophe information (decrees, risk maps, claim guidance) others might leave it dispersed across insurers, regulators, consumer bodies or municipal sources. If the country specific website aims to pull together authoritative information in a similar way to the CSSBDA, integrating this information in the country specific website will likely require bespoke software configuration for each country. Different data sources (PDF guidance notes, interactive portals etc.) imply different methods to capture the information such as APIs in some places, web scraping or manual curation in others. In addition, these public information sources may be subject to varying update frequencies and reliability. This makes a single software codebase extremely difficult if the core function is data aggregation.

In light of these considerations, a good approach may involve a shared platform with reusable components (content management system, templates, accessibility, analytics, multilingual framework) but country-specific components for information on the insurance framework, data connectors and user pathways. This keeps development scalable while respecting national differences. The alternative of fully bespoke websites for each country may provide the cleanest user experience but increases cost, maintenance burden and dependency risk if external data sources change. This would imply one platform with tailored implementations rather than unique websites for each country.

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## Appendix 1: Willingness to pay estimates for green roofs

Table 7: WTP estimates average values, 90% and 95% confidence intervals. Estimates are obtained after performing the Krinsky-Robb procedure (20000 draws)

<i>Willingness to Pay</i>	Control			Pro-social			Pro-self		
	Mean	CI lower (95%)	CI upper (95%)	Mean	CI lower (95%)	CI upper (95%)	Mean	CI lower (95%)	CI upper (95%)
		CI lower (90%)	CI upper (90%)		CI lower (90%)	CI upper (90%)		CI lower (90%)	CI upper (90%)
<i>Species_small</i>	103.2	83.07	126.2	120.84	97.32	147.6	110.9	84.47	141.50
		85.92	122.2		100.7	142.8		88.40	136.03
<i>Species_large</i>	152.7	124.1	184.7	196.82	161.1	237.1	183.3	145.0	227.59
		128.5	179.1		166.2	230.3		150.9	219.86
<i>Flood</i>	103.0	85.20	122.7	120.40	99.24	144.1	139.2	112.7	169.33
		87.88	119.4		102.3	139.8		116.4	163.69
<i>Visibility</i>	17.26	5.37	30.03	13.00	0.97	25.62	7.94	-6.06	22.04
		7.14	27.82		2.91	23.46		-3.87	19.76
<i>Cooling</i>	72.09	57.61	88.77	71.51	56.15	89.71	105.66	83.50	131.35
		<b>59.74</b>	<b>85.82</b>		58.47	86.45		<b>86.68</b>	<b>126.84</b>
<i>Lifespan</i>	2.79	1.95	3.85	2.72	1.87	3.83	4.55	3.36	6.03
		2.07	3.65		1.97	3.61		3.52	5.75
<i>SQ (asc)</i>	-554.5	-682.4	-444.3	-573.3	-718.3	-449.5	-646.2	-828.5	-493.93
		-659.6	-460.3		-690.8	-468.3		-796.3	-515.21

## Appendix 2: Cost-benefit analysis sensitivity analysis

### Extension of the CBA to other regions (loop 2 and 3)

#### *Value transfer methods*

The full CBA was performed only for the Netherlands. For the Nordic (Loop 2) and Mediterranean (Loop 3) regions, Value Transfer methods were applied to adjust the Dutch results.

Adjustments for benefits based on willingness to pay (WTP) were made using Purchasing Power Parity (PPP) indices, which are commonly used in benefit transfer to account for cross-country differences in income levels and price structures. WTP measures reflect preferences and ability to pay rather than physical quantities, and PPP therefore provides an appropriate proxy for adjusting welfare-based benefit estimates across countries. PPP indices were derived from Purchasing Power Parities in the European Union (countries), expressed as an index with Belgium = 1, and based on 2024 values (Source: EUROSTAT). Dutch WTP estimates were rescaled to Finland and Italy using the ratio of national PPP indices relative to the Netherlands, ensuring consistency in real purchasing power across regions.

For the cooling benefit, indoor cooling benefits are adjusted using Cooling Degree Days (CDD) as a proxy for cooling demand. The rationale is that the magnitude of indoor and outdoor cooling benefits provided by green roofs depends primarily on the frequency and intensity of warm conditions that require cooling.

The cooling benefit estimated for the Netherlands is therefore scaled to other regions using the ratio of regional CDDs (projected for 2030) relative to the Dutch baseline. Data is extracted from the Horizon 2020 project Heat Roadmap Europe (Paardekooper et al., 2018). Because cooling benefits are strongly climate-driven, this adjustment is applied before any income-related scaling. In practice:

- For **Finland**, cooling benefits remain negligible and are slightly lowered due to lower CDD values. They are still included though: although cooling demand and air-conditioning penetration remain low in Nordic countries, they may see an increase due to climate change.
- For **Italy**, cooling benefits are included and scaled upward substantially due to higher projected cooling demand. The CDD ratio between Italy and the Netherlands is used to scale up the demand for cooling, in addition to the PPP ratio. However, cooling benefits are not linear in nature, therefore the effect of the ratio is dampened by a parameter. It is set to 0.25 in the main analysis, and then set to 0 in sensitivity analysis (thus not accounting for CDD at all).

Investment and maintenance costs were adjusted separately from benefits. While benefit transfer relies on Purchasing Power Parity (PPP) to reflect cross-country differences in willingness to pay, PPP is not appropriate for transferring market-based construction costs, which depend on input prices rather than welfare levels. Instead, investment and maintenance costs were adjusted using construction cost indicators obtained from Eurostat. These indicators capture differences in labour costs, material prices, energy inputs, and sectoral productivity across countries, and are therefore more consistent with the social cost concept used in cost-benefit analysis.

Cost estimates derived for the Netherlands are scaled to Finland and Italy using the ratio of national construction cost indices relative to the Dutch baseline. The same is applied to both installation and



maintenance costs, reflecting the largely construction- and labour-intensive nature of green roof implementation.

Table 8: Value transfer parameters

Method	Source	Values		
		Netherlands	Finland	Italy
Purchasing Power Parity (PPP)	Eurostat (2024)	1,099	1,108	0,862
Construction Producer Cost	Eurostat (2024)	134,2	122,1	122,7
Cooling Degree Days (2030 projections) (in number of days)	Heat Roadmap Europe (Paardekooper et al., 2018)	48	49	644

## Results

### Finland case

#### Private benefits only

	Overlying		Replacing	
	Low range	High range	Low range	High range
NPV	-€ 263,64	€ 165,84	-€ 399,46	€ 72,61
CBR	0,37	1,62	0,28	1,15

#### Public and private benefits

	Overlying		Replacing	
	Low range	High range	Low range	High range
NPV	-€ 56,46	€ 466,37	-€ 192,28	€ 373,15
CBR	0,87	2,24	0,65	1,80

### Italian case

#### Private benefits only

	Overlying		Replacing	
	Low range	High range	Low range	High range
NPV	-€ 255,72	€ 259,51	-€ 392,21	€ 165,83
CBR	0,39	1,69	0,30	1,35

#### Public and private benefits

	Overlying	Replacing

	Low range	High range	Low range	High range
NPV	-€ 112,83	€ 475,03	-€ 249,32	€ 381,36
CBR	0,73	2,26	0,55	1,81

### Benchmark with literature

Given the simplified nature of the replicated CBA for Loops 2 (Nordic) and 3 (Mediterranean), results are benchmarked against existing CBAs of green roofs and similar nature-based solutions in those regions to assess their plausibility and consistency with the literature.

#### *Nordic region (Finland)*

Two main CBAs conducted in Finland provide a useful benchmark for Loop 2.

Nurmi et al. (2016) perform a social cost–benefit analysis of extensive green roofs in Helsinki, with a strong emphasis on scenic (aesthetic and psychological) benefits, estimated using hedonic pricing methods. Their results indicate a wide range of outcomes depending on design assumptions and benefit inclusion, with net present values ranging from approximately  $-4.7 \text{ €/m}^2$  to  $+37.9 \text{ €/m}^2$ . In addition to benefits considered in the present analysis (aesthetics, biodiversity, cooling), their study also includes air quality improvements and sound insulation, which are not explicitly monetised in this CBA.

A previous study by Nurmi et al. (2013) reaches similar conclusions. The authors find that private benefits alone are generally insufficient to justify green roof investments at prevailing cost levels, particularly for commonly available pre-grown vegetation systems. However, when public benefits are included, the CBR increases substantially, ranging from 0.9 to 2.2, compared to 0.7 to 1.8 when only private benefits are considered. Importantly, benefits are shown to be positively correlated with precipitation, temperature, and proximity to the city centre.

These findings are consistent with the results of the loop 2: while cooling benefits remain limited due to low cooling demand, the inclusion of non-market public benefits (e.g. biodiversity and aesthetics) achieves positive social NPVs. Differences in absolute values can largely be explained by differences in valuation methods (hedonic pricing versus stated preferences), benefit scope, and cost assumptions.

#### *Mediterranean region (Italy)*

Several Italian studies provide relevant reference points.

A probabilistic lifecycle-based CBA by Bianchini & Hewage (2012) estimates the social net present value of extensive green roofs at approximately  $400 \text{ USD/m}^2$  (around  $340 \text{ €/m}^2$  at the time of publication). Their analysis integrates multiple private and public benefits over the full lifecycle and applies Monte Carlo simulations to explicitly address uncertainty. The relatively high NPVs reported are consistent with the higher cooling demand and longer periods of heat stress typical of Mediterranean climates.

In contrast, Biasin et al. (2023) analyse green roofs in Turin and find negative CBR when multiple benefits (including flood regulation and temperature mitigation) are considered. High implementation costs are identified as the primary limiting factor. The authors conclude that economic viability strongly depends on targeted and context-specific design and implementation, rather than uniform large-scale deployment.

More recent, spatially explicit evidence is provided by (Quagliolo et al., 2026) who conduct a CBA of green roofs in Rapallo (Italy) focusing on pluvial flood risk mitigation. Even when considering only flood damage reduction benefits, CBR range between 0.63 and 1.74, depending on cost assumptions. The authors show that green roofs can be economically viable when spatially targeted to maximise stormwater retention effects. Including additional benefits such as cooling, biodiversity, and aesthetics—as done in the present study—would be expected to further improve these ratios.

Overall, the Mediterranean results obtained in this study—while sensitive to assumptions regarding cooling benefits—fall within the range of outcomes reported in the Italian literature. The comparatively high NPVs observed in some scenarios are consistent with studies highlighting the strong role of climate-driven benefits, particularly cooling, while also reinforcing the importance of cost assumptions, spatial targeting, and careful benefit transfer.

### Sensitivity analysis

In the CBA, 2 additional sensitivity analysis are performed, using a lower and higher discount rate, based on the [Dutch national guidelines](#) for conducting CBAs: 1.85% and 2.65%. The two CBA presented below are performed for the Dutch case only; using the avoided damages estimates for valuing the flood risk benefit. The rest of the methodology is similar to the CBA presented throughout the report.

Table 9: CBA sensitivity analysis using low and high discount rates

#### Low discount rate

##### Private benefits only

	Overlaying		Replacing	
	Low range	High range	Low range	High range
NPV	-€ 311,30	€ 119,30	-€ 460,58	€ 16,84
CBR	0,33	1,29	0,12	1,03

##### Public and private benefits

	Overlaying		Replacing	
	Low range	High range	Low range	High range
NPV	-€ 106,47	€ 416,73	-€ 255,75	€ 314,27
CBR	0,77	2,00	0,58	1,61

#### High discount rate

##### Private benefits only

	Overlaying		Replacing	
	Low range	High range	Low range	High range
NPV	-€ 311,30	€ 119,30	-€ 460,58	€ 16,84
CBR	0,33	1,29	0,12	1,03

##### Public and private benefits



	Overlaying		Replacing	
	Low range	High range	Low range	High range
NPV	-€ 106,47	€ 416,73	-€ 255,75	€ 314,27
CBR	0,77	2,00	0,58	1,61

## Appendix 3: Flood risk modelling

### Abstract and Conclusion of a Thesis

Pluvial flood risk reduction from Blue-green roofs in Amsterdam,  
the Netherlands

A cost-benefit analysis on the direct damage reduction of pluvial floods through Blue-green roofs

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04/06/2024

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### Abstract

Climate projections suggest extreme precipitation events (>20mm/hr) will be twice as likely by 2050 in the Netherlands (KNMI, 2023). This leads to increased challenges concerning pluvial flooding in the urban landscape, where sewage systems are already regularly at capacity. One adaptation measure that may offer significant risk reduction from pluvial flooding is Blue-Green roofs (BG-roofs). BG-roofs are green roofs, covered in vegetation, with a blue retention layer underneath for capturing precipitation during extreme weather events. The aim of this study is to quantify the potential of BG-roofs to decrease direct damages from pluvial flooding in the city of Amsterdam, The Netherlands. This study aims to gain insight into the benefits of BG-roofs with respect to the reduction of direct pluvial flood risk damages in various scenarios in the city of Amsterdam.

Using inundation maps modelled from precipitation events, damages are estimated for three BG-roof scenarios related to which roofs can support BG-roofs. From these, damage functions are used to estimate yearly direct damages and yearly damage reduction. In addition, costs per m<sup>2</sup> were retrieved from the RESILIO project to execute a cost-benefit analysis (CBA).

Results showed an inundation lowering of ~1 cm depending on the scenario and the modelled precipitation event. The three BG-roof scenarios were investigated for the current and future

climate, and a CBA was executed using 8 cost-scenarios. Results indicated that in 6 out of 24 cost-benefit scenarios, BG-roofs were a cost-efficient method of reducing direct damage from pluvial flooding in the current and future climate. This suggests that even without considering indirect damages and other co-benefits of BG-roofs (e.g. increased biodiversity), BG-roofs have the potential to be a cost-efficient investment. Results highlight that driving down maintenance costs

will significantly improve NPV (Net Present Value). The CBR (Cost Benefit Ratio) varies significantly between regions; the regions of “Centrum” and “Zuid” have significantly higher CBR and strongly positive NPV, while other neighbourhoods such as “Zuid-Oost” and “Nieuw-West” have a very low CBR and a strongly negative NPV. The difference may lie in the amount of BG-roofs constructed in the “Base” scenario, the construction density and land-use types. Challenges for BG-roof implementation include: high initial investment costs, most benefits being an emergent property, and an offset between investors and beneficiaries (i.e. the benefits are enjoyed by everyone, but the costs are concentrated).

Overall, BG-roofs are potentially a very cost-efficient nature-based solution to a variety of challenges that we currently face in the urban landscape. Future research should shed more light into the total benefits of BG-roofs in Amsterdam and other cities, as well as to what extent costs may be reduced through e.g. economy of scale. Such a CBA should be executed on the most recent climate projections (KNMI, 2023). Additionally, a citywide CBA considering all benefits of BG-roofs should be executed to properly assess the value of BG-roofs in Amsterdam.

### **Overall conclusion**

In this thesis the potential of BG-roofs as an inundation - and consequently direct damage - reduction measure was investigated for the city of Amsterdam. Through the generation of inundation maps in various BG-roof scenarios the direct damages were determined and a CBA was executed, with the benefits defined as the reduced direct damage from pluvial flooding per scenario.

BG-roofs have the potential to significantly reduce inundation ( “Base” : ~0.7 cm ) in the city of Amsterdam. While this may not seem like a lot, it represents ~10% of the average inundation. Inundation reduction between scenarios differs most in older neighbourhoods such as “Centrum” , “Zuid” and “West” , here the majority of buildings was constructed prior to 1960 which leads to significantly less inundation reduction in the “Base” scenario than in the “Before 1960” and “All Sizes” scenarios. The “Base” rooftop scenario generally had the highest CBR, while the “All Sizes” rooftop scenario had the lowest CBR. This suggests an optimum in BG-roof implementation as benefits are not linear to total BG-roof area. Results indicated that direct damage reduction from BG-roofs roofs leads to a positive NPV in 25% of cost-benefit scenarios for the current and 2050-WH climate. The NPV is significantly higher in the future climate. For all rooftop scenarios, “overlying” had the potential to yield a positive NPV if maintenance costs could be reduced ( “low maintenance” scenario).

Not all neighbourhoods have equal potential for BG-roof implementation. Generally, regions with high building density and a higher concentration of high-value land use types, such as “Zuid” and “Centrum”, had a significantly more positive NPV than regions with less building density, such as “Nieuw-West” and “Noord”.

This indicates that even without considering any co-benefits of BG-roofs, such as indirect-damage reduction, UHI reduction and improved biodiversity, BG-roofs have the potential to be cost efficient. Through economy of scale, maintenance and construction costs could likely be reduced, leading to a higher CBR and higher chance of positive NPV in all scenarios. Nonetheless, most of the benefits of BG-roofs are an emergent property that only show when implemented at a large enough scale. Thus, a method should be determined to ensure large scale implementation of BG-roofs if implemented. Additionally, currently, costs of BG-roofs are for the owner of the roof, while benefits are enjoyed by everyone. Transferring some of the costs toward beneficiaries will be a necessary measure to ensure investment into BG-roofs.

Generally, the NPV obtained in this report is higher than the NPV obtained by Haer et al. (2022). While Haer et al. (2022) report higher NPV potential than the highest value obtained in the research of this thesis, which excludes all co-benefits and indirect damages. Furthermore, negative NPV values were twice as large in the report by Haer et al. (2022) for the “replacing high-cost” equivalent scenario. Surprisingly, Haer et al. (2022) do obtain positive NPV for the “replacing low-cost” equivalent scenario whereas no positive values were obtained for this scenario in this report. This may be due to the inclusion of co-benefits and indirect damages in the report by Haer et al. (2022).

Some opportunities for future research include a CBA for the most recent climate projections. Additionally, currently a CBA on Amsterdam is underway which considers all benefits of BG-roofs, including: direct damage reduction, indirect damage reduction, UHI effect reduction, improved insulation, improved biodiversity, recreative purposes and increased property value. Such an extensive CBA could potentially be converted into a framework for executing cost-benefit analyses on other urban areas than Amsterdam. Additional research opportunities lie in defining the extent to which smart valve BG-roofs perform different from standard BG-roofs, and what effect this has on the CBR. It would also be valuable to better define construction and maintenance costs between different BG-roof scenarios, as this would increase understanding of which scenario is most cost-efficient for the city of Amsterdam.

Overall, BG-roofs are potentially a very cost-efficient nature-based solution to a variety of challenges that we currently face in the urban landscape. They greatly reduce damage from pluvial flooding and have many co-benefits. Naturally, it should not be expected that BG-roofs alone will be the single solution to these challenges, but BG-roofs have the potential to play an integral role in reducing risk and improving health, quality of life, and happiness.



## Appendix 4: Barriers, enablers and incentives of NBS insurance products for European insurers

		Netherlands	Boreal region	Mediterranean
<b>Barriers</b>	1. Absence of a robust business case			
	2. Limited awareness and knowledge of climate risks			
	3. Siloed, sectoral approach to climate adaptation			
	4. Unclear role of insurers in climate adaptation			
	5. Adjusting the building structure is costly			
	6. Regulatory hurdles related to permissions			
	7. Risk distribution and insurability			
	8. Limited home insurance uptake			
	9. Wildfire susceptibility			
<b>Enablers</b>	1. Differentiating insurance premiums			
	2. Information infrastructure on prevention			
	3. Build Back Better approach			
	4. Adjusting insurance policy coverage			
	5. Public-private collaboration			
<b>Incentives</b>	1. Exchanging best practices			
	2. Developing climate adaptation labels			
	3. Data on nature-based solutions and risk reduction			
	4. Creating internal and external awareness			
	5. Establishing a long-term vision			
	6. Collaborating with key stakeholders			
	7. Governmental support			
	8. Green roof standards			



**PIISA**

Piloting Innovative Insurance  
Solutions for Adaptation

## D3.11 Pilots for Cities and well-being

## Appendix 5: Green roof workshop – Mediterranean area

The relevance of green roofs for climate change adaptation in urban environments has been increasingly emphasized. Green roofs represent a viable opportunity to implement adaptation solutions without necessitating the use of the already scarce urban land. As reported within PIISA deliverables,<sup>19</sup> green roofs offer numerous benefits to both their owners and cities, like, for instance, thermal insulation for buildings and the promotion of habitats for urban biodiversity.

But what about European citizens' perceptions? As presented in PIISA survey on European citizens<sup>20</sup>, this solution seemed to be already familiar to many Europeans citizens: about 65% of the sample declared to know what a green roof is. However, that familiarity appeared largely conceptual rather than evidence based and few interviewed can list the multiple benefits linked to green roofs. Indeed, when asking the citizens about the actual adoption of this solution, only 6% of respondents reported having installed a green roof on their own house.

Looking ahead, it was interesting to check the willingness to consider installing a green roof on their home. One citizen in three (34%) declared that would adopt this option, nevertheless, once costs were made explicit, the figure quickly diminished with only 23% still willing to consider installing it.

Among the barriers of their limited adoption, we found attitudinal barrier with 33% of respondents declaring that they are simply not interested in doing so. Evidence highlights three further obstacles: structural, informational and financial. The 24% of the sample reported that their roof is not flat, making installation difficult or outright impossible. Lack of knowledge was mentioned by the fact that 9% were unaware that a green roof could be fitted to a private dwelling at all, with another 6% felt they do not have sufficient guidance on installation and maintenance of these solutions. Eventually, financially speaking only 6% pointed to the absence of local incentives or to high up-front expenses as decisive barrier.

In general, the evidence gathered points to a recurrent pattern: awareness and declared interest have not yet crystallised into widespread action, with our analysis suggesting two main reasons for this disconnection. First, most citizens do not regard the solution as personally relevant for different reasons. Second, when asked which incentives might persuade them to invest, respondents express no clear preference. This very flatness implies that most people have never seriously examined a green roof retrofit. In short, it seems the discussion is still taking place in the abstract and it has yet to reach the practical ground on which real decisions are made.

So, after analysing the demand side of Green Roofs (whose results are presented above and in D3.3) the project also investigates the supply side, which is discussed in the following section. Politecnico di Milano organized 8 targeted interviews with the main Italian insurance carriers (representing about 45% of Gross written premium in Italy) and a workshop open to professionals in the financial industry

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<sup>19</sup> PIISA, D3.3 Plan for evaluating barriers and enablers for green roof insurances in the Netherlands: [https://piisa-project.eu/assets/deliverables/D3.3\\_Plan%20for%20evaluating%20barriers%20and%20enablers%20for%20green%20roof%20insurances%20in%20the%20Netherlands.pdf](https://piisa-project.eu/assets/deliverables/D3.3_Plan%20for%20evaluating%20barriers%20and%20enablers%20for%20green%20roof%20insurances%20in%20the%20Netherlands.pdf)

<sup>20</sup> PIISA, From Awareness to Action: European Citizens' Perceptions, on Climate Adaptation and NBS. A key focus on green roof  
[https://piisa-project.eu/assets/deliverables/publications/PIISA\\_GreenRoofReport\\_POLIMI.pdf](https://piisa-project.eu/assets/deliverables/publications/PIISA_GreenRoofReport_POLIMI.pdf)

(insurers mainly), to further discuss preliminary findings. In particular, top management and head of damage insurance sector were interviewed with the scope to assess important insights about these themes, so to understand the point of view of those that actually price the risks just mentioned. Several points were touched: the level of adoption of NbS, including green roofs, in their offers and in their models, the willingness to recognize incentives or discounts in the policy for customers implementing these solutions, the role of the insurer in the adaptation context and the main barriers and the main enablers to their implementation.

The results showed that insurance carriers, in general terms, are almost all aware of what NbS solutions (such as green roofs) are and that they are key players in their development. Nevertheless, they also emphasized that the crucial role is played by reinsurers, which are those that are capable of assuming and properly pricing such risks, provided they have access to sufficiently broad and reliable global and historical data to assess them accurately.

Thus, insurances, by now, did not take into considerations NbS such as green roofs in their offers, either including or excluding them. To do so, they need the benefits of these solutions to be defined quantitatively in order to understand if they can mitigate the main risks for which each policy is built. In fact, as it clearly emerged from the interviews, it is not sensible to think of a policy only to cover green roofs, rather, it is relevant to think of how the presence of green roofs can impact policies that already exist, such as the homeowners one.

On a premium-setting perspective, we asked insurers about their willingness to recognize incentives or discounts in the policy for customers implementing these solutions. Moreover, to reinforce the results from the interviews, we asked the same questions during the workshop. As we can see in Table 10, according to the different risks that were exposed, there was not a unanimous response on any of the two occasions. Qualitatively, several factors suggest a potential positive impact on the insurance premium (i.e., a reduction), while others point to a negative effect (i.e., an increase in the premium). However, in the absence of quantitative data, it is not possible to assess either the individual effect of each factor or the overall magnitude of the positive and negative impacts, and therefore to estimate the net effect on the premium.

Table 10: Green Roof impact on insurance premium. Source: interviews with 8 major insurance carriers (45% of GWP) and workshops with 11 players from insurance and banking sector

Risk or Challenge Related	Impact on premium	Description	Source
Durability	Positive	<b>Extended roof durability:</b> If designed properly, green roofs can protect the underlying roof from temperature fluctuation, increasing its lifespan by 15-30 years.	Interviews
Fire	Positive	<b>Increased fire resistance:</b> A well-maintained green roof acts as a fire-resistant insulation, unlike photovoltaic panels, that are viewed by insurers as increasing fire risk.	Interviews
Water-management	Positive	<b>Reduced water damage and improved insulation:</b> Green roofs help drain and retain rainwater, thereby decreasing exposure to water-related damage.	Interviews; Workshop



Water-management	Positive	<b>Structural risks (Weight and Roots):</b> Installing a green roof introduces structural challenges due to weight of soil and retained water, requiring load-bearing assessment on existing buildings.	Interviews; Workshop
Weather events	Positive	<b>Protection against weather events:</b> Green roofs act as a physical protective layer against extreme weather events, for instance the hails, reducing damages to the underlying structures (with respect to traditional roofs or solar panel).	Interviews; Workshop
Weather events	Negative	<b>Risk of leaks and drainage problems:</b> A green roof can cause significant water and moisture damage inside a building, especially if the roofing membranes are poorly installed or if they later become detached. Inadequate maintenance can also contribute to the problem.	Interviews; Workshop
Quantification	Negative	<b>Irrelevance to the most common claims (the condominium paradox):</b> For comprehensive property insurance policies, the main claims (thus, risks) are related to electrical failures or the rupture of old pipes. Green roofs do not mitigate these specific damages, making it difficult for insurers to justify significant premium discounts.	Interviews
Quantification	Negative	<b>Inability to price due to lack of historical data:</b> As NbS are still niche, insurers do not possess the historical series needed to statistically assess the risk. Consequently, at present, the economic impact on retail policy pricing is essentially not possible to estimate.	Interviews
Quantification	Negative	<b>Inability to Price Due to Lack of Certified Data:</b> The use of alternative data sources, such as predictive analytics or real-time monitoring data, remains difficult to integrate into insurance pricing models. Insurers are generally unable to incorporate new parameters into their models unless the underlying data is formally certified. As a result, external sensors that collect this information must themselves be certified in accordance with insurance industry requirements. Only then can the data they generate be considered reliable and eligible for inclusion in underwriting and pricing models.	Interviews

Furthermore, the role played by reinsurers, the availability of historical data, technical validations and the creation of a new insurance infrastructure represent the most relevant aspects that insurance carriers would like to address to include green roofs in insurance policies.

In fact, beyond the role of reinsurers and the availability of historical data (mentioned above), insurers emphasized the need for standardization and technical certification of the solution. This could be achieved, for example, through the collection of measurable, objective parameters validated by qualified experts or systems. Furthermore, insurers require reliable monitoring technologies capable of continuously verifying the proper functioning and performance of the solution over time.

Moreover, it is essential to recognize that, in order to include green roofs in insurance policies, the sector requires not only innovative insurance products but also a supportive ecosystem capable of creating the necessary conditions for their acceptance. This includes raising awareness among customers at both the public and private levels. Insurers' role should primarily focus on providing technical expertise, for example developing data-driven alert systems, while responsibility for physical preventive measures and territorial maintenance should rest with the Public Administration.

In conclusion, in the context of our analysis, climate change is driving a shift from "Risk Transfer" (insurance) to the need for "Risk Mitigation" (climate adaptation), given that the increasing frequency of medium-scale events threatens long-term solvency. Hence, NbS act as an opportunity to enhance resilience, providing a proven reduction in risk, thereby decreasing the occurrence of financial losses. However, insurers currently lack data and information to incorporate these solutions (NbS) into their underwriting models, thereby generating pricing inefficiencies. At present, this remains a niche market with a neutral impact on pricing. To scale effectively, the sector could transition from a passive underwriting approach to active ecosystem partnerships involving Technology, the Public Sector, and Reinsurance, provided that we are able to demonstrate, in a quantitative way, that NbS reduce risks on which policies are built. Green roofs undoubtedly generate social benefits and co-benefits; however, these do not easily translate into measurable risk-reduction benefits for individual properties or homes, nor into insurance premium discounts. Given the installation costs and ongoing maintenance requirements, in the absence of a tangible returns, such as a reduction in the insurance premium paid, citizens may be unlikely to perceive them as a worthwhile investment. As a result, adoption rates may remain limited, leading to a loss of the associated co-benefits as well.



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## Appendix 6: Creative assets and formats

Each ad set included three distinct visual creatives, with each creative adapted into a horizontal format, and a vertical format. All ads combined visual content and text, with minor variations in tone and wording across creatives, allowing for a qualitative assessment of message reception while maintaining overall coherence. All advertisements redirected users to the French-language version of the CSSBDA, ensuring consistency between the ad content and the landing page.

Ad set 1 visuals

1	 <p><b>Sécheresse: habitez vous sur un terrain sensible au mouvement du sol ?</b></p> <p><b>Faire l'évaluation des risques à votre adresse</b></p>  <p>Projet européen financé par Horizon Europe &amp; CINEA <b>PIISA</b></p>
2	 <p><b>Les erreurs à éviter avant de signer un contrat immobilier</b></p>  <p>Une initiative du projet européen PIISA, financé par Horizon Europe &amp; CINEA <b>PIISA</b></p>
3	 <p><b>Vendre un bien à risque : mission difficile !</b></p> <p>Découvrez les bonnes pratiques sur notre site</p>  <p>Projet européen financé par Horizon Europe &amp; CINEA <b>PIISA</b></p>



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## D3.11 Pilots for Cities and well-being

### Ad set 2 visuals

	<p><b>Habitez vous sur un terrain sensible au mouvement du sol ?</b></p> <p><b>48%</b> Territoire national français exposé à un risque moyen ou élevé</p> <p><b>10M</b> Maisons potentiellement concernées</p> <p><b>50%</b> Dommages immobiliers causés par des mouvements de sol non indemnisés ces 9 dernières années</p>  <p><b>Faire l'évaluation des risques à votre adresse</b></p>  <p>Projet européen financé par Horizon Europe &amp; CINEA <b>PIISA</b></p>
	<p><b>Savez-vous que le climat peut impacter directement votre assurance habitation ?</b></p>  
	 <p><b>50%</b> des dommages immobiliers causés par des mouvements de sol non indemnisés ces 9 dernières années</p> <p><b>Et vous, avez-vous vérifié votre assurance ?</b></p>  <p><b>PIISA</b> Piloting Innovative Insurance Solutions for Adaptation</p>

## Appendix 7: Methods and data used for soil drought projections

The current soil drought projections were derived from output data from 14 global climate models that participated in Phase 6 of the Coupled Model Intercomparison Project (CMIP6, Eyring et al., 2016) (Table 11). The models selected for the study have demonstrated at least moderate performance in simulating the future climate of Europe (Ruosteenoja, 2021). In addition, it was required that soil moisture data had to be available at multiple depths (CMIP6 variable acronym “mrsol”). For the period 1950–2014, long-term mean soil moisture and occurrence of dry episodes were derived from historical model runs. For the years 2015–2100, we primarily explored responses to the medium-severity SSP2-4.5 greenhouse gas scenario (O’Neill et al., 2016; Meinshausen et al., 2020). Since deep soil drought episodes tend to develop slowly, the model output data were analysed at a monthly mean temporal resolution. According to the model simulations, the soil is generally driest during late summer and early autumn. Consequently, dry episodes were searched from the season between June and November.

Table 11: List of the climate models analysed: the acronym and country of origin of the model

	Model	Country
1.	MIROC6	Japan
2.	TaiESM1	China (Taipei)
3.	BCC-CSM2-MR	China (Peoples)
4.	NorESM2-MM	Norway
5.	HadGEM3-GC31-LL	Britain
6.	UKESM1-0-LL	Britain
7.	MPI-ESM1-2-HR	Germany
8.	MPI-ESM1-2-LR	Germany
9.	CNRM-CM6-1	France
10.	CNRM-ESM2-1	France
11.	CMCC-CM2-SR5	Italy
12.	CanESM5	Canada
13.	ACCESS-CM2	Australia
14.	ACCESS-ESM1-5	Australia

Compared to recently published studies on the occurrence of deep-soil drought in France in the past and future (Barthelemy et al., 2024, 2025), the spatial resolution of our analysis is much coarser. Thus, the objective is to gain an overall picture of the occurrence of soil drought across the entire European continent rather than discerning fine-scale details. To prepare future projections, Barthelemy et al. (2025) used fine-grid EURO-CORDEX (Jacob et al., 2014) regional model simulations. However, these model runs do not adequately consider the anticipated decrease in atmospheric aerosol load. This means that the future climate is likely to warm too slowly and be excessively humid (Boé et al., 2020).

Such a systematic distortion does not occur in the global CMIP6 model ensemble. In addition, using CMIP6 models involves the advantage that the number of independent model runs is larger than in the EURO-CORDEX ensemble.

We are preparing a scientific research article that will explain the analysis methods in more detail than the present report. That paper will also provide many additional findings that could not be included here.

## Appendix 8: Assessment of Technical Readiness Level (TRL) of CSSBDA

PIISA Task 3.2.2 was tasked to develop ‘a guide to homeowners on financial risk assessments regarding case shrinkage-swelling clay soils.’ During the first development phase, this was defined an online web tool designed to educate homeowners about their financial risks associated with inadequate insurance cover for property damage caused by CSS events. The methodology was based upon open access data sets that cover a variety of domains. To more accurately describe usage of the web tool, it was named Clay Shrink Swell Building Damage Assessor (CSSBDA).<sup>21</sup>

At the beginning of the project, there were web tools available for homeowners to qualitatively assess risks to their properties. However, these were not specifically designed for homeowner users, did not include CSS damage risk or a financial risk estimate, and did not have an insurance focus. This situation corresponds to TRL 2-3.

A test version of CCSBDA was built and piloted in the City of Lyon, France. Deliverable 3.6: Lessons learned from testing usage in Lyon, France analyses lessons learnt from pilot testing in the City of Lyon during the period from March to August 2025 which were then integrated into our planning and work activities for replicating the CSSBDA at French national level.

The CSSBDA is primarily intended to be used by homeowners throughout France although other stakeholders can also use the tool. It is technically functioning, has been tested in real life and found to be functional by users. Subject to continued maintenance and updates, the CSSBDA can continue to operate in France. In addition, research on the CSS risk level and insurance framework in five other Member States suggests that developing an equivalent tool in these countries could be explored. The CCSBDA developers assess that the tool has reached TRL 7.

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<sup>21</sup> Clay shrink-swell building damage assessor (CSSBDA) is the new name for what is referred to as the climate adaptation dashboard in the Grant Agreement (Task 3.2.2).

## Appendix 9: Assessment of Technical Readiness Level (TRL) of green roof insurances

PIISA Task 3.2.1 focuses on the evaluation of green roof insurances barriers and enablers for the European insurance industry to provide urban climate risk reduction. Unlike technology-oriented pilots, this pilot does not aim to develop a physical or digital technology. Instead, it develops and validates an analytical and research-based approach (economic valuation, behavioural studies, and stakeholder interviews) with the objective of ultimately tending towards the formulation of European business models for green roofs. Given this scope, the TRL assessment refers to the maturity of the conceptual solution and business model framework, rather than to a technological artefact.

At the start of the project, insurers' engagement with green roofs and NBS was largely exploratory and fragmented. While isolated initiatives existed (most notably the Interpolis green roof initiative) there was no structured framework for evaluating the economic value of green roofs, understanding behavioural drivers of adoption, or translating these insights into scalable insurance-related business models. Existing practices were characterised by limited data, lack of standardised valuation methods, and uncertainty about insurers' roles beyond traditional risk transfer. This corresponds to TRL 2–3, where the concept of insurance-supported NBS was formulated but not yet empirically validated or systematised.

During PIISA, the pilot progressed across multiple European regions. In the Netherlands (Loop 1), the pilot analysed an existing insurer-led green roof initiative, producing full societal cost–benefit analyses, willingness-to-pay estimates, and empirical evidence on the effectiveness of insurance incentives and informational nudges. These results were co-developed and discussed with insurers, municipalities, water authorities, and real-estate stakeholders, thereby grounding the framework in a relevant operational environment.

In Loops 2 and 3, the pilot further tested the transferability and robustness of the framework through interviews, workshops, and comparative analysis in Boreal and Mediterranean regions. While no new insurance products were launched within the project timeframe, the framework was applied to diverse climatic, institutional, and market contexts, allowing barriers, enablers, and region-specific adaptations to be identified. This multi-context validation goes beyond conceptual development and provides evidence of applicability in real-world settings.

The final output of the pilot consists of validated business model concepts, supported by empirical economic evidence, behavioural insights, and stakeholder feedback, which insurers can use as a basis for product development, incentive design, and strategic decision-making. Although full operational deployment and commercial uptake fall outside the scope of PIISA, the pilot demonstrates that the proposed approaches are feasible, credible, and relevant for real insurance markets.

Based on the above, the Green Roof Insurance Business Model Pilot is assessed as having progressed from TRL 2–3 at the start of the project to TRL 5-6 by the end of PIISA.

TRL 2–3 (start of project): Conceptual formulation of insurance-supported green roofs and NBS, with limited empirical validation and fragmented practice.

TRL 6 (end of project): Business model framework and analytical approach demonstrated and validated in relevant operational environments through real insurer cases, economic experiments, and stakeholder engagement across multiple European regions.

Reaching higher TRL levels (7–9) would require insurers to implement, pilot, and mainstream specific green roof insurance products or incentive schemes at scale. The PIISA pilot provides the necessary analytical foundation and decision-support framework to enable such future implementation in the future.