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THE MITIGATION OF SOCIO-NATURAL HAZARDS THROUGH SMART INSURANCE CONTRACTS

Doctoral Thesis

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MITIGATION OF SOCIO-NATURAL HAZARDS THROUGH SMART INSURANCE CONTRACTS

Doctoral Thesis

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ANNOTATION

Climate change has amplified the frequency and severity of natural calamities, encompassing a growing trend of extreme climatic events and facing substantial threats to global communities, ecosystems, and economies. Within this background, the intertwining of urbanization and climate change, impacting societal and economic dimensions, pose key challenges for European urban centers in the foreseeable future.

A spectrum of financial instruments has emerged to finance projects reducing hazardous impacts on communities, standing out as a powerful and versatile tool for managing the financial consequences of natural disasters. For instance, Catastrophe Bonds can be employed to transfer risks tied to potential disasters to financial markets, while Resilience Bonds have been introduced to support resilient infrastructure initiatives, reducing the susceptibility to large-scale risks in potential disasters.

Thus, insurance mechanisms assume a pivotal role in mitigating climate change-related disasters by providing financial support to implement risk mitigation strategies and becoming essential drivers for managing the risks associated with climate change.

This Doctoral Thesis delves into insurance's multifaceted and multidisciplinary role in protecting individuals, communities, and societies against the financial burdens of socio-natural disasters. The research seeks to provide a comprehensive understanding of the dynamic mechanisms through which insurance functions as a risk transfer and risk reduction instrument. It also examines its potential for influencing disaster preparedness, resilience, and urban-societal adaptation. By combining empirical evidence, theoretical insights, and case studies, this research investigates the evolving role of disaster insurance, including the challenges and opportunities it presents in the face of an increasingly unpredictable climate.

More specifically, this thesis aims to contribute to clarifying the proactive role of insurance in disaster risk management to provide policymakers, insurer companies, and researchers with valuable insights into optimizing insurance frameworks for a more resilient and sustainable future. More in detail, a final System Dynamics model is created to assess the feedback effects of floods on urban areas in the Latvian context by implementing a novel Bayesian adaptive insurance scheme mechanism. This model integrates an innovative and proactive role for the insurance sector, involving the insurance company directly in co-financing risk reduction and mitigation investments. The model assesses the impacts of natural hazards through probabilistic simulations, utilizing the probability-impact curve for socio-natural hazards to explore the multidimensionality, dynamics, short- and long-term perspectives, and different likelihoods of flood occurrence, not captured yet in one single assessment tool. The validation of the research approach in case studies allows for an understanding of the limitations and strengths of the developed tool.

The thesis introduction outlines the practical significance of the subject toward the specific study's objectives, tasks, and hypotheses. The first chapter conducts a literature analysis, examining key aspects related to the definition of socio-natural hazards, urban and infrastructural resilience, and the evolving role of insurance companies in socio-natural risk reduction. It emphasizes novel tools such as Smart Contracting for implementing Blockchain Technology and underscores the key role of this technology in insurance mechanisms for cultural heritage. This initial section explains the research needs in connection with the Doctoral Thesis.

The second chapter discusses the research methods employed, while chapter three details the results obtained from studies aligned with the proposed research method. The results chapter provides the main findings from each part of the methodological approach. It emphasizes a novel mechanism based on a Bayesian adaptive insurance scheme addressing flooding risk directed towards public administration. This mechanism incorporates Smart Contracts and is further applied in developing a dynamic urban assessment tool for socio-natural hazards, with a specific focus on floods in the Latvian context. The thesis concludes with recommendations and conclusions to promote a more proactive role of the insurance sector towards disaster risk reduction strategies and mechanisms.

ANOTĀCIJA

Klimata pārmaiņas ir pastiprinājušas dabas katastrofu biežumu un smagumu, tajā skaitā pieaugošu ekstremālo laikapstākļu skaitu, kas rada nozīmīgus draudus sabiedrībai, ekosistēmām un ekonomikai visā pasaulē. Šajā kontekstā pilsētu attīstības un klimata pārmaiņu savijums, rada nopietnus izaicinājumus Eiropas pilsētām tuvākajā nākotnē.

Ir parādījies finanšu instrumentu klāsts, lai finansētu projektus, kas samazina bīstamas ietekmes uz kopienām, izceļoties kā spēcīgs un universāls rīks dabas katastrofu seku pārvaldīšanai. Piemēram, katastrofu obligācijas var izmantot, lai pārnestu ar potenciālām katastrofām saistītos riskus finanšu tirgos. Noturības obligācijas ir ieviestas, lai atbalstītu izturīgu infrastruktūras iniciatīvas, samazinot neaizsargātību pret liela mēroga katastrofu riskiem. Šādi apdrošināšanas mehānismi ieņem izšķirošu lomu klimata pārmaiņu izraisīto katastrofu mazināšanā, nodrošinot finansiālu atbalstu riska mazināšanas stratēģiju īstenošanai un kļūstot par būtiskiem vadītājiem klimata pārmaiņu radīto risku pārvaldīšanā.

Šajā disertācijā ir veikti pētījumi par apdrošināšanas daudzpusīgo lomu indivīdu, kopienu un sabiedrības aizsardzībā pret dabas katastrofu radītājām finansiālajiem zaudējumiem. Pētījums cenšas sniegt visaptverošu izpratni par pieejamiem apdrošināšanas mehānismiem, kas darbojas kā riska pārneses un riska samazināšanas instrumenti. Apvienojot empīriskus pierādījumus, teorētiskās atziņas un gadījumu pētījumus, darbā tiek pētīta apdrošināšanas mehānismu lietošana pilsētu noturības un pielāgošanās klimata pārmaiņām kontekstā.

Disertācija sniedz ieguldījumu apdrošināšanas aktīvās lomas skaidrošanā katastrofu riska pārvaldībā, lai nodrošinātu politikas veidotājiem, apdrošināšanas kompānijām un pētniekiem vērtīgu ieskatu apdrošināšanas sistēmas optimizēšanā klimata noturīgākai un ilgtspējīgākai nākotnei. Pētījumu rezultātā īstenojot inovatīvu adaptīvo apdrošināšanas shēmu mehānismu, kas balstīts Beiesa uz pieeju, tiek izveidots Sistēmu Dinamikas modelis, lai novērtētu plūdu radītās sekas uz pilsētu Latvijas kontekstā. Šis modelis integrē apdrošināšanas sektora inovatīvu un aktīvu lomu, kurā apdrošināšanas kompāniju tieši iesaistās riska samazināšanas investīciju līdzfinansēšanā. Ar izveidotā modeļa palīdzību tiek novērtēta dabas katastrofu radītā ietekme, izmantojot varbūtības-ietekmes līkni plūdu radītajām ietekmēm. Modelis tiek lietots, lai izpētītu piedāvātā inovatīvā apdrošināšanas mehānisma dinamiku, īstermiņa un ilgtermiņa perspektīvas attiecībā uz dažādām plūdu riska varbūtībām. Visi minētie aspekti līdz šim vēl nav ietverti vienā novērtējuma rīkā apdrošināšanas nozarei. Izstrādātās pētījuma pieejas validācija gadījuma pētījumos ļauj saprast rīka ierobežojumus un stiprās puses.

Disertācijas ievadā ir aprakstīta temata praktiskā nozīme attiecībā uz konkrēta pētījuma mērķiem, uzdevumiem un hipotēzēm. Pirmajā nodaļā tiek veikta literatūras analīze, izmeklējot galvenos aspektus, kas saistīti ar dabas radīto apdraudējumu definīciju, pilsētu un infrastruktūras noturību, un apdrošināšanas kompāniju lomu dabas katastrofu risku samazināšanā. Tajā tiek uzsvērti jauni rīki, piemēram, viedie līgumi, kas tiek ieviesti bloku ķēdes tehnoloģiju, un uzsvērta šīs tehnoloģijas galvenā loma apdrošināšanas mehānismos infrastruktūrai, kas atbilst kultūras mantojuma definīcijai.

Otrajā nodaļā tiek apspriestas izmantotās pētījumu metodes, bet trešajā nodaļā ir izklāstīti rezultāti, kas iegūti no pētījumiem atbilstoši izvēlētajām pētījuma metodēm. Rezultātu nodaļa sniedz informāciju secinājumiem un rekomendācijām. Disertācijā tiek īpaši uzsvērts jauns apdrošināšanas mehānisms, kas balstīts uz Beiesa adaptīvo metodi un tēmē atrisināt ar plūdiem saistītus riskus un publiskajā pārvaldē. Šis mehānisms integrē viedos līgumus un tiek pārbaudīts gadījuma izpētē ar speciāli izstrādātu dinamisku novērtējumu rīku Latvijas kontekstā. Pētījumā sasniegtās atziņas un rekomendācijas var tikt izmantotas, lai veicinātu apdrošināšanas nozares aktīvāku lomu katastrofu riska samazināšanas stratēģiju un mehānismu ieviešanā.

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Introduction

Natural disasters, including hurricanes, earthquakes, floods, wildfires, and tornadoes, heavily hit human lives and economies, causing extensive damage to infrastructure, homes, and businesses. Socio-natural hazards, including pandemics, are amplifying this trend and continue to increase in frequency and intensity due to climate change and urbanization. These aspects address the importance of exploring effective strategies for mitigating their impact [1].

In fact, if not well-faced, these socio-natural hazards can escalate into catastrophic events, making communities even more exposed to severe impacts of such occurrences in terms of physical damage to material or immaterial assets and financial or life losses [2]. Specifically, during the last 15 years, there has been a recorded increase in disasters at a rate of 2% [3]. This increase is reflected in economically relevant losses [4], gaining the attention of the scientific and professional communities to find novel and effective insurance methods as resilient management tools for risk reduction.

In its 2021 report [2], Swiss Re assessed more than 50 severe flood events globally, resulting in nearly 26,000 lives lost at the EU level. Overall, the world incurred economic losses totaling $80 billion, with approximately 50% covered by insurance payments [5].

In July 2021, a large area involving the eastern part of the Czech Republic, Germany, and Benelux countries faced unprecedented rainfall, resulting in the loss of 41 and 200 lives and several thousands of devasted homes and people [6], while the estimated insured damages exceeded of the substantial amount of € 2 billion [7].

Always in 2021, the worldwide value of insured damages from natural catastrophes reached about € 100 billion. This ranked it as the fourth most expensive year since 1970, contributing to the average annual increase of 5 to 6 percent in losses related to natural disasters over the last few decades [8].

This general trend has been going on for the last 40 years, however, it is also expected that losses will be more severe by climate change within the next years as global warming affects environmental-related disasters due to global temperature has been steadily rising [9].

Based on loss statistics and trends, insurance companies have long assumed that climate change is in progress. Additionally, the insurance coverage against natural hazards has adjusted benchmark figures, expecting the following changes [10]: *increased loss potentials*, in terms of estimating the worst-case annual loss like Possible Maximum Loss (PML); *shorter high-intensity recurrence periods*, raising questions about whether climate-driven loss events can still be considered accidental actuarial events; *increased prevention and adaptation strategies* from natural and socio-natural hazards aims to limit negative consequences, reducing losses significantly and promoting both individuals and organizations to invest in resilient practices and infrastructure. These aspects reflect the need for a proactive attitude from the insurance sector towards managing disaster risks.

This role is also acknowledged in the Sendai Framework for Disaster Risk Reduction [11], which recognizes insurance's crucial role in boosting resilience and lessening the impact of disasters on individuals, communities, and nations throughout the disaster management cycle. Through providing financial protection, insurance supports recovery efforts, aiding in rebuilding lives and infrastructure and serving as a potent incentive for risk reduction and adaptive measures. The Sendai Framework underscores the significance of insurance within a collaborative effort among governments, the private sector, and communities to develop comprehensive risk reduction strategies. This collaborative approach aims to implement tailored and robust insurance solutions, thereby reducing risk and disaster more effectively and enhancing resilience towards complex urban and landscape systems. On the other hand, if governments offer full compensation for damages, citizens are less incentivised to get insured, decreasing the overall demand for insurance coverage.

According to Paleari's study [12], there are several factors affecting the overall benefits and sustainability of insurance mechanisms when coping with natural disasters that are only in part directly insurance-related. The first one is related to the time reference. In fact, insurance works only in an *ex-post* situation in terms of compensation to minimize the effects of natural disasters. This perspective by Paleari [13] identifies an interesting dynamic affecting citizens' demand for insurance coverage: the lower the insurance penetration, the higher the pressure is on governments to finance the recovery of disaster losses.

The second one relies on the concept of disaster risk management [14] in connection with the prioritization of recovery [15] or risk reduction strategies [16]. In fact, prevention and mitigation are defined by insurance companies during risks and potential loss assessments, creating a cap for the level of insurability (or re-insurability) faced with insurance accessibility and affordability [17]. Several studies highlight this aspect regarding the moral hazard potentially undermining any economic benefit [18].

Given this background, it is evident that disaster risk reduction policies play a pivotal role in promoting social welfare, fostering economic growth, and safeguarding environmental well-being. Within these strategies, insurance becomes a crucial and flexible instrument for effectively mitigating the profound financial impact of socio-natural disasters. Their role in supporting community and urban resilience increased.

Thus, always aligned with Disaster Risk Reduction (DRR) strategies within the Sendai Framework priorities, recently, the use of an integrated approach involving the whole insurance industry, local and national governments together with the experiences offered by donors, NGOs, and academia has significantly developed [19], becoming a research key driver. Towards this multidisciplinary interest, exploring the dynamic nexus between socio-natural hazards, insurance, and technological innovation becomes fundamental, specifically leveraging Smart Insurance Contracts as an innovative instrument for mitigating the intricate socio-environmental impacts of disasters and their connection with rising IT technologies like blockchain.

Smart Insurance Contracts represent a paradigm shift in risk management, encompassing advanced technologies, real-time data analysis, and adaptive coverage options to move beyond the traditional insurance boundary. At the same time, blockchain-based tools provide the interface for real-time climate data collection and registered damages. On the one hand, this can automatically certify the acquired information within each step of the process, both in terms of the regulatory and financial framework and the implementation of risk mitigation infrastructures [20]. On the other hand, it can improve the robustness of calculating potential losses and risk premiums and streamline the bureaucratic process of insurance contracting and premium pay-off.

This thesis aims to analyze and explore the role of insurance in addressing socio-natural hazards by introducing a proactive approach towards the investments and support of Disaster Risk Reduction strategies, which not only transfer risk but actively reduce it. Moreover, it delves into the domain of behavioural economics, exploring the capacity of Smart Insurance Contracts to incentivize behavioural changes that foster disaster preparedness, promote risk mitigation, and enhance societal adaptation.

This doctoral thesis explores the theoretical foundations, empirical evidence, and practical applications of Smart Insurance Contracts in mitigating socio-natural hazards, focusing on flood risk. It addresses the research gap concerning the limited exploration of resilience financial tools within the insurance sector. The research finally aims to conduct an integrated analysis to assess the dynamics toward a more favourable and proactive role of the insurance system.

To address the issue of minimizing damage costs and safeguarding insured assets, still considered knowledge gaps in the existing literature, the thesis introduces a novel insurance method embedding the mechanism of a Smart Insurance Contract as a disaster risk reduction tool. The goal is to support urban policy planning by investigating the role of insurance mechanisms in protecting against climate change-related risks. The thesis finally underscores the importance of insurance in promoting resilience and sustainable development for financing Disaster Risk Reduction (DRR) measures.

Objectives and Tasks

The thesis aims to develop a quantitative assessment model that can support insurance companies and urban planners in building urban resilience against socio-natural hazards at a local level by implementing innovative insurance mechanisms. The main objectives for achieving the goal are:

- Examination of quantitative methodologies commonly utilized by insurance companies to evaluate risk premiums;
- Identification of the state-of-art of key concepts, models, and frameworks employed in evaluating risk within insurance policies and investigation of any recent developments, innovations, or emerging trends in the quantitative assessment of risk premiums within the insurance sector;
- Evaluate the potential gaps in technological advancements, data analytics, and risk premium evaluation;
- Developing a novel conceptual framework for a novel risk insurance mechanism, evaluating the insurance system as pivotal role towards disaster risk reduction and mitigation with insights on the use of Smart Contracting as an adaptive and resilient insurance scheme with an emphasis on floods;
- Include selected case studies that exemplify the application of the developed framework in determining risk premiums referring to socio-natural hazards;
- Integrating the main findings from the case studies into a model developed and applied in an urban Latvian context for assets and communities prone to flood by the development of a system dynamic model towards;
- Providing suggestions for further research on the topic and implementation of the developed tool.

Hypothesis

Considering the overall concern about climate change and the need to mitigate the risks of socio-natural hazards, new and more proactive insurance tools may play a key role. However, there is limited research on using and implementing resilience financial tools within the insurance sector. This constraint raises concerns because it could result in growing long-term damage costs as the threat of climate-related calamities increases. Thus, this research addresses the attention towards integrated and multidisciplinary research to evaluate the dynamics within an insurance sector's more favourable and proactive role.

To fill in this knowledge gap and assess the usefulness and efficiency of new insurance instruments embedded in a proactive role of the insurance sector as a driver for risk mitigation and prevention measures, the core question of the proposed case study is "*to what extent the applications* *of a novel insurance mechanism can be used for co-financing disaster resilience projects by mitigation and adaptation strategies enhancing community resilience against weather-related hazards*"?

The hypothesis of this Doctoral thesis to this question is that the integration of Smart Insurance Contracts, driven by advanced technologies, data analytics, and real-time risk assessment, can significantly enhance the resilience of communities and reduce the socio-economic impact of natural disasters and socio-natural hazards, leading to more sustainable and adaptive disaster risk management strategies. This hypothesis postulates that the dynamic and proactive nature of Smart Insurance Contracts when effectively implemented, improves financial risk transfer, drives behavioural change, promotes disaster preparedness, and enhances societal adaptation to mitigate such hazards' social and environmental consequences. The hypothesis to be examined relies on the postulate that a multidisciplinary approach, encompassing engineering perspective, legislative implementation, and insurance dynamics, can be beneficial in covering the limitations of traditional insurance methods in disaster risk reduction and natural hazard mitigation.

Scientific significance

As socio-natural hazards continuously threaten the resilience of communities and ecosystems globally, there is an urgent requirement for new perspectives, innovative solutions, and practical approaches to disaster risk reduction. This doctoral research stands as an interface and intersection of cutting-edge technologies, behavioural science, and environmental adaptation, providing a unique viewpoint on how Smart Insurance Contracts can drive transformation in disaster risk management.

Through a multidisciplinary lens centered on the key role played by insurance in DRR mechanisms, this research represents an improvement towards comprehending the opportunities and challenges that lie ahead in the challenge to make our societies more resilient, adaptive, and sustainable in the face of socio-natural hazards.

The scientific topicality of this research is underlined by the current state-of-art of the insurance sector related to climate-change-linked disasters threatening sustainable development worldwide. In fact, it is expected that adverse climate change effects will significantly increase the frequency, intensity, spatial extent, and duration of socio-natural hazards. Moreover, the insurance market has not yet found a valid approach to face the effects of climate change in combination with the increasing threats of natural hazards. This poses a high risk for disaster events, with a particular focus on mitigative tools.

This doctoral study's unique approach to tackling the complex and interconnected problems presented by socio-natural hazards is what makes it innovative from a scientific standpoint. This research contributes to the improvement of research in several innovative ways:

1. Application of Smart Contracting and IT solutions in the insurance sector to make disaster management more resilient, efficient, and effective;
2. The key role of proactive risk management within insurance frameworks is providing financial indemnity after a disaster by implementing Smart Insurance Contracts to actively reduce risks and vulnerabilities and the recovery time of a damaged asset;
3. Investigating how Smart Insurance Contracts can improve urban planning if exposed to risk, with an emphasis on flood, supporting disaster preparedness, and promoting risk-reduction actions.

The scientific novelty of this PhD research thus lies in its pioneering exploration of Smart Insurance Contracts as a novel approach to addressing the complex challenges of socio-natural hazards. By evaluating the impact of integrating advanced technologies, and behavioural incentives, within proactive risk management closely involving the insurance companies and comprehensive urban adaptation strategies, this research opens new ways for more effective, sustainable, and adaptive disaster risk mitigation.

Practical significance

The findings of the Doctoral Thesis are significant for urban planners and risk reduction managers, providing knowledge and evidence of how a proactive role of insurance can contribute to strengthening urban resilience aligned with the Sendai Action Plan 2015-2030 for DRR against socio-natural hazards. Moreover, it represents a potential new paradigm for the insurance industry.

The approaches and methods developed in the thesis have been defined on the gaps that urban contexts face when developing and implementing DRR action plans, which are addressed in the proposed research method.

As communities worldwide tackle increasing vulnerability to floods, the study examines the benefits and applications of employing innovative insurance solutions. By integrating advanced technologies and risk mitigation strategies, the research offers practical insights into how smart insurance contracts can play a pivotal role in enhancing resilience, reducing losses, and fostering sustainable and more resilient approaches to flood management.

The study's findings contribute to a better understanding of the effectiveness of leveraging smart insurance mechanisms for mitigating the impact of floods on communities and their socio-economic environments. The thesis describes the role of Smart Insurance Contracts supporting a dynamic and proactive insurance role, creating a better decision strategy for coping against socio-natural hazards, with an emphasis on floods.

The developed tool implemented in a System Dynamics model fills the existing and actual knowledge gaps identified in scientific literature by providing a novel approach for interviewing disaster risk reduction mechanisms and insurance dynamics against socio-natural hazards.

Insurance companies can use the developed model with national and local urban contexts for resilience strategies against natural hazards and to develop tailored business models.

The contractual and recursive tool structure includes social, economic, environmental, and infrastructural aspects of the insurance system and disaster risk reduction urban resilience assessment. Thus, applying the developed tool also supports the link between the disaster risk reduction field and the policy planning of other sectors like urban planning, improving public investment in risk reduction measures, and providing relief for the immovable assets sector.

This research incorporates case studies and practical applications of Smart Insurance Contracts, offering empirical evidence and practical insights that can inform policy and industry decisions. It bridges the gap between theory and practice, making the findings immediately relevant to stakeholders.

The recommendations and frameworks developed in the study can also be eventually integrated into existing urban planning at the EU, national, and regional levels. The proposed model provides a useful decision support tool for disaster management, moving toward a different proactive role for insurance companies towards a more resilient, sustainable, and safe future.

Research framework

This doctoral study proposes a final System Dynamics model based on a novel Bayesian adaptive insurance scheme. This mechanism incorporates Smart Contracts and is further applied in developing a specific dynamic urban assessment for socio-natural hazards, with a specific focus on floods in the Latvian context.

This model is designed to assess the potential of insurance playing a proactive role in disaster risk reduction within socio-natural hazards (refer to Figure 1), comparing it to conventional insurance mechanisms. Various methods for calculating insurance premiums for assets exposed to socio-natural hazards are examined to achieve this goal. These methods are further integrated into developing a new conceptual framework, shaping a novel definition and implementation of risk insurance. This process is elucidated in Figure 1, within the research steps 1 to 3.

The doctoral thesis uses a System Dynamics modelling approach to assess the potential advantages of a novel insurance mechanism based on Smart Contracting for urban assets and communities exposed to socio-natural risks. This approach addresses the underlying risks of disasters, in contrast to a traditional disaster insurance strategy that primarily focuses on providing financial security for asset recovery. The thesis, developed and validated through ten scientific publications, explores various aspects of engineering, legal considerations, and quantitative theoretical and practical systems. It introduces an innovative tool for implementing socio-natural risk mitigation strategies, emphasizing the proactive role that insurance can play.

The overview of the thesis is presented in Figure 1, outlining four steps and their corresponding predefined objectives. Figure 1 illustrates the four primary interrelated studies and their detailed results, which are presented in the respective sections of the thesis.

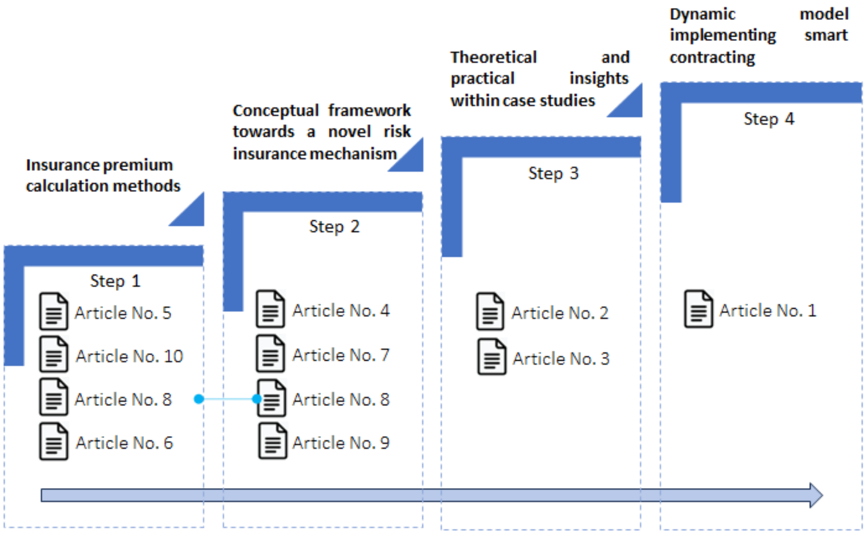

Figure 1. The research framework of the Doctoral thesis.

Based on ten peer-reviewed research articles (Articles from No. 1 to No. 10 in the Approbation section) presented at international scientific conferences and published in international scientific journals, the research framework has been used to address the specific research objectives and questions. These articles detail individual case studies employing different methodologies integrated into a dynamic urban resilience assessment tool for natural hazards.

The thesis comprises an introduction and four chapters: a literature review, research methodology, results and discussion, and final conclusions. The introduction outlines the aim of the doctoral thesis, the scientific and practical significance of the developed tool, and the scientific articles published on the thesis topic. The approbated results are based on the list of publications presented at international scientific conferences (see the Approbation section).

Chapter 1 presents a literature review analyzing how the insurance sector deals with socio-natural hazards. This section explores the current relevance of research field-specific terminology, with a focus on trends in increasing the frequency of disasters linked to climate change. It defines types of socio-natural hazards, examines insurance's role in changing exposures to socio-natural disasters, and discusses the roles of smart contracting and blockchain technology as resilience-enhancing strategies within the insurance sector. Traditional disaster risk reduction assessment within the insurance sector is also covered.

Chapter 2 details each step of the methodology of the doctoral thesis, leading to the scientific articles that validate the research objectives. Chapter 3 focuses on the results achieved, particularly emphasizing the development and application of a dynamic evaluation of an innovative insurance mechanism in response to a specific urban resilience assessment tool for natural hazards.

The final chapter provides overall conclusions and recommendations for applying the tool in policy planning.

Approbation

The results of the author's research have been presented and discussed in several scientific conferences and published in 10 peer-reviewed scientific journals.

1. M. Feofilovs, **A. J. Pagano**, E. Vannucci, M. Spiotta, and F. Romagnoli. Climate change-related disaster risk mitigation through innovative insurance mechanism: a System Dynamics model application for a case study in Latvia International. *Risks*, 2024 (in review).
2. **A. J. Pagano**, F. Romagnoli, and E. Vannucci. Non-incomes risk mitigation mechanisms for cultural heritage: role of insurances facing Covid-179. *Environ. Clim. Technol.*, 2022, Vol. 26, no. 1, pp. 871-882.
3. **A. J. Pagano**, F. Romagnoli, and E. Vannucci. COVID-19 Effects on Cultural Heritage: The Case of Villa Adriana and Villa D'Este. *Environ. Clim. Technol.*, 2021, Vol. 25, no. 1, pp. 1241-1252.
4. **A. J. Pagano**, F. Romagnoli, and E. Vannucci. Climate change management: a resilience strategy for flood risk using Blockchain tools. *Decis. Econ. Financ.*, 2021, Vol. 44, pp. 177-190.
5. **A. J. Pagano**, F. Romagnoli, and E. Vannucci. Quantitative and Financial Aspects of Resilience Bonds in the Context of Recursive Insurance Contracts. A Cost Benefit Analysis. *Environ. Clim. Technol.*, 2020, Vol. 24, no. 3, pp. 387-402.
6. **A. J. Pagano**, F. Romagnoli, and E. Vannucci. Insurance against Natural Hazards: Critical Elements on the Risk Premium Evaluation in the Italian Context. *Environ. Clim. Technol.*, 2020, Vol. 24, no. 3, pp. 373-386.
7. **A. J. Pagano**, E. Vannucci, and F. Romagnoli. Flood risk: financing for resilience using insurance adaptive schemes. *International Journal of Plant Chemistry, Soil Science and Plant Nutrition of the University of Pisa, The Effects of Climate Change Agrochimica - Special Issue*, 2019, pp. 305-322.

8. A. Bellieri dei Belliera, M. Galeotti, **A. J. Pagano**, G. Rabitti, F. Romagnoli, and E. Vannucci. Flood risk insurance: the Blockchain approach to a Bayesian adaptive design of the contract. In *Afir ERM*, 2019, pp. 1-19.
9. **A. J. Pagano**, F. Romagnoli, M. Spiotta, and E. Vannucci. Implementation of Blockchain Technology in Insurance Contracts against Natural Hazards: A Methodological Multi-Disciplinary Approach. *Environ. Clim. Technol.*, 2019, Vol. 23, no. 3, pp. 211-229.
10. **A. J. Pagano**, M. Feofilovs, and F. Romagnoli. The relationship between insurance companies and natural disaster risk reduction: overview of the key characteristics and mechanisms dealing with climate change. *Energy Procedia*, 2018, Vol. 147, pp. 566-572.

Other scientific publications

1. M. Feofilovs, A. Gravelsins, **A. J. Pagano**, and F. Romagnoli. Increasing resilience of the natural gas system with implementation of renewable methane in the context of Latvia: A system dynamics model. *Energy Procedia*, 2019, Vol. 158, pp. 3944-3950.

Reports at scientific conferences

1. A. J. Pagano, F. Romagnoli, and E. Vannucci. Non-incomes risk mitigation mechanisms for cultural heritage: role of insurances facing Covid-19. International scientific conference of Environmental and Climate Technologies, CONECT 2021. Riga, Latvia, May 11-13, 2022.
2. A. J. Pagano, F. Romagnoli, and E. Vannucci. COVID-19 Effects on Cultural Heritage: The Case of Villa Adriana and Villa D'Este. International scientific conference of Environmental and Climate Technologies, CONECT 2021. Riga, Latvia, May 11-13, 2021
3. A. J. Pagano, F. Romagnoli, and E. Vannucci. Quantitative and Financial Aspects of Resilience Bonds in the Context of Recursive Insurance Contracts. A Cost Benefit Analysis. International scientific conference of Environmental and Climate Technologies, CONECT 2020. Riga, Latvia, May 13-15, 2020.
4. A. J. Pagano, E. Vannucci, and F. Romagnoli. Flood risk: financing for resilience using insurance adaptive schemes. Giornata di studio, Le attività dell'Università di Pisa sul tema degli effetti del cambiamento climatico. Pisa, Italy, December 6, 2019.
5. A. Bellieri dei Belliera, M. Galeotti, A. J. Pagano, G. Rabitti, F. Romagnoli, and E. Vannucci. Flood risk insurance: the Blockchain approach to a Bayesian adaptive design of the contract. AFIR-ERM Colloquium 2019, Innovating Actuarial Research on Financial Risk and ERM. Florence, Italy, May 21-24, 2019.
6. A. J. Pagano, F. Romagnoli, and E. Vannucci. Implementation of Blockchain Technology in Insurance Contracts against Natural Hazards: A Methodological Multi-Disciplinary Approach. International scientific conference of Environmental and Climate Technologies, CONECT 2019. Riga, Latvia, May 15-17, 2019.
7. A. J. Pagano, M. Feofilovs, A. Gravelsins, and F. Romagnoli. Increasing Resilience of the Natural Gas System with Implementation of Renewable Methane in the Context of Latvia: A System Dynamics Model. 10th International Conference on Applied Energy "ICAE2018". Hong Kong, China, August 22-25, 2018.
8. A. J. Pagano and O. Tumule. Comparative bankruptcy procedural law aspects of cross-border and domestic avoidance action. XIX International Scientific Conference: Latvia 100: Expectations, Achievements and Challenges. Riga, Latvia, April 19, 2018.
9. A. J. Pagano, M. Feofilovs, and F. Romagnoli. The relationship between insurance companies and natural disaster risk reduction: overview of the key characteristics and mechanisms dealing with

climate change. International scientific conference of Environmental and Climate Technologies, CONECT 2018. Riga, Latvia, May 16-18, 2018.
10. M. Feofilovs, A. J. Pagano, and F. Romagnoli. Market development and support schemes for biomethane: SWOT analysis in context of Latvia. International scientific conference of Environmental and Climate Technologies, CONECT 2018. Riga, Latvia, May 16-18, 2018.

1. LITERATURE REVIEW

1.1. Socio-Natural hazards

Effects of climate change on natural hazards

Climate change is currently catalyzing attention in the legal discourse surrounding environmental protection. This issue is timely and necessitates various appropriate actions. Furthermore, this phenomenon is characterized by its escalating pressure and its consequences on both the landscape and human communities. These consequences are typically classified as natural disasters or catastrophes [21]. A natural catastrophe is defined as an event caused by a (natural) agent of exceptional intensity and unpredictable character based on the standard precautionary measures adopted by the involved communities. Noteworthy examples include floods, storms, earthquakes, cyclones, tsunamis, droughts, forest fires, heatwaves, ice and frost waves, and hail.

Available statistics underscore the impacts of natural disasters and the challenges communities have grappled with during the last decades. According to the Emergency Events Database (EM-DAT), there has been a noticeable increase in the reported number of disaster events worldwide over the last three decades, specifically from 1990 to 2020. The majority of the reported and analyzed hazards fall under the categories of hydrological and meteorological disasters [22] (see Figure 1.1).

Figure 1.1. Trend of disaster events by disaster type during the period 1990-2019 [22].

The reported number of hazards started to increase swiftly around the 1960s. As mentioned by several authors [23], more accurate reporting leads the scientific community to account for a higher number of events and losses. Increasing communication and cooperation among several countries can be one of the possible reasons for such a trend in the reported number of disasters.

Table 1.1.

Total number of disasters, by type during the period 1990-2019 [24]

Disaster type	**Number of disasters (1990-2019)**	**Percentage (%)**
Flood	4119	41.5%
Storm	2942	29.6%
Earthquake	818	8.2%
Landslide	551	5.6%
Extreme temperature	524	5.3%
Drought	475	4.8%
Wildfire	341	3.4%
Volcanic activity	154	1.6%
Total	**9924**	**100%**

The aforementioned statistics clearly illustrate how climate change amplifies the likelihood of catastrophic rainfall-related disasters, especially the global rise in temperatures. The risk of droughts increases due to the escalating global temperatures, which also contribute to heightened storm intensity and increased precipitation.

Changes in the intensity and frequency of droughts, storms, floods, extremely high temperatures, and wildfires serve as the most conspicuous indicators of these trends. Natural resources such as land and water will be particularly susceptible to future instances of extreme and regular rainfall events and calamities caused by climate change. Since 1990, flooding has emerged as the most frequent and disastrous natural disaster. Between 1990 and 2019, a total of 924 natural disasters occurred, with 42% of them being floods.

During this period, thirty major natural catastrophes were attributed to storms, including cyclones, hurricanes, tornadoes, blizzards, and dust storms. Storms and floods combined account for 71 disasters that have occurred since 1990 [25] (see Figures 1.2 and 1.3).

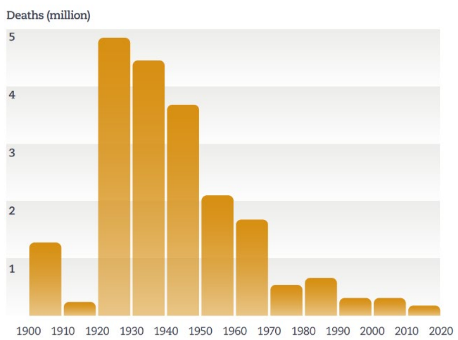

Figure 1.2. Total deaths per decade (1900-2020) [26].

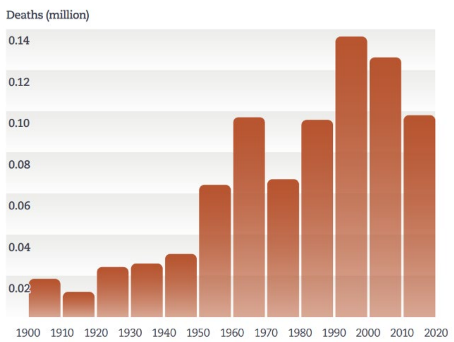

Figure 1.3. Total deaths per decade (1900-2020) – excluding top-50 [26].

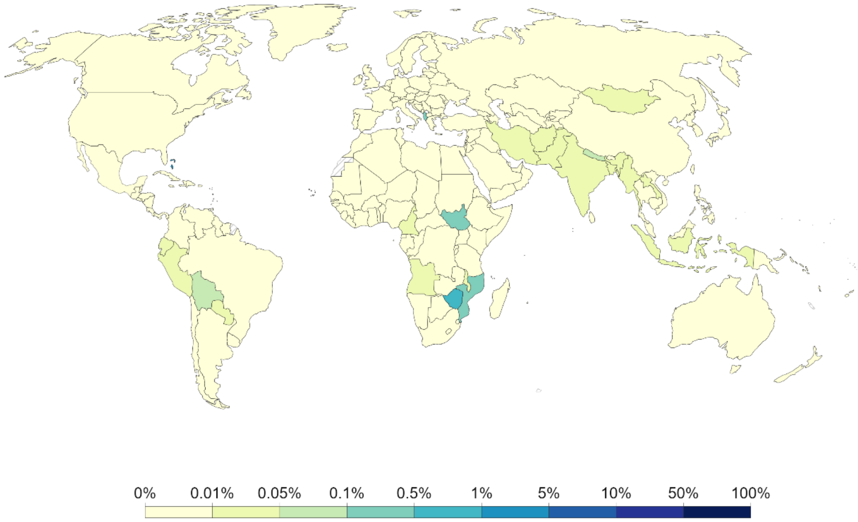

Figure 1.4. Deaths from natural disasters as a share of total deaths, 2019 [27].

Meanwhile, the available data from EM-DAT highlights a decrease in the number of deaths in natural disasters from 1990 to 2019 (Figures 1.4 and 1.5). While this may appear controversial given the increasing number of hazards, it can be readily explained by the so-called *learning effect*. This underscores the observation that communities, over time, have learned from past disaster events to better assess and cope with natural hazards. This learning is attributed to infrastructure development and more precise emergency response measures, achieved by immediately disseminating information and data via alarms, radio, and television [28].

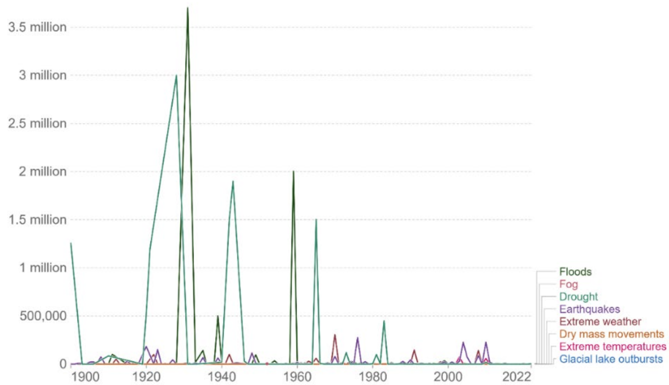

Figure 1.5. Deaths from natural disasters by type, World, 1900 to 2022 [29].

Though it is possible to observe a severe decrease in human life losses, on the other hand, there is still an increasing number of people injured and affected by natural disaster events during the last 20 years.

This aspect can be explained by the abovementioned tendency of population growth and economic and infrastructure development [38], which increases potential loss and disruption associated with the hazard even if the probability and intensity of hazard activity remain constant [30].

Figure 1.6. Annual average number of millions of people affected by disaster type [31].

Table 1.2.

Relationship between hazards/people/losses in the years 2019-2022 [31]

	2019	2020	2021	2022
Overall losses in US$ b (Munich Re)	166	210	280	270
Uninsured losses in US$ b (Munich Re)	109	128	160	150
Insured losses in US$ b (Munich Re)	57	82	120	120
Recorded events (CRED)	505	380	407	387
Deaths (CRED)	27,199	17,664	18,274	30,704
People affected in million (CRED)	109.2	97.6	103.5	185
People displaced by disasters in million (IDMC)	24.9	7	23.7	8.7
People in million living in acute food insecurity driven by weather extremes (FSIN)	33.8 25 countries	15.7 15 countries	23.5 8 countries	56.8 12 countries

Thousands of small-scale disasters occur globally due to factors such as flooding, landslides, fires, and storms. These incidents often go unreported in transnational databases. Nevertheless, their impact can be just as devastating as larger disasters, resulting in fatalities, injuries, and the loss of livelihoods. An analysis of reports from 104 nations revealed that between 2005 and 2017, fragile and medium-sized, localized, and ongoing disasters accounted for USD 68 billion in overall economic losses.

These losses represent a significant hardship as they tend to be borne by low-income households, vulnerable businesses, and local and national governments [32].

Moreover, losses from slow-onset threats, such as droughts, are not always accurately accounted for. Their consequences often accumulate gradually over an extended period, and their impacts are challenging to measure. When slow-onset disasters are included in the risk profile of the Asia-Pacific region, annualized economic losses increase more than fourfold to USD 675 billion, constituting approximately 2.4 percent of the region's GDP (compared to previous assessments) [33].

To establish the environmental context, a taxonomy of natural threats was developed based on existing literature, frameworks, and international resources [5] in the fields of disaster management, climate change adaptation [34], and heritage preservation [35]. The hazard inventory now encompasses specific risks and dangers that could potentially harm cultural heritage sites. Special attention was given to the suitability of the hazard inventory for historic conservation and the unique needs of the pilot sites.

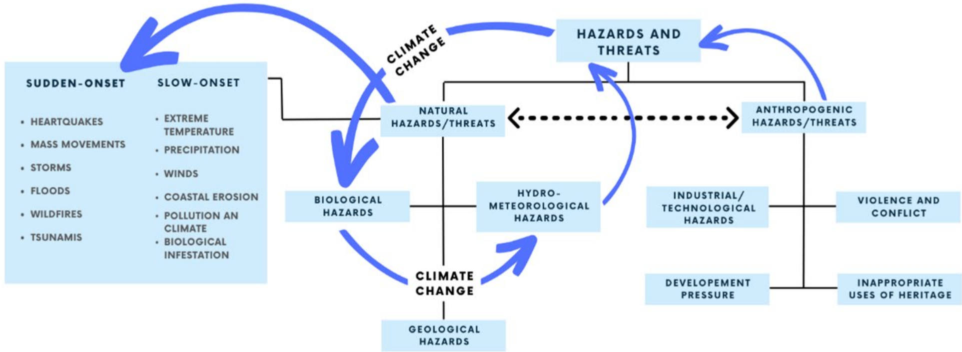

Figure 1.7. Classification of socio-natural hazards [36].

The three primary categories of natural threats and hazards are geological, hydrometeorological, and biological. Most of these dangers and threats can be categorized as "socio-natural hazards" because natural and human-made forces can cause them. For example, landslides, acid rain, and riverbed erosion may result from a combination of environmental factors (such as rainfall) and human activities (such as land-use change and pollution).

While anthropogenic hazards (e.g., technological hazards, social conflict, and development pressure) are acknowledged in the theoretical framework, they were excluded from the assessment procedure as they fell beyond the scope of the STORM project [36].

The hazards are further categorized based on the rate of onset to appropriately manage the immediate and long-term consequences on heritage monuments. Thus, the hazard assessment procedure incorporated sudden-onset hazards (e.g., earthquakes, storms, and floods) and slow-onset hazards (e.g., wetting–drying cycles and wind-driven rain). Future changes due to climate change, such as projected alterations in hydrometeorological hazards (e.g., precipitation intensity and heat waves), were also considered in the assessment procedure.

Europe's situation and future scenarios

Climate change increases the frequency, severity, and intensity of extreme weather events [37]. These hazards threaten the global economic landscape, impacting companies and households in diverse ways. In Europe, hydrological events have emerged as the most destructive extreme natural hazards thus far [4].

In 2021, Belgium and western Germany experienced severe flash floods, resulting in the tragic loss of over 196 lives [38]. The economic toll of hydrological events in Europe averaged around 3.5 billion USD per year over the period from 1980 to 2020 [49]. Projections suggest that annual economic flood losses in Europe may surge to 20–40 billion EUR by 2050 under high-end climate scenarios [50]. There's a tangible concern that by the end of the century, the number of Europeans exposed to floods could more than double, rising from approximately 220,000 in the reference period (1981–2020) to 455,000 [39].

Turning attention to developing countries, the majority of economic damage due to natural hazards appears concentrated in the agriculture sector [40] [41]. The estimated average annual economic loss per year attributed to climate-related hazards in developing countries over the 1980–2020 period is 24 billion USD [42]. Between 2005 and 2015, extreme hazards cost developing countries a staggering 96 billion USD in livestock and crop production losses, with floods, droughts, and other weather-related disasters contributing to 78% of these losses [41].

Forecasts suggest that the impacts of climate change could force an additional 32 to 132 million individuals into extreme poverty by the end of 2030 [43].

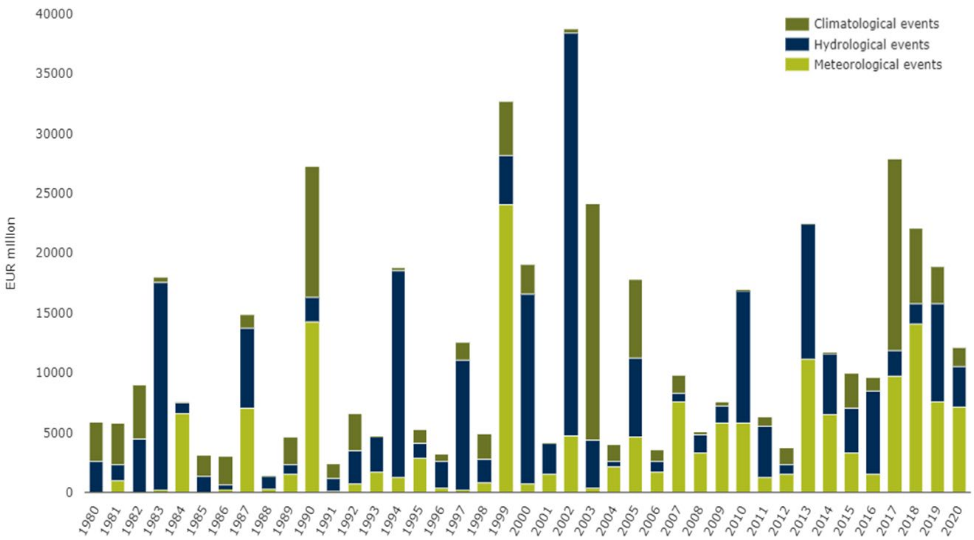

Figure 1.8. Annual economic damage caused by weather and climate-related extreme events in the EU Member States [44].

According to Figure 1.8, it is evident that climate-related threats to human health and potential economic losses encompass temperature extremes, excessive precipitation, and droughts. Monitoring the impact of such threats is crucial for guiding policy and ensuring that appropriate measures are taken to minimize harm.

In pursuit of its "smarter adaptation" goal, the EU adaptation strategy aims to enhance our understanding of adaptation by pushing the boundaries of current knowledge. The EU is a signatory to the UN Sendai Framework for Disaster Risk Reduction (SFDRR), which sets a target year of 2030 for reducing disaster-related losses and economic impacts [45].

Climate-related risks are estimated to have caused 487 billion euros in economic losses across the EU-27 Member States between 1980 and 2020. Natural disasters have become more frequent, and without mitigating and disaster risk reduction measures, they could lead to even more severe losses in the future. Analyzing trends in economic losses is challenging, partly due to the high variability in occurrence from year to year.

The EU adaptation plan aims to bolster the resilience of Member States, ensuring they are prepared to handle risks and adapt to the impacts of climate change. This proactive approach aims to prevent economic losses and other adverse effects [46].

The average annual (inflation-corrected) losses stood at approximately EUR 9.5 billion in 1981–1990, 11.0 billion in 1991–2000, 13.2 billion in 2001–2010, and 14.5 billion in 2011–2020.

However, due to the fact that a relatively small number (3%) of singular events accounted for a substantial portion (around 60%) of the economic losses, identifying clear trends is challenging [47].

Extreme weather events linked to climate change are projected to occur more frequently worldwide, as indicated by the Intergovernmental Panel on Climate Change [48]. This poses a potential impact on various industries, and systemic breakdowns could extend throughout Europe, leading to increased economic losses. Nevertheless, the future cost of climate-related risks hinges on several additional parameters, including population size, the value of exposed assets, and the frequency and severity of incidents.

A comprehensive, integrated approach is imperative to effectively respond to and manage these risks. A fundamental objective of the EU's updated adaptation plan, currently in development, is to enhance society's resilience to climate change by prioritizing prevention, preparation, response, and recovery [49].

1.2. Insurance against socio-natural hazards

The phenomenon involves the more frequent occurrence of specific geophysical and hydrometeorological hazards, such as landslides, flooding, land subsidence, and drought. These hazards result from interacting natural elements with overused or degraded environmental resources and land [50].

This description signifies situations where specific hazards are more likely to manifest due to human activities, contributing to the overall burden of disasters. Evidence suggests that responsible management of land and environmental resources can diminish and prevent these socio-natural hazards [12].

Weather insurance is recognized as one of the adaptation tools advocated by the policy community to assist businesses and households in adapting to a more volatile and harsh climate [51].

In weather insurance, a bonded payment value is utilized in place of the extreme, universally occurring value of an extreme weather event. This approach pools risks across geographies and time periods, aligning with the law of very large numbers. By consolidating the risks of numerous individuals and businesses, variations from the anticipated loss become less likely, effectively lowering overall risk. Furthermore, it redistributes risks from risk-averse clients to other risk-neutral insurance companies.

Weather insurance accelerates recovery and mitigates the adverse effects of extreme weather events on welfare [23]. Consequently, insurance emerges as a crucial option for addressing global "climate change" or "temperature change" impacts for both homes and businesses. While coverage for weather risks is not a new concept, the imperative for adaptation in the context of global climate change has brought it to the forefront for both experts and policymakers [52].

A recent World Bank and European Commission research evaluated Europe's financial preparation to respond to and recover from disasters [53]. It was shown that residential buildings account for more than half of all losses due to flood and seismic risk.

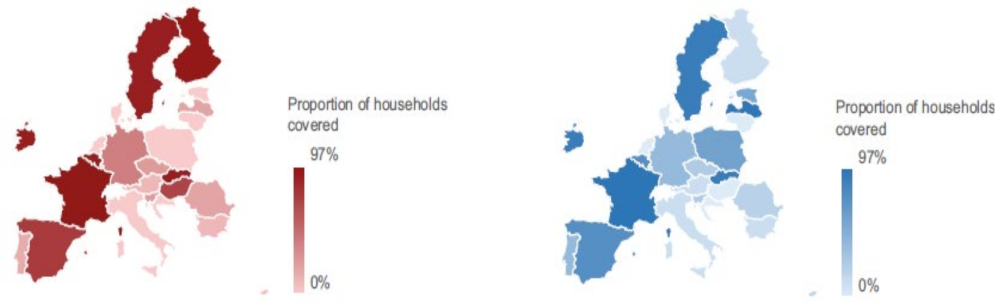

Figure 1.9. Proportion of households covered by catastrophe insurance against earthquakes (left) and floods (right) [54].

However, less than half of the EU member states' populations are protected by disaster insurance (see Figure 1.9). This indicates that there is a significant protection gap and that many people must recover with the help of the government [55].

Table 1.3

Indicators of earthquake and flood risks in EU countries (Austria, Belgium, Germany, Spain, France, Italy) [13]

Member State	**World Risk Index 2018 (EU-28 ranking)**	**Index of physical exposure**	**Total direct damage as % of annual average GDP, 1990-2017**
AT	2.92	Earthquake: 4.0 Flood: 5.5	Earthquake: - Flood: 1.31 %
BE	2.77	Earthquake: 2.7 Flood: 4.0	Earthquake: 0.02 % Flood: 0.06 %
DE	2.42	Earthquake: 2.7 Flood: 6.1	Earthquake: - Flood: 0.91 %
ES	2.80	Earthquake: 4.3 Flood: 5.4	Earthquake: 0.02 % Flood: 0.13 %
FR	2.34	Earthquake: 3.0 Flood: 6.4	Earthquake: - Flood: 0.42 %
IT	4.12	Earthquake: 6.1 Flood: 5.4	Earthquake: 1.62 % Flood: 1.19 %

Table 1.3, as reported by Paleari [5], is utilized for descriptive and comparative purposes in presenting information on insurance schemes. However, it's important to note that this table does not cover risk assessment activities or awareness-raising campaigns supported by insurance companies, which can significantly reduce risk.

The percentage of insurance premiums over a country's gross domestic product, known as the insurance penetration rate (GDP), is a key metric representing the portion of a nation's wealth covered by insurance. The more developed the insurance market, the higher the penetration rate. This rate is categorized into four bands: very low (0–10%), medium/low (11–50%), medium/high (51–89%), and very high (90–100%).

Various risk mitigation strategies are discussed, including deductibles and compensation limits (D&C), the collection of risk-based premiums reflecting hazard or vulnerability levels, and the exclusion of properties in high-risk areas. Additionally, the distinction between natural hazard insurance coverage in voluntary versus mandatory plans is highlighted, with the latter either mandating insurance against natural disaster losses or extending property insurance to cover catastrophe risks (compulsory offer or purchase).

"Push factors" influencing people to obtain insurance are discussed, encompassing both "insurance-related factors" and "external factors." Bundling, required in compulsory schemes, and add-on schemes, which lack bundled components, are explored. Flat premiums are described under "risk reduction methods," acting as incentives for those most at risk to purchase insurance.

The overview of national insurance programs is based on a comprehensive analysis of literature, including peer-reviewed papers, government and international institution reports, national legislation, desk research, and personal communications. While the information is as complete as possible, there are still knowledge gaps due to limited information on some insurance plans [56].

Despite the positive impacts of insurance, an oversized proportion of losses from extreme weather events remains uninsured, not only in the southern part of the world but also in developed economies. While 45% of losses from natural catastrophes were insured in high-income countries from 2008 to 2017, this figure was only 7% in low-income countries [2].

One reason for this disparity is that extreme weather events affect numerous individuals simultaneously, limiting risk pooling and necessitating higher premiums to cover the remaining risk [57].

Another contributing factor to low insurance penetration is the tendency of individuals to underestimate the likelihood of rare events like natural disasters, often relying on public post-disaster relief [58].

Consequently, with climate change increasing the frequency and intensity of extreme weather events, the need for insurance may rise, but providing insurance may become more challenging [18].

1.3. Risk perception

This section proposes a classification of insurance companies' adaptation measures to the impact of climate change.

Natural insurance uptake and demand perception of the economic agents towards saliency of natural hazard square measure analyzed, and the need to be compelled to interact with adaptation ways to mitigate damages is very important.

Some studies analyze the danger perception of economic agents associated with climate and alternative natural hazards [59] and state that socio-demographic factors play a big role in risk perception studies within the perception with socio-demographic factors like gender, age, and financial gain level [60].

Whilst Lujala et al. [61] checked out the affected space from a distance, they acknowledged that in juncture with perception distance, it is often classified into three sections that square measure spatial distance (physical), which affects perception, while temporal distance (refers to however before long folks think about the consequences of amendment global climate change temperature change) and social distance (refers to however folks believe climate change affects folks like them) have an effect on preference.

In keeping with Habiba et al. [62], in their analysis of the Bangladesh farming community, the study found that once viewing the mitigation programs in terms of their adoption and absorption by the community it is a two-step method.

Habiba et al. [62] state that the two-step method of adoption and mitigation effectiveness involves accepting that the climate is ever-changing, so adoption.

Petrolia, Landry, and Coble [72] state that once viewing the demand for insurance against natural hazards, the acceptance and understanding of the danger square measure is vital before the agents adopt that is insinuated within the two-step method.

Reynaud, Aubert, and Nguyen [63] state that the coping appraisal is very keen on the threat appraisal level of worry and danger, during which it should reach a specific threshold for it to begin.

The coping appraisal embraces many sides of perceptions, including the perceptions regarding one's protecting self-efficacy, response prices, and action efficaciousness.

In keeping with Reynaud, the study adds the threat experience appraisal and also the reliance on non-individual protection ways.

Carlton [64] checked out the USA and analyzed the consequences of extreme and severe drought on global climate change beliefs, risk perception, and adoption angles and observed that attitudes and beliefs didn't change. However, the danger perception did amendment with agents worrying regarding drought and pests over flooding, while Lujala et al. [65] found that gender, academic level, and political preferences do contribute to an individual's perception and angle toward natural hazard problems. Moreover, some of the results obtained by Lujala concur with the extra variable in PMT by Reynaud as they observed that personal experience of the events and their harm helps to vary individual perspectives and points of view, while Wachinger et al. [66] tried to elucidate the explanations and the reasons why there's a weak relationship amongst risk perception, angle and private action and observed that seem to be three reasons, such as experience and motivation, trust and responsibility and private ability, during which personal ability includes economic and private conditions.

Two of the most important scholars who have struggled and tried to draw up a possible abovementioned classification are definitely Dlugolecki [67] and Mills [68]. Dlucolecki has developed a classification divided into four categories: risk reduction, damage control, product price adaptation, and risk transfer [67]. Mills, on the other hand, has obtained greater feedback both from the doctrine and the insurance market. In particular, Mills proposes a classification divided into ten categories of adaptation measures according to economic, financial, technical, and policy factors [68]. The next six categories of the ten adaptation categories are those related to climate change. For the first group of categories, Mills [68] points out that insurance companies promote and encourage any activity to understand the climate change problem because data collection, catastrophe modeling, and risk analysis are necessary to evaluate climate change risks. In practice, in order to gain greater knowledge of the dynamics of climate change, insurance companies, in addition to the standard work referred to the civil code and the insurance code of any legal system, invest in their own research, creating research teams or assigning external research institutes for specific tasks. Mills also points out that insurance companies are "building awareness and participating in public policy" for the second category [68].

In order to stimulate the protection of private property against disaster, policyholders must be acquainted with and aware of climate change impacts, possibilities of long- term physical risk reduction, and related adaptation.

The third category group, "aligning terms and conditions with risk-reducing behavior", aims to make policyholders aware of the impact or, even better, to push them to consciously and actively reduce the risk associated with it through specific implementation measures.

The next category related to the adaptation measure refers to "new insurance products and services". Specifically, these new economic tools are necessarily and closely linked to already existing insurance products offered by the insurance companies.

1.4. Infrastructural and urban Resilience

The concept of resilience has changed over the past several decades and is frequently examined in conjunction with the idea of sustainability [69]. As a result of their close connection and frequent interchange, it is imperative to take these two ideas into account jointly [70].

A story that has inspired many particular themes and geographic situations, particularly in metropolitan areas, includes the idea of sustainability and, subsequently, resilience [71].

Resilience is increasingly being utilized to understand highly complex, dynamic social systems like urban regions [72]. It can offer insights into complicated issues concerning sustainability and vulnerability. Although the term "resilience" has been useful in many academic fields, many different definitions of it vary according to the subject matter [73].

Controversy surrounds the notion of resilience and, by implication, the meaning of urban resilience, and many publications have attempted to address this controversy [74] [75]. The definition of resilience sometimes uses unclear terms. It is challenging to operationalize or apply resilience to complex urban environments that are always changing due to the lack of a generally acknowledged concept [70].

Urban resilience is a term used to describe a multifaceted, dynamic process among stakeholders to reduce urban vulnerabilities and prepare and adapt the urban environment to absorb and recover from external and internal disruptions [76]. Urban resilience is portrayed as a dynamic and developing process that aids cities in achieving their objectives of being ready for quickly functioning interdependent and effective systems [77].

An urban area's social, institutional, economic, environmental, and infrastructure dynamics are defined as a multidimensional process [78]. These dynamics have an impact on how stakeholders, including managers in the public, private, and nonprofit sectors and organizations, policymakers, and researchers, respond to and get ready for the stresses and strains that urban areas must endure [79]. These limitless pressures and strains include environmental deterioration, civil instability, and economic crises. Some design elements of current insurance schemes and the level of government engagement are explained by political ideas and opinions on the responsibilities that private insurers and the public sector should play in compensating disaster losses. For instance, in nations with strong social cohesion, governments frequently accept high loss potential, moral hazard, and cross-subsidies between residents at high and low risk in exchange for affordable insurance [80].

The demand for insurance is influenced by prior disasters, which has occasionally led to the introduction of government-backed insurance programs or the development of alternative public safety measures to manage disaster risks [81].

1.5. Sendai framework for disaster risk reduction

The importance of a stronger understanding of disaster risk has been additionally remarked on by the Sendai Framework 2015–2030, which appointed risk information a basic role in supporting all the phases of the disaster cycle. The Sendai Framework was adopted in 2015, marking the end of more than 20 years of rising interest in disaster risk reduction within the framework of the United Nations. The General Assembly's resolution 44/236, which started the International Decade for Natural Disaster Reduction on January 1, 1990, was a significant turning point in this area.

The International Strategy for Disaster Reduction was adopted in 1999 by the General Assembly in response to progress made during the Decade addressed to lessen natural disaster-related casualties, poverty, property destruction, and social and economic disruption through coordinated international effort, particularly in developing nations.

The first step started with the progress gained through the General Assembly resolution 54/219 adopting the International Strategy for Disaster Reduction in 1999 [82], which was further included in the Hyogo Framework. The outcomes of the Hyogo Framework provided the background for the key actions and roadmaps within the Sendai Framework. Its goal is to lower disaster risk and losses on all fronts within the period of 2015–2030. It established four priorities and seven targets to address disaster risk reduction and provides explicit guidance on the role of governments and stakeholders, including the United Nations [83]. The Sendai Framework offers a systemic perspective on the underlying variables affecting risk management and the effects of catastrophes. The Yokohama Strategy for a Safer World and other earlier frameworks for reducing disaster risk established the paradigm for risk reduction [84]. The document clearly outlines the key steps to enhance risk information, emphasizing the importance of consolidating current information and considering all risk components (i.e., hazard, exposure, and vulnerabilities) and their potential interactions. It also emphasizes promoting the use and strengthening of baselines at relevant spatial scales and their periodic updating. Additionally, the document underscores the importance of effectively disseminating this knowledge to various stakeholders [85]. Moreover, the Sendai Framework underlines the importance of promoting comprehensive multi-risk analyses by taking into account climate change scenarios [86]. This shift was addressed and even reinforced in the Sendai Framework, which increased the prominence of elements like the inclusion of technological and biological hazards, the focus on risk management (in addition to risk reduction), governance, and a wider view of sectoral action, including the 38 references to health [45].

According to the European guidelines developed within the Sendai Framework for Disaster Risk Reduction, there are three fundamental pillars for an effective catastrophic risk reduction policy: scientific understanding of the phenomena, risk communication, and optimal management. With reference to the latter, the four phases of disaster risk management (DRM) are identified in risk mitigation and prevention to reduce exposure and vulnerability to them and prevent natural hazards from becoming natural disasters through structural reinforcements, effectiveness of technical construction standards, micro-zoning and territorial restrictions; b) preparation and planning for adverse events; c) effective response both immediately after the event and in the short-medium term; d) structural, economic and social recovery and recovery [11]. The role of the insurance sector in pivotal in all risk reduction policies but mostly addressed to find an effective response both in the immediate aftermath of an event and over the short to medium term, encompassing structural, economic, and social recovery. The transfer of risks, through appropriate insurance and transfer policies, is an open option for both the public operator and the private entity. As for both involved subjects, given the stringent budget constraints, it is necessary to carefully evaluate the trade-off between risk reduction and risk transfer, knowing that the first is the key factor for minimizing human losses and the second is crucial for ensuring a prompt restart of affected territories.

1.6. Insurance companies' different approaches to socio-natural disasters

The funding gap resulting from natural disasters could potentially be addressed through the utilization of insurance instruments. The significance of insurance in mitigating the adverse macroeconomic and welfare impacts of disasters has recently been underscored in studies conducted by the European Insurance and Occupational Pensions Authority (EIOPA) and the European Central Bank. These studies suggest that the economic downturn following a disaster could be mitigated if a substantial portion of the damages is covered by insurance. This mechanism is of utmost importance, considering an increase in the impact effect from socio-natural hazards predicted by the catastrophic risk models drafted by the World Bank [82] and the European Commission [87]. Such models predict that big earthquakes and floods might cause more than EUR 50 billion in damage in some nations. In every year, there is a 1% chance that this loss will occur.

The potential insurance operations related to a natural hazard exhibit significant variation based on the country where the insurance is headquartered and where the contract is established [5]. These differences are noteworthy, and in concluding this literature review, it appears essential to outline the most salient ones. One primary distinction involves the interplay between private insurance and public interventions, which can manifest across a spectrum ranging from exclusive reliance on the market to a complete public monopoly.

Meanwhile, interesting forms of cooperation between the public and private sectors through reinsurance [88] through public bodies or addressing the risk to the financial markets [89] can also be relevant [90].

A second difference relates to the type of risks covered, which can essentially provide for three different types of coverage: the mono-linear, meaning coverage of a single type of risk, such as hurricanes or earthquakes; the one protecting a list of specific events; the open one that covers any natural catastrophe [56].

The cost of covering risk is preeminent. The cost of the policies may vary depending on the amount of the capital insured, based on the type of risk, the lower or greater exposure of a specific territory to the risk considered, or the incentives that the public body makes available to the insurance companies [91]. It is also necessary to consider the damages covered; in fact, most of the systems cover only direct material damage, for example, some systems only consider buildings, and others include goods contained in homes).

However, there are cases in which coverage also extends to the loss of income due to the calamitous event [92]. Another difference concerns the limit of the insurance claim [93]. Despite the fact there are few systems that, thanks to the state guarantee, offer unlimited damage coverage, generally, a maximum limit is set for the compensation for each type of damage or for each type of event. In addition, there are almost always specific deductibles designed to discourage customers from claiming compensation for irrelevant or unproven demonstrable damages [94]. The bureaucratic part linked to issuing an official natural disaster declaration should not be minimized. Generally, this declaration is issued by an appointed specific public body and is necessary to open a claim.

The last characteristic of different insurance companies approach to natural hazards concerns the financial reserves of guarantee [95]: due to the need to maintain a considerable tied-up capital to guarantee interventions to natural disasters, some countries stimulate the accumulation of funds of guarantee through favorable fiscal arrangements, other countries, on the other hand, implement other measures, more inherent to the financial market such as those related to the contingent capital [96].

Table 1.4 provides a summary of the actual mechanisms connected to the insurance company strategy.

Table 1.4

Insurance Companies' approach and state of the art [52]

	Mechanism	Description	Advantages	Challenges
Alternative risk transfer tools/ insurance-linked securities (ILS)	*Natural Catastrophe Bonds*	Type of insurance in which securities are involved (derivative bonds) that transfer natural catastrophe (re)insurance risks to the capital market.	For investors: relatively high payback and low correlation involvement with other asset classes mean promise of diversification. For sponsors: CAT bonds allow access to quite a large pool of capital and guarantee long coverage periods. More convenient in these terms than conventional re-insurance.	• Diffusion and disclosure of bonds in relation to the population less accustomed to the financial and reinsurance world. • Reduce the total cost of the operation and simplify the legal and economic documentation.
Traditional insurance Weather	*Indemnity insurance: (a) Single Peril (b) Multiple Peril*	The type of insurance by which the claim is calculated on the basis of the degree of damage from the event immediately following the moment the event takes place.	The amount and emoluments payable by the insurance company are based on actual damage, and the project and the methods of distribution are established on a contractual basis.	• Particular attention is addressed to: moral hazard, adverse selection, and high cost for the conclusion of the operation.
Alternative risk transfer tools (ILS)	*Weather Derivatives*	Type of insurance in which intermediation takes place that provides options on weather indices (i.e., a rainfall index) for specific sectors.	It can indifferently be used on a sector or on a company basis (level) and allows access to the financial market by reducing the risk on the part of the insurance company, just like the CAT bonds tool, which is one of the cardinal principles of the so-called reinsurance.	• Disseminate a weather index accessible to the entire population to prevent the most vulnerable people from being excluded. • The costs and the diffusion due to its purely financial conception have always hindered the evolution of this tool.

Each of these insurance mechanisms offers unique benefits and faces specific challenges, and the choice among them depends on the nature of the risk, the preferences of the insured, and the prevailing market conditions.

Natural Catastrophe Bonds are financial instruments designed to provide funding in the aftermath of a predefined catastrophic event, such as hurricanes, earthquakes, or floods. Investors purchase these bonds, and if the specified disaster occurs, the principal may be used to cover the losses incurred by the issuer. The main advantages of this mechanism are that it allows insurers and reinsurers to transfer a portion of their risk to the capital markets and provides rapid access to funds for disaster response and recovery, meanwhile potentially attracting a diverse set of investors, including hedge funds and institutional investors. They can still be complex due to the need for clear trigger mechanisms and risk modeling, with the possibility that the bond payout does not perfectly align with the actual losses incurred [17].

Indemnity insurance is a traditional form of insurance where the policyholder is compensated for the actual financial losses incurred due to a covered event. It aims to restore the insured party to their financial position before the loss. The advantages rely on the customization of the policy to meet specific needs and cover a wide range of perils. It is thus to the actual losses suffered by the insured. Nevertheless, this mechanism still shows a risk that those most likely to face losses might be more inclined to purchase insurance, potentially leading to higher premiums. The indemnity model may involve a more extended claims settlement process [38].

The third type (i.e., weather derivatives) are financial instruments whose value is linked to weather conditions. These can be used to hedge against financial losses resulting from adverse weather, such as temperature extremes, precipitation levels, or other meteorological events. They made a more tailored risk management system, allowing businesses to hedge against weather-related risks that impact their operations. In this case, derivatives can be structured to cover specific weather parameters relevant to the insured party. The main challenges are the potential mismatch between the derivative's payout, the actual financial impact of adverse weather conditions, and the limited applicability (i.e., suitable primarily for businesses heavily dependent on weather-sensitive activities) [97].

Pasquini, Steynor, and Waagsaether [98] stated that there are two types of decision-making techniques that economic actors use when faced with uncertainty, and these approaches might be normative and descriptive. Moreover, Pasquini et al. [99] claim that economic agents' support for likelihood, the delay in consequences or outcomes, and hence the lack of information define uncertainty.

Similar to Pasquini’s perspective, the normative method uses mathematical and analytical techniques, such as expected utility theory and theorem theory, to help individuals make reasonable decisions [100].

While descriptive approaches to decision-making look into a specific decision-making method like the prospect theory and try to understand the limitations of the human mind, Pasquini et al. [98] looked into the biases in decision-making when purchasing insurance, and the study discovered that economic agents make heuristic decisions.

According to the latter, the heuristic decision-making approach entails agents using shortcuts to make decisions in order to save time and due to limited psychological feature capacities.

According to the latter, the heuristic decision-making approach entails agents using shortcuts to make decisions in order to save time and due to limited psychological feature capacities.

The heuristic decision-making biases originate in the four basic issues of W*hat You See Is All There Is*, *Representativeness*, *Availability*, and *Effect*. Pasquini et al. [99] state that availability is determined once economic agents create choices supported by the recollections and that they live the likelihood of chance supported by those recollections, while [101] state that representative heuristics rely on creating a call of an incident supported what proportion it represents a typical scenario. It is necessary to notice that economic agents use three decision-making biases to analyze the uncertainty and their adoption strategy to mitigate effects. These biases embrace mental accounting versus, however possible, the thought of loss or gain [102].

Once viewing the psychological science in natural insurance, it seems necessary to assess the strictness of economic agents towards insurance as shown within the study by different Authors [103].

Hu [104] states that the digitalization of flood maps into the web and communication of economic agents on social media inflated the importance of flood risks and increased the uptake of flood insurance. While Segal et al. [105] observed that the rise within the fusing effects of hazards as a perform of concern inspired prosocial behavior and adaptation of price mitigating programs. Nowadays, it is necessary to notice that it has been found that prosocial behavior existed amongst the people who attributed the occurrence of a hazard to a supernatural event. According to the study of Böhmelt [106], the importance of natural hazards usually increases after a disaster and attenuates itself after a short period [107] as insurance take-ups spike simply once the hazard tones down.

The study by Gallagher [108] observed that uptake from non-affected regions is additionally inflated and is according to the Bayesian model theorem that permits forgetting or incomplete data concerning past events. On the other hand, Dumm et al. [109] found that the result attenuates because the losses fade from memory. The result of losses on demand is far higher for newer losses. According to the latter study, the representative heuristic model shows that individual policyholders outweigh the likelihood of another harmful event occurring by nearly five hundredths once such an event has occurred.

1.7. The ESG and the insurance sector

ESG stands for Environmental, Social, and Governance, representing a framework for evaluating a company's impact on sustainability and ethical practices. Environmental factors assess a company's ecological impact, social criteria gauge its relationships with stakeholders and community, while governance evaluates its leadership, ethics, and transparency. ESG considerations are crucial for investors, insurers, and businesses aiming to align with responsible and sustainable practices, fostering long-term value and positive societal impact [56].

The connection between the ESG approach and the insurance sector underscores a transformative shift toward sustainable and responsible business practices. Embracing ESG principles offers several notable examples for the insurance industry, such as integrating environmental factors into risk assessment, aligning insurers with climate-conscious policies, and promoting resilience against climate-related events [110].

Secondly, a strong ESG commitment enhances social responsibility. By prioritizing social impact, insurers can contribute to community well-being and address societal challenges. This includes promoting diversity and inclusion, ensuring fair labor practices, and supporting initiatives that benefit the broader public [111].

Furthermore, it should be emphasis that governance practices underpin the foundation of a robust ESG approach. Implementing transparent governance structures fosters trust among stakeholders, including policyholders, investors, and the public. Effective governance is crucial for navigating regulatory landscapes and ensuring ethical decision-making within the insurance sector [112].

Moreover, the adoption of ESG principles in the insurance sector aligns with evolving consumer preferences. Modern policyholders increasingly seek insurance providers that share their values and demonstrate a commitment to sustainability. This shift in consumer behavior emphasizes the business case for insurers to integrate ESG considerations into their strategies [113].

Thus, the connection between the ESG approach and the insurance sector reflects a broader commitment to sustainable, ethical, and socially responsible business practices. This integration mitigates risks associated with environmental and social factors and aligns insurers with the expectations of a conscientious and environmentally aware clientele. As the insurance industry continues to embrace ESG principles, it is likely to play a pivotal role in promoting a more sustainable and resilient global economy [114].

It should be emphasized that at the European level, a new approach has taken hold to verify the sustainability of the insurance itself [115]. It is well known that there is a lack of risk-related experience and data that can be used to determine premiums, particularly in areas where there is a lack of or underdevelopment of a real insurance market (such as with cyber risk or so-called NATCAT for certain natural disasters) or when it is impossible to compare products [116]. The subject chosen by the insurance business must be cautious when creating the rates in the lack of trustworthy data for the evaluation of the premium in order to preserve the portfolio's overall balance and, ultimately, to confirm throughout time the accuracy of the decisions made. Environmental, social, and governance (ESG) sustainability factors are frequently excluded from data processing tools [56].

Making informed investing decisions while maximizing risk management, avoiding being overly cautious and conservative, and applying these principles can be quite intriguing.

To begin working toward a resolution, it appears that a different cultural approach is required, one that can deeply inspire the participants in the insurance dynamics and foster in-depth knowledge while attempting to comprehend the nature of these data and their close relationship to the likelihood that the harmful event anticipated in the contract will occur [88].

The significance of the cultural approach is inextricably linked to the crucial regulatory-systematic shift already outlined and, obviously, to better knowledge of the rights of both parties during the contract's formulation.

Giving an eye at a supranational context, for instance, the European Commission has supported and developed the H2020 NAIAD project to gather and analyze data and information for the creation of a platform in which new insurance instruments or investments are made - to counteract the risks resulting from floods and droughts - in which the prevention, management, and resilience measures adopted (the so-called Nature based solution - NBS) are considered [117].

Similar to this, it has already been shown in the same supranational context that there is a connection between sustainability, corporate governance, asset value, and the impact it has on a company's share performance, even in unrelated fields.

Concluding this section, it is noteworthy that on December 8, 2017, during the climate change conference held in Paris in 2015, many of the major asset managers, pension funds, and insurance companies signed a declaration in support of the focus on the importance of improving the transparency and public disclosure of the ESG rating by issuers, in addition to the Financial Rating [118].

1.8. Blockchain Technology and socio-natural hazards

Thanks to the invention of the Blockchain in 2014, the twenty-year-old Vitalik Buterin, made public the characteristics of what then became the most platform for the event and performance of sensible contracts: Ethereum. The aim of this platform is to supply a Blockchain with a tech tool with an intrinsic programing language, which might be accustomed to building "contracts" and to inscribe functions in order that these contracts are self-executed in accordance with the pre-set rules: all this just by writing the logic of their operation in a few lines of code [119].

There is no globally accepted definition of a Smart Contract due to its recent appearance on the legal scene and its technological complexity.

A simple definition is that of an agreement whose execution e is automatic, so an algorithm for computer transactions, which is compliant with the terms of the contract, albeit perhaps a correct definition, even thinking on the scope of the thesis was provided by the Italian IVASS (Italian Institute for Insurance Supervision), according to which smart contracts are contracts written in a language that can be electronically and automatically executed and performed by a computer, whose clauses can produce actions without external intervention based on data received in input and processed according to predefined rules [120].

Following the occurrence that the characteristics of any good or data can be somehow digitized and represented by a code, all this can be stored and secured in a distributed register (ledger), even from a dynamic point of view; the operations and the agreements between the nodes of the network can be traced, and the Blockchain technology itself can automatically perform their performance without any external intervention.

This perspective has become possible thanks to the Smart Contracts, which, as IT [121] protocols, formalize all the elements of an agreement and automatically perform the terms of the contract when the conditions foreseen by the agreement occur and are fulfilled (even the conditions are therefore predefined and codified).

In brief, to provide a significative statement to better understand, it seems appropriate to conclude that "*a smart contract is a piece of code which is stored on a Blockchain, triggered by Blockchain transactions, and which reads and writes data in that Blockchain's database*" [122].

The development and evolution of Smart Contracts have been spreading, and so has their application. In addition to the first platform, Ethereum, other open-source projects were born to create and develop more sophisticated Smart Contracts (for example, Mastercoin) [120].

The implementation of blockchain technology against socio-natural hazards represents a promising frontier in leveraging decentralized and secure systems to enhance disaster preparedness, response, and recovery. Blockchain, originally designed to underpin cryptocurrencies, is a distributed ledger technology that offers transparency, immutability, and decentralization.

In the context of socio-natural hazards, blockchain can be applied in various ways. Firstly, its decentralized nature ensures that critical information related to disaster management is distributed across a network of nodes, reducing the risk of a single point of failure. This can be particularly valuable in maintaining essential records, such as land titles, identification documents, and infrastructure data, which are vulnerable during and after disasters [123].

Smart contracts, self-executing contracts with the terms of the agreement directly written into code, play a pivotal role in automating disaster response and recovery processes. For instance, insurance payouts triggered by predefined conditions, such as weather patterns or seismic activity, can be executed automatically through smart contracts, expediting the financial assistance to affected parties. This enhances efficiency and reduces traditional insurance processes' bureaucratic hurdles [124].

Blockchain's transparency ensures accountability in the distribution of aid and charitable donations. By recording each transaction on an immutable ledger, stakeholders can trace the flow of funds from donors to beneficiaries, minimizing the risk of corruption and ensuring that resources reach those in need. This transparency fosters trust among involved parties and the general public, encouraging greater participation in relief efforts [125].

Moreover, blockchain's decentralized and tamper-proof nature contributes to data integrity and security. During disasters, there is an increased risk of data manipulation, whether for misinformation or malicious purposes. Blockchain's cryptographic techniques make altering information extremely difficult, ensuring the reliability of critical data, such as emergency response plans, medical records, and supply chain information [126].

In terms of socio-natural hazard prediction and monitoring, blockchain can facilitate the secure sharing of data among various stakeholders, including government agencies, research institutions, and NGOs. This collaboration can lead to more accurate risk assessments and early warning systems, enabling communities to better prepare for impending disasters [127].

Despite the promising applications, challenges persist in the widespread adoption of blockchain for socio-natural hazards. Issues such as scalability, energy consumption, and regulatory frameworks need to be addressed. Additionally, there is a need for increased awareness and education about blockchain technology among stakeholders involved in disaster management [128].

Thus, the implementation of blockchain technology against socio-natural hazards holds significant potential to revolutionize disaster preparedness, response, and recovery. Through its decentralized and transparent features, blockchain can enhance data integrity, automate processes, and ensure the efficient and accountable distribution of resources during times of crisis. As technology continues to mature and address its existing challenges, its role in mitigating the impacts of socio-natural hazards is likely to become increasingly prominent.

1.9. Smart insurance contracts

"Smart contracts" are the development of the research of Nick Szabo, who was a reference author in the data encryption landscape in the late nineties. In 1997, he published two papers [6] in which he theorized a system of transfer of rights performing a mathematical algorithm derived from the system of vending machines.

In 1998, he released the third paper in which he decided to formalize the concepts drafted in both previous works. In his scheme, a property right *ad hoc* is included in a title intended to circulate, together with related data [129].

The transfer is put into mathematical-cryptographic security, and the property title is placed in a chain of previous securities as a guarantee of the continuity of operations [91].

The most peculiar implementation of crypto-currency is the Bitcoin currency implemented in different protocols such as Ethereum and its cryptocurrency Ether (second to *bitcoin* by capitalization and by currency/dollars exchange).

This new platform allows using the so-called Smart Contracts [130]. In the insurance sector, types of insurance have been developed using Smart Contracts. The first example, among others, is InsureETH, a British startup in the airline reimbursements/compensations field.

Another example is that of the pilot project of the American International Group (AIG) jointly with IBM and Chartered Bank, who worked looking for multinational insurance coverage and prepared an IT insurance Smart Contract.

It appears necessary worth adding that recently, AXA insurance [131], in order to provide refunds following a delay or cancellation of a flight, has developed an extremely interesting smart contract.

Fizzy insurance appeared revolutionary because, as described in the AXA portal, it excludes any kind of negligence, which is typical of traditional insurance [132] dynamics.

Regardless of any external event or subjective/objective responsibility and liability, the smart insurance contract automatically compensates in case of flight delay [133] due to the innovative combination of parametric insurance and blockchain technology, ensuring the inviolability of data locked in the platform [134].

The previous background emphasizes how smart insurance contracts play a pivotal role as a risk reduction mechanism in the face of socio-natural hazards, offering innovative solutions that enhance efficiency, transparency, and resilience. In the context of disasters such as floods, earthquakes, or climate-related events, these contracts leverage advanced technologies, including blockchain and smart contracts, to address the unique challenges associated with risk management [135].

One significant contribution of smart insurance contracts lies in their ability to expedite the claims process during and after socio-natural hazards [136]. Traditional insurance often involves lengthy assessments and paperwork, leading to delays in compensating affected individuals and businesses [137]. Smart contracts, triggered automatically by predefined conditions like extreme weather events, initiate the claims process instantly, facilitating rapid payouts [138]. This accelerated response is critical in providing timely financial assistance to those impacted, aiding the recovery time and minimizing the disaster's economic impact [134].

Transparency is another key feature that makes smart insurance contracts valuable in the context of socio-natural hazards. The decentralized and tamper-proof nature of blockchain ensures that all transactions, from policy issuance to claims settlements, are recorded transparently. This transparency builds trust among stakeholders, including policyholders, insurers, and regulatory bodies. It also enables a clear audit trail, crucial for post-disaster assessments and ensuring that resources are allocated efficiently [119].

The use of parametric insurance, enabled by smart contracts, further enhances the efficacy of risk reduction. To determine payouts, parametric insurance relies on predefined triggers such as wind speed, rainfall, or seismic activity. This eliminates the need for time-consuming loss assessments and ensures swift compensation based on objective and verifiable data. In the aftermath of a socio-natural hazard, where traditional assessment methods may be hindered, parametric insurance provides a reliable mechanism for prompt financial support [139].

Additionally, blockchain technology's decentralized and secure nature reduces the risk of fraud in insurance claims. The immutability of the blockchain ensures that it cannot be altered once data is recorded. This feature is particularly beneficial in situations where fraudulent claims may arise amidst the chaos of a natural disaster. The integrity of the claims process is preserved, promoting fairness and accuracy in payouts [125].

While adopting smart insurance contracts in the context of socio-natural hazards holds immense promise, challenges remain. Regulatory frameworks must evolve to accommodate these innovative mechanisms, ensuring compliance with legal standards. Moreover, there is a need for widespread education and awareness among both insurers and the insured to promote the understanding and acceptance of these technologies [140].

Thus, smart insurance contracts serve as a transformative tool for reducing risks associated with socio-natural hazards. By leveraging technology to streamline processes, enhance transparency, and expedite responses, these contracts contribute significantly to building resilience in the face of disasters. As technology evolves and stakeholders embrace these innovations, smart insurance contracts are poised to become integral to comprehensive disaster risk reduction strategies.

1.10. Interconnecting cultural heritages, blockchain and insurance

Cultural heritage is a wealth that has its own resources inherent within the innate objective meaning to be exploited even if sometimes new ones have to be compelled, in terms of individuals, skills, and money or within the variety of capital contributions for maintenance or, again, for substantial changes in content and kind. Cultural heritage contributes to identity, image, education, landscape, land management, housing heritage, cultural and religious requirements satisfaction, tourist attraction, etc.

First, it appears necessary to define the scope of the discussion or clarify what underlies the meaning of ‘cultural property’, pars pro toto of the wider concept of cultural heritage [7].

The expression originates in the Convention for the Protection of Cultural Property in the Event of Armed Conflict, signed in The Hague in 1954 [141].

From there, the notion of ‘cultural property’ effectively entered into the internal legal language, with, in the beginning, sporadic references in some of the very first regional laws, and then, after a while, started to be used ‘officially’ with the aforementioned law establishing the Ministry of the sector, which was called precisely ‘Ministry of Cultural and Environmental Heritage’.

The aforementioned Commission's work concluded with a Final Report (Protocol), accompanied by a series of Declarations, which could be seen as an organic proposal for legislative modification [142].

What emerged wasn't solely the results of a superficial analysis of the state of the cultural heritage, but a careful analysis, while not rhetorical and poor in outline judgments.

The Commission brought out a general state of precariousness and decay of the Italian archaeological, artistic, historical, environmental, archival, and book heritage that could not (and cannot) be attributed only to ‘funding deficiencies, but to the specific idea that one has of cultural heritage.

It is appreciated only in parts or only as an artistic value, often not considering the relevance that this has as a testimony of history.

In the first place, a very broad notion of ‘cultural heritage of the nation’, since it included ‘all assets referring to the history of civilization’; secondly, and this would be the definition that will acquire broader notoriety, a defining criterion was introduced general and residual, for which ‘any other good that constitutes material testimony having the value of civilization’ is a cultural valuable asset [141].

This expression broke into social consciousness and represented a check and fact of modernity, as the idea of recognizing cultural value only to assets with a certain artistic and aesthetic value was still extremely relevant.

The way was also paved for what is defined as ‘minor goods’, meaning such goods that do not possess the required minimal requirement of ‘unrepeatability’ [143].

The essential characteristics of the cultural asset are somehow derived: the ‘materiality’ and the ‘value of civilization’, when cultural assets are defined as ‘immovable or movable things’ of an author who is no longer living [144].

Another requirement that emerges from the analysis of the legislation is the dimension, so the 'cultural' character can consist of both 'individual' goods and 'universality of things' (collections, collections, series).

The third aspect, on the other hand, concerns the registry of the property since it must be the work of an author who is no longer living, and the realization has taken place for at least fifty years, for it to be considered cultural.

Cultural heritage, as a *unicum*, can be seen as a broad concept and includes the natural as well as the cultural environment. It encompasses landscapes, sites, historic places, and built environments, as well as bio-diversity, past and continuing cultural practices collections, living experiences, and knowledge. It records and assesses the long processes of historic development, forming the essence of different national, regional, indigenous, and local identities and is an integral part of modern life [145].

It is a dynamic reference point and a positive tool for growth and change. Each locale or community has a unique history and collective memory that are irreplaceable and serve as a crucial building block for growth both now and in the future [13].

The main focus of the International Conference was this concept of legacy that was presented in 1999 at the XII International General Assembly on the management of tourism in Mexico that turned out to be the main subject for the International Council on Monuments and Sites to focus on to develop and assess relating to the presentation and interpretation of the historical site, places, and cultural diversities. Another definition of heritage is that given by UNESCO to the Convention 'concerning the protection of the world cultural and natural heritage' adopted by the XVII General Conference held in Paris in November 1972 [146], which distinguished natural heritage from cultural one.

The latter, the only one of interest in this thesis, was proposed in these terms: 'the following shall be considered as' cultural heritage': monuments: architectural works, works of monumental sculpture and painting, elements or structures of an archaeological nature, inscriptions, cave dwellings and combinations of features, which are of outstanding universal value from the point of view of history, art or science; groups of buildings: groups of separate or connected buildings which, because of their architecture, their homogeneity or their place in the landscape, are of outstanding universal value from the point of view of history, art or science; sites: works of man or the combined works of nature and man, and areas including archaeological sites which are of outstanding universal value from the historical, aesthetic, ethnological or anthropological point of view' [14].

The diversity of points of view on the meaning of the term 'heritage' [147] depends on whether it could have acquired several different dimensions: it is considered synonymous with vestiges of the past of any kind or the product of modern conditions attributed to the past and influenced by it, or the whole cultural and artistic production of the past or present, and even a significant commercial activity, generically identified as a heritage industry, based on the sale of goods and services related to it [17].

In order to highlight the dynamics related to cultural heritages and the insurance field, it is worth observing how, anticipating the *infra* outlined case study, given a pretty recent report issued by the Italian Association of Insurance Companies (ANIA) in 2017, stated that 'the catastrophic events of August 2016 in the Centre of Italy have highlighted, once again, how vulnerable the Italian territory is and to what extent the historical buildings in Italy are incapable of withstanding earthquakes, even ones that are not particularly severe. Based on the estimates of the Department of Civil Protection, the earthquakes of the summer of 2016 caused damage of over € 23.5 billion, of which € 12.9 billion for damages to private dwellings (the estimate includes direct damage, both public and private – namely the destruction of buildings, infrastructure, crops and damage to businesses and enterprises, cultural heritage, power networks, gas, and water distribution systems – and eligible costs, borne by the state in response to the emergency' [148].

The preservation of cultural assets depends on disaster prevention. Determining the degree of damage to both movable and immovable cultural heritage after a disaster requires careful management and thorough examinations.

The Italian experience with the Department of Civil Protection (CPD) and the Ministry of Civil Protection seems applicable to the European environment in this regard [149].

It actually appears to be a consistent strategy to establish a special committee that has recently issued, distributed and published behavioral models developed by specially trained teams after an earthquake. These models enable damage descriptions, vulnerability index calculations, and intervention cost calculations.

A number of European nations have created and implemented significant web-based information and guidance systems for emergencies connected to natural catastrophes, particularly floods. But regrettably, they frequently lack specific advice and guidelines on preserving and protecting cultural heritage [150].

Generally, preventive measures for hazards—regardless of their type—are divided into two groups: structural and non-structural. Because they are frequently unsightly, upsetting, and expensive, structural measures are difficult to implement when protecting cultural heritage.

Using rules to protect cultural assets from natural disasters creates a dilemma because historic monuments' originality, authenticity, aesthetic qualities, and values should not be compromised [151]. However, only one European Standard is currently available to protect cultural heritage from earthquakes.

Recent experiences with catastrophic damage and genuine chances to modify the built environment to lessen such harm suggested that certain adjustments to the pertinent criteria may be made and put into practice.

Insurance firms play three roles in risk management: they manage physical risk, manage financial risk, and manage investments [152]. They may connect to vulnerable clients and investors through their insurance, reinsurance, and investment activities [153].

From what is mentioned above, the intersection of cultural heritages, blockchain implementation, and insurance heralds a transformative period. The synergistic relationship between these elements creates a dynamic framework that addresses the unique challenges cultural institutions, artifacts, and heritage sites face.

Blockchain's decentralized and tamper-proof ledger technology emerges as a cornerstone in preserving cultural authenticity. By providing an immutable record of ownership, provenance, and historical significance, blockchain ensures trust in the documentation and tracking of cultural assets. This combats illicit activities like theft and forgery and establishes a transparent foundation for collaboration among institutions, governments, and the global community. In this context, integrating smart contracts within this framework adds a layer of efficiency and responsiveness to insurance processes related to cultural heritage. Automation of claims triggered by predefined conditions, such as damage or loss, accelerates indemnification, resulting in a timely influx of financial support, crucial for restoring and protecting cultural artifacts in the aftermath of unforeseen events.

Thus, the role of insurance in cultural heritage extends beyond financial compensation, becoming a proactive force in risk mitigation and prevention. Insurance mechanisms incentivize robust preventive measures as cultural institutions and heritage sites face diverse threats, from natural disasters to human activities. This can include investments in advanced security systems, climate control technologies, and disaster preparedness strategies, contributing to the overall resilience of cultural assets.

Moreover, the connection among cultural heritages, blockchain, and insurance democratizes access to protection. Smaller institutions and even individual collectors can benefit from tailored insurance solutions facilitated by blockchain's transparency and the programmability of smart contracts. This inclusivity fosters a global culture of responsibility and care for our collective heritage, irrespective of scale or geographic location.

While this symbiotic relationship promises transformative benefits, challenges remain. Integrating blockchain into cultural heritage necessitates standardized protocols and international cooperation to ensure interoperability and widespread adoption. Regulatory frameworks must evolve to accommodate the unique features of blockchain and smart contracts, fostering a conducive environment for their application in the cultural sector.

It can be summarized that the connection among cultural heritages, blockchain implementation, and insurance reflects a paradigm shift in how we approach the preservation of our global legacy. It represents a harmonious collaboration between technological innovation, risk management, and cultural stewardship. As this integration matures, it holds the promise of safeguarding our past and shaping a more resilient and inclusive future for cultural heritage preservation.

2. METHODOLOGY

Aligning with the key research questions specified in the research hypothesis and the research objectives and emphasizing its scientific significance, this doctoral study endeavors to articulate the conclusive proposal for a System Dynamics model based on a novel Bayesian adaptive insurance scheme. This mechanism incorporates Smart Contracts, which are considered a dynamic urban assessment tool for socio-natural hazards, with a specific focus on floods in the Latvian context.

This model is designed to assess the potential of insurance playing a proactive role in disaster risk reduction within socio-natural hazards (refer to Figure 2.1), comparing it to conventional insurance mechanisms. Various methods for calculating insurance premiums for assets exposed to socio-natural hazards are examined to achieve this goal. These methods are further integrated into developing a new conceptual framework, shaping a novel definition and implementation of risk insurance. This process is elucidated in Figure 2.1, within the research steps 1 to 3.

The final research step aims to consolidate the specific outputs derived from research steps 1 to 3. These findings will be incorporated into assessing the proactive role that insurance companies can play in investing in risk reduction projects. The model will be tested using a case study focused on an urban context in Latvia exposed to floods. A comprehensive overview of the research methodology is presented in Figure 2.1, encompassing four steps aligned with the predefined objectives of the thesis.

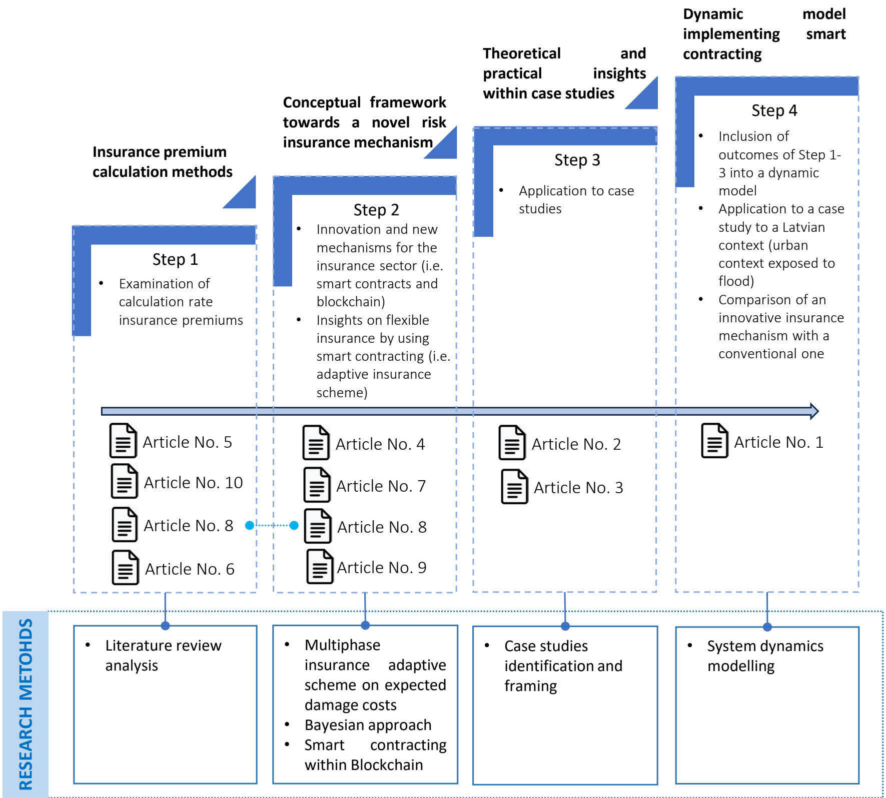

Figure 2.1. Research framework and methods of the Doctoral Thesis.

As mentioned, the research methodology encompasses a comprehensive approach involving four distinct research steps. It starts with an in-depth analysis to verify the current state of the insurance industry in dealing with and managing socio-natural disasters. An analytical study follows this step focused on the characteristics of innovative IT technology (e.g., *Blockchain* technology) within the realm of smart insurance contracts, encompassing fictional and real cases.

Implementing a private insurance or banking finance system, particularly from an economic and quantitative standpoint, is also aligned with applying and implementing *Resilience Bonds* to sustain an innovative model for mitigating catastrophic risks. Towards this direction, step 3 of the research involves the application of the contractual insurance instrument for immovable public assets (i.e., cultural heritage). This aim seems essential to assess mitigating risk measures associated with non-incomes and losses.

In step 4, the insights gained from the separate application of these defined quantitative approaches were utilized to develop a dynamic insurance contractual assessment tool tailored specifically for socio-natural hazards, implementing quantitative and probabilistic methods. Within this latest approach, the simulation of different socio-natural hazards within the model explicitly represents the uncertainty inherent in disaster risk management.

This research methodology ensures a holistic exploration of the main research aspects addressed to this Doctoral thesis, contributing to advancements in the field's academic and practical aspects. In fact, the overall research framework integrates insights from insurance, risk management, and technology fields and also analyzes potential legal aspects. Based on the latest research in insurance, risk modeling, and smart contracting, the literature review is addressed to better understand insurance's pivotal role in investing in risk reduction.

The consistency of the proposed research framework is highlighted by the definition and frame of the conceptual framework implemented in a System Dynamics model integrating feedback behaviour, simulations, and real-world data. This approach represents a potential interface and platform to engage different stakeholders, effectively triggering collaboration among industry professionals, insurers, and policyholders to ensure practical relevance.

2.1. Insurance premium calculation method

This stage is addressed to conduct an extensive literature review to identify existing premium calculation models analyze historical data and case studies to understand current insurance industry practices towards utilising statistical and actuarial methods to assess risk factors and their impact on premium calculations. The objective is to explore and evaluate various methodologies for calculating insurance premiums, focusing on assets exposed to socio-natural hazards (see approbation Papers No. 5, 8, and 10).

Insurance calculation method portfolio

Given the specific nature of insurance derivation, the first methodological step is inherent in the calculation of the premium rate (see Approbation Publication No. 5, 6, 8, and 10).

In particular, in the context of the calculation methods in the insurance framework, the author has tried to highlight the standard steps for explaining the mechanisms relating to the general rate.

Forecasting the portfolio and evaluating the profitability of the current and future insurance operations is possible thanks to a thorough examination of the insurance portfolio covered by the contracts (type of insurance as a whole or by-products).

The assessment of the insurance portfolio's quality is one of the key factors in the company's final grade. A complete examination of the current insurance portfolio is necessary in order to set goals for the medium- and long-term periods by business lines (products and/or insurance) and to ensure the financial security and solvency of the insurance firm [116].

Table 2.1

The main indicators of the insurance portfolio [154]

Key indicators	Characteristic
Diversification of portfolio insurance	The high level of portfolio diversification and lack of dependence on large customers ultimately have a positive effect on the final financial result of insurance operations.
The stability of the insurance portfolio	The level of stability of the insurance portfolio affects, first of all, a high level of extension of insurance contracts. A stable insurance portfolio has a positive effect on the profitability of insurance operations.
Unprofitability by activity	Group loss ratio reflects the correctness of payment, which is covered by insurance.
The technical result is along the lines of business	Characterizes the ratio of earned premium to the cost of the lines of business. It is necessary to determine the profitability of the business.
The relative magnitude of the risks taken	The relative magnitude of the risks taken by ratio to the size of equity determines the susceptibility to catastrophic risks.

The loss ratio is sometimes determined as the distribution of losses for each insurance contract over the course of the insurance contract as the ratio of paid losses to the premium received in the underwriting year in order to obtain a speedier conclusion. As a result, this computation is possible only when the contract for a specified period is made.

Some businesses use a technique known as "cash settlement loss," which assumes a correlation between all losses paid on the portfolio throughout a given period and all premiums received during that same period to quickly assess the portfolio in terms of cash flows. Since this figure does not account for segment losses, analysts are unable to review the tariff policy.

The evaluation of a portfolio is based on statistical measures of its dynamics. According to the average of the sum insured portfolio and the average insurance price, by the number of contracts in each period and the premiums collected on these contracts. These facts are required for the analysis that follows the proposed tariff change. Calculations of the portfolio's average rate are also necessary.

A sensible tariff policy with the appropriate size net rates serves as the foundation of a cost-effective portfolio. The probability of occurrence of insured events was calculated for this portfolio assessment using statistical data on the incidence of accumulated losses, the average magnitude of the damage, and other factors.

Table 2.2

Key indicators and specification [154]

Sufficiency	Coverage	Solvency
The share of insurance premiums insurance reserves for risky types of insurance	Coverage level of insurance reserves own funds	The degree of coverage of the insurance premium own funds and insurance reserves, the recommended value of the index not less than 150%
*K1 = Insurance reserves / netto-premium of risk insurance * 100%*	*K4 = Own capital / technical insurance reserves netto * 100%*	*K1 = (Own capital + insurance reserves) / (netto - premium of risk insurance) * 100%*
Normal less 100%	Normal more 50%	
Coverage level reserve declared, settled losses cash	Adequacy of inflows in the form of insurance premiums to cover the running costs of the insurance premiums, the current cost of doing business, management, and operating expenses, excluding expenses related to investing activities	The share of own funds and insurance reserves in the company's assets
*K2 = Cash flow / reserves claims * 100%*	*K5 = (netto-premium of risk insurance) / costs of the proceedings * 100%*	*K2 = (Own capital + Insurance reserves) / total capital * 100%*
Normal less 100%	Normal more 700%	Normal more 80%
Level of cover unearned premium reserve accounts receivable (recommended - less 100%)	Coverage level reserve declared, settled losses cash	The share of equity in the obligations of the company, not related to insurance contracts, the recommended value of the coefficient of not less than 100%
*K3 = Receivables under insurance, coinsurance / unearned premium reserve) * 100%*	*K2 = Cash / allowance claimed, unsettled losses * 100%*	*K3 = Own capital / non insurance liabilities * 100%*
	Normal less 100%	

When a number of conditions are met, including strong insurance reserves and an appropriate investment strategy, an insurance company's sufficient own funds guarantee its solvency. Therefore, focusing on reserve calculation, appraisal, and coverage is crucial. Insurance reserves have a financial meaning that indicates the insurer was able to fulfill its obligations. For each type of commitment, an insurer covers the appropriate insurance reserve according to the internationally approved scheme for generating insurance reserves.

Table 2.3

The main indicators of the insurance portfolio [154]

Fields of analysis (tariff factor)	Analysis results
Territory into the insurance contract	Reveals territorial differentiation on loss and assesses the adequacy of regional coefficients.
Sales channel	To evaluate the effectiveness of sales channels in order to select the least loss.
Agent	As a result of analysis in the context of loss of designers selected designers with the lowest loss ratio.
The primary conclusion I am running a few minutes late; my previous meeting is running over extension	Allocated risk population for primary and extended contracts to carry out a comparative analysis of the key characteristics of profitability.
Brand, model	Reveals the target segments with the highest profitability.
Insurance contract	
Insurance sum	Risk profiling in the context of the insurance sums allows you to select the most interesting segments of sales

By meeting these requirements, the company is able to rapidly modify its motor insurance tariff policy and achieve break-even insurance operations. The analysis's findings will determine whether the selection criteria be widened or deepened.

An investigation of the portfolio's subjective qualities reveals the insurance portfolio's problematic facets. These qualities are arbitrary because, on the one hand, the number of client companies eventually influences both the client-to-company ratio and the company's reputation. On the other hand, the quantity and seriousness of regulatory authorities' complaints (compared to the volume of contracts) suggest the number of unhappy clients and, eventually, the extent to which the customer fully covers each client's insurance products.

Static methods in an insurance company: analysis of the portfolio

Unprofitability in insurance operations is a measure of how well an insurer is performing its activities other than life insurance. This measure can be calculated for all types of insurance or for each type individually. The sequence of calculation is determined by the foundation for the calculation, which may be underwriting, the operational year, or the time at which a loss first occurs (the insured event).

The proportion of insurance payments to accumulated (paid or earned) premiums at the end of the underwriting year includes reserves for incurred but unreported claims as well as the estimated allowance for losses.

At the end of the calendar year, the ratio is determined by subtracting the reserves for insurance payments (losses) from the denominator, which includes premiums paid during the calendar year, from the numerator, which includes reserves for insurance payments (losses) at the end of the calendar year. For calculating on-year loss events, as shown by equation 1, the denominator is the premium received during the calendar year, with the numerator being insurance payouts for insured events that happened during the calendar year, plus insurance reserves for losses sustained during the calendar year [149].

$$Loss\ Ratio = \frac{Loss\ Adjustments}{Premium\ Earned}\ Expense\ Ratio = \frac{Underwriting\ Expenses}{Net\ Premium\ Written}$$
$$Combined\ Ratio = (Loss\ Ratio + Expense\ Ratio) \tag{1}$$

Often, in order to get a quicker result, the loss ratio is calculated as the ratio of paid losses to the premium received in the underwriting year, the allocation of losses for each insurance agreement during the term of the same insurance agreement. Thus, this calculation is made possible only after the contract for a specific period [139].

Some companies, for rapid portfolio assessment in terms of cash flows, use a so-called cash settlement loss, which implies a correlation of all paid losses on the portfolio over a given period Casco on all premiums received in the same period.

As this calculation does not account for segment losses, experts are unable to review the tariff policy.

By the number of contracts in each period on the collected premiums on these contracts, according to the average of the sum insured portfolio, the average insurance premium.

These data are necessary for the subsequent analysis for tariff revision. Calculations of the average rate for the portfolio are also needed.

More analysis on the payment of commission is the basis for the discount policy and budget presentation discounts to insurance intermediaries. A sensible tariff policy with the appropriate size net rates serves as the foundation of a cost-effective portfolio.

For this vital portfolio assessment, on the basis of statistical data on the incidence of accumulated losses and the average size of the damage, the highest probability of occurrence of insured events is determined. Separately calculated the average paid loss and the average loss claimed [155].

Catastrophe scenarios, here intended in terms of natural hazard, might provide different economic and financial results, the most common of which are the curve of average annual loss (Annual Average Loss, AAL) and curve of probability of exceedance (Exceedance Probability, EP) [52].

The AAL is sometimes defined as "pure" or "claims report award/awards" and can be inserted into the final premium jointly with an allowance for expenses and the return on the fixed initial capital [156]. The EP curve is usually described as a graphical figure of the probability that a loss occurred by possible events, such as natural hazards, exceeds a certain amount/sum [157].

Reading points on the curve give different interpretations and points of view on the severity and frequency of losses.

These curves are very useful to insurers and reinsurers [158] to determine the size and distribution of potential losses in their portfolios.

The EP curve allows insurers to determine the probable maximum loss (hereafter referred to as PML = Probable Maximum Loss) for a portfolio of buildings in a certain timeframe due to a natural hazard occurrence.

The insurer first determines the percentage risk it deems acceptable and then checks the total loss amount for that specific probability level on the curve EP.

It appears absolutely essential for the continuation of the discussion that the authors conduct and deal with the theoretical questions described above in a table and a graph so that how the insurance companies determine the risk and the price starting from a numerical base is partially clarified, i.e., the determination of the percentage of exceedance probability [56].

2.2. Conceptual framework towards a novel Risk Insurance Mechanism

The second methodological step aims to frame and evaluate a conceptual framework for a Novel Risk Insurance Mechanism, including the insights gained from the premium calculation methods (see Approbation Publication No. 4, 7, 8, and 9).

This research method is a step to synthesize findings from the premium calculation exploration, identifying gaps and shortcomings in existing insurance mechanisms with the aim to further propose innovative concepts and structures for risk insurance, considering both theoretical foundations and practical implications.

Moving towards a new paradigm involving insurance mechanisms in disaster risk reduction strategy emphasizes resilience's interdisciplinary nature, which includes the social, economic, institutional, infrastructure/engineering, and community structures and any related data.

Multiphase contracts and blockchain: emphasis on the Italian context

The desired multi-period implementation within smart insurance contracts is subject to the actual fact that, periodically, through the storage of information from external certified sources using blockchain technology, the contractual structure can change, i.e., the premium, the total sum of compensation, or the determination of the proportion of the percentage of risk.

The minimal and necessary options of a multi-phase contract are described as follows:

- The agreement is based on a bilateral provision whereby the insured party pays the company, at predetermined intervals, a sum known as the insurance premium, and in the event that the insured event occurs, the company compensates the harmed party. This is burdensome, so it adopts the standard scheme of an insurance contract [123];
- Aleatory, in the sense that the insured event's occurrence is unknown even after it has been identified, documented, and laid out; information technology [159] ;
- Information technology (IT), in that the contract's terms are agreed upon via an online platform using blockchain technology. Specifically, the employment of a digital signature tool to convey consent constitutes one of the signature methods [160];
- Blockchain Technology. A technology made out of nodes and arcs can be fixed in the conventional supply chain's nodes and arcs structure, making it possible to utilize it to capture the supply chain's organizational and network risks;
- Real-time data flow refers to the ability of a Blockchain contract structure to receive data and information about the insured asset and its related environment and to be able to change the contract's initial terms on a regular basis [57];
- Automatic renegotiation, also known as automatic consensus, refers to the contract's ability to change its initial terms on a regular basis based on the flow of data [161].

In this methodological phase, the author, by connection with local insurance companies, has focused attention on the study of the legislation within the Italian panorama.

It is required to describe the typical insurance contract within the framework of the Italian civil code, which furthermore does not fundamentally differ from that of other significant European nations. According to Article 1882 of the Civil Code, insurance is a contract whereby the insurer agrees to compensate the insured for losses incurred as a result of claims within the agreed-upon limitations or to pay a lump sum or an annuity if an incident involving human life occurs.

As a result, the first mentioned characteristic — that the contract is burdensome — can be absolutely transferred to the new agreement because it is a necessary component and fundamental to the definition [162].

Regarding the *alea*, the risk is attributed to the hypothetical chance that an occurrence that would be destructive and detrimental to the subject's particular interest occurs as a determining factor of the insurance contract.

It is simple to comprehend how it can continue to exist in a "latent" state, which is more accurately referred to as potential or materialize, once the hypothetical possibility is realized.

Therefore, the risk must be objectively uncertain (i.e., caused by external causal factors and not by the parties, unaware of the possibility of occurrence and when), although it must be possible (albeit with a greater or lesser likelihood of verification that only affects the amount of the premium), while also being harmful and detrimental to the protected interest [163].

Since the absence of this state *ab origine* determines the *ex tunc* validity of the contract due to lack of cause (Article 1895), and since the termination of the contract results in the termination of the relationship, again, the state of objective and absolute uncertainty that characterizes its essential features with the probabilistic forecast of the fact, human or natural, which is detrimental to the protected interest must already exist effectively at the time of adherence to the policy. So, even including this feature in the new contract is not prevented.

IT aspects in connection to blockchain use and real-time data flow can be summed up as follows [134]:

- Verify the flow of data, in particular to any possible communication of the delay or arrival on flight time,
- Certify the data received and
- Payment of the agreed sum whenever the delay occurs.

To develop this thesis, it is essential to emphasize that practically all of the elements are adaptable to the contract implementation project, some of which are inherent *ex se*, such as compensation and the *alea*, and others for after implementation, such as Blockchain.

As the steps that must be managed to move on to the next phase are determined at the beginning, a smart contract can thus be conceived of as a multiphase contract. This seems to be the case with the resilient method's mitigation process [164].

The various steps of the process are as follows: the initial data collection relating to climatic phenomena (and their effects on flood phenomena) and the damage they cause, for which the Blockchain can act in terms of certifying that the data comes from reliable sources; the stipulation of the contract both in the insurance part and in the financing part of the mitigation work; the certification of the timetable for the construction of the mitigation work; and the completion of the mitigation work [165].

The so-called *Big data*'s new opportunity for data collection, including for traditional insurance risks like health, driving, climate, and seismic events, along with the Blockchain approach's role in validating it, appear to be the ideal conditions for widespread adoption of smart contracts in the insurance industry.

Quantitative and Bayesian approaches

Selecting one of high current interest among the potential domains for using a Bayesian adaptive scheme in multi-periodic insurance coverage, namely the risk associated with extreme climatic events, and in particular, studying the flood risk.

It is prodromal a multidisciplinary approach to conduct this type of research because the macro-fields involved include actuarial science for the quantitative analysis, engineering expertise for assessing flood risk in a particular area, legal perspective to provide proper legal support for smart contracts in a multiperiodic scenario, and informatics expertise to describe the process made possible by blockchain technology [166].

In order to maximize total territorial resilience, it is necessary to evaluate how prospective infrastructure enhancements, including physical and/or soft measures, can be made.

In this context, it is necessary to create quantitative or semi-quantitative methodologies that could assess the optimization of the capacities defining the resilience of an urban system and/or community in a manner akin to a cost-benefit analysis.

In this regard, during the past ten years, special focus has been placed on the selection of specialized risk assessment techniques with a focus on the measurement of vulnerable regions and communities at risk [167].

The engineering perspective, which is emphasized by the technical aspect of this method, emphasizes the significance of considering the critical infrastructure's vulnerability assessment, particularly as it relates to urban networks at risk for natural disasters like floods [168].

As the methodology can identify resilience characteristics at the urban scale and plan for enhancing strategies, the study of Serre et al. [169] proposes an assessment of the impacts of potential disruption of urban networks on the evaluation of the capacities that characterize the level of resilience of an urban environment.

2.3. Theoretical and practical insights within case studies

The third methodological step aims to gain theoretical and practical insights into applying the novel risk insurance mechanism through case studies. Selecting case studies and applying the developed conceptual framework to assess the effectiveness of the novel risk insurance mechanism in real-world scenarios is the background of the third research step in this thesis, which effectively incorporates qualitative and quantitative data, interviews, and on-site observations for a comprehensive understanding.

The case studies of *Villa Adriana* and *Villa d'Este* were selected as examples of cultural heritage prone to social-natural hazards. Before conducting an in-depth analysis of the two key elements outlined, the research methodology considered two key implementation phases.

The first methodological element dealt with a cross-search of the national Italian database and the UNESCO database of cultural sites of economic and social value that are managed commercially, either directly or through competitive bidding processes. This section was researched using the UNESCO online page in order to learn more about the Italian cultural heritage, which has been shown to be one of the most negatively impacted and affected by the pandemic outbreak. It can also support a financial analytical analysis. In order to conduct the research, data on cultural heritage sites were compared with the UNESCO list.

In order to draw attention to the distinctive characteristics and key elements built into the framework above, the second methodological aspect refers to the legal/regulatory dissemination of the implementation of provisions that have influenced the issue of cultural heritage at the national level. This methodological segment specifically covered the analytical examination of the laws pertaining to the subject of cultural heritage up to the level of national application of binding legislation.

The next methodological decline focuses on quantitatively analysing potential catastrophic events and associated economic effects (losses).

The analysis and economic study of the balance sheets, which can be found on the relevant website, at least in the last three years, was the focus of the fourth section, which followed the identification of the Cultural Site. This was done in order to have a scalar projection of the most important indicators between costs and incomes. The last three years of accessible data were analyzed qualitatively and quantitatively, with the most important balance sheet elements being highlighted and annuities being compared to produce a progressive historical analysis.

The final portion examines the consequences of the pandemic on cultural activities in general and the national territory sites in particular through research for statistical data and reports.

2.4. Dynamics model implementing smart contracting

The latest methodological approach endeavors to construct a System Dynamics model incorporating smart contracting to simulate and evaluate the proposed innovative risk insurance mechanism. Utilizing system dynamics modeling techniques to represent the dynamic interactions among various components of the insurance system appears to be the most suitable tool for framing complex interactions. Implementing smart contracting features within the model automates processes and simulates real-time responses, as detailed in the approval publication No. 1.

This approach also holds relevance in the context of urban disasters, where disaster management remains a challenging issue, necessitating creative solutions for the development of urban resilience measures. This perspective gains added significance when considered within the framework of Sustainable Energy and Climate Action Plans (SECAPs) for Municipalities [138].

For example, in the scholarly work of Serre et al. [169], urban resilience is comprehended and divided into three fundamental capacities: resistance capacity, absorption capacity, and recovery capacity. The recommendation is to establish urban and engineering networks capable of mitigating flood risk. A similar approach to assessing resilience was proposed by Bruneau et al. [170], introducing the "4Rs" (Robustness, Redundancy, Resourcefulness, and Rapidity). The resilience of specific tools is described by the qualities of the system matching these 4Rs.

These conceptual and (semi) quantitative model methods, grounded in the selection of an appropriate set of indicators, could serve as the cornerstone for creating a framework to evaluate the efficacy of specific mitigation and/or adaptation techniques. Numerous examples of urban catastrophes underscore the ongoing challenges in managing urban flooding, particularly under unstable conditions. Strategic and creative methods are crucial for developing effective urban resilience strategies.

Therefore, it is evident that in risk assessments [171], hazards must be identified, along with the probabilities of their occurrence and quantification of the effects they would have on vulnerable locations. This facilitates the creation of adaptive management strategies [167].

Application of System Dynamics for insurance mechanism analysis

This section delineates the proposed smart insurance mechanism, an outcome derived from previous studies within the thesis. The novel smart insurance mechanism put forth in the thesis is tailored to insure against natural disasters while facilitating insurance companies' active involvement in disaster risk mitigation. This approach signifies a progressive step in the insurance industry's proactive engagement with disaster risk reduction. Given that the issues under investigation are dynamic rather than static, the System Dynamics (SD) methodology has been chosen for the analysis of the proposed smart insurance mechanism. The SD approach enables the exploration of the complexity and dynamic challenges associated with the insurance policies under scrutiny. In the thesis, a case study is conducted using the SD approach, focusing on insurance for local communities in Latvia grappling with the impacts of climate-related disasters on their real estate assets.

The System Dynamics methodology was pioneered by J. Forrester and colleagues at the Massachusetts Institute of Technology (MIT) in the 1950s [172]. The SD approach allows the study of different systems with the help of feedback loops, delays, and non-linear relationships between system components. The core tenet of SD is that interactions and feedback between a system's numerous components determine how the system behaves as a whole. The key concepts for the SD approach application are introduced in Table 2.4.

Table 2.4

Key concepts in system dynamics modeling [173]

Causal Loop Diagrams	Causal loop diagrams are graphical representations used to visualize the relationships between the variables in a system and the direction of influence. They help identify feedback loops and understand the underlying dynamics.
Feedback loops	Feedback loops occur when the output of a system component influences its own behavior or that of other components in the system. There are two types of feedback loops: positive feedback loops, which amplify changes in the system, and negative feedback loops, which tend to stabilize the system.
Stocks and flows	Stocks represent accumulations of resources or quantities within the system (e.g., inventory, population), while flows represent the rates at which these resources move between stocks.
Delays	Delays in system dynamics refer to the time it takes for an action or change in one part of the system to have an effect on other parts. Delays can lead to oscillations or non-intuitive behaviors in the system.
Simulation	SD models are typically implemented using computer simulation software. These models allow analysts to experiment with different scenarios and policies, helping them understand how the system responds to changes over time.

Numerous disciplines, ranging from corporate management and economics to public policy, environmental studies, and engineering, extensively employ system dynamics modeling. This methodology empowers decision-makers to identify potential obstacles, gain insights into the behavior of complex systems, and assess policies and tactics before implementation. Understanding the workings of dynamic systems facilitates better planning, decision-making, and problem-solving [174]. System dynamics systems have proven effective in resolving intricate problems within various insurance-related industries, laying a robust foundation for the objectives of this study [175] [176]. The application of System Dynamics for the analysis of insurance mechanisms in this study can be encapsulated in four steps illustrated in Figure 2.2.

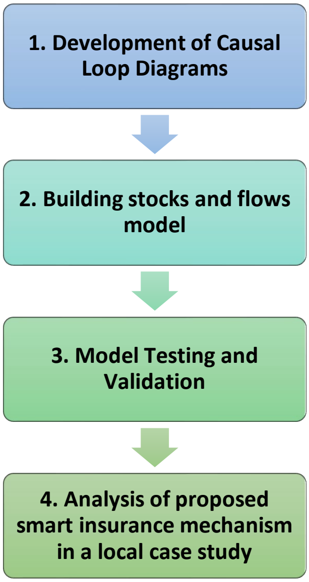

Figure 2.2. Four steps of System Dynamics application for insurance mechanism analysis

The study is elaborated in detail in the publication No. 1, is in review in an open-access journal, and is included in the Annex of the thesis. The development of causal loop diagrams, building stock and flow models, and the validation process are expounded upon in the subsequent sections of this sub-chapter. An analysis of the proposed smart insurance mechanism in a local case study is presented in the results chapter, specifically in Section 3.4.

Development of Causal Loop Diagrams

The initial step in creating the System Dynamics (SD) model involves defining the dynamic problem and the model's hypothesis, illustrating the problematic behavior of the system, and proposing a hypothetical solution, respectively. This dynamic problem and hypothesis are most effectively represented by a causal loop diagram (CLD) [172].

Causal loop diagrams (CLDs) illustrate the interaction of variables in the SD model through connections symbolized by arrows. Positive relationships among variables are denoted by a plus sign, while negative relationships are indicated by a minus sign. It's important to note that in CLDs, the connected variables' symbols signify only the change in the link between the two variables without considering the entire system's change. These connected variables can form loops, known as feedback loops, in the SD model. Each type of loop can have a positive or negative impact on other loops in the system:

- Reinforcing loops amplify changes within a system, potentially causing exponential growth or decline, and are marked with the letter R in CLD. Reinforcing loops embedded in the system are often the cause of problematic behavior.
- Balancing loops, marked with the letter B in CLD, have the opposite effect of reinforcing loops. They tend to restore equilibrium or maintain stability within a system due to their counter-interaction with the changes in the initial variable in the loop.

To address the dynamic problem and implement the hypothesis in the SD model, CLDs are constructed based on a review of the literature and expert knowledge of the selected system under study. Once the key variables and their interrelationships are identified in the conceptual model developed with CLDs, the empirical model structure that simulates the system's behavior is created.

The dynamic problem in this study is defined as follows: existing disaster insurance mechanisms cover the costs of disasters but do not prevent the risk of future damage causes, which are increasing due to the impact of climate change, resulting in an increase in the frequency and intensity of extreme weather events.

The dynamic hypothesis in this study is defined as follows: advanced insurance mechanisms implemented by a smart insurance contract can help reduce damage costs by supporting investment in disaster risk mitigation measures, thus protecting insured assets and, at the same time, attracting new customers due to a more effective insurance scheme.

Building Stock and Flow Model for a local case study

The stock and flow models have been developed to empirically analyze the dynamic problem and implement the hypothesis. Utilizing stock and flow models facilitates the exploration of the dynamic behavior of a system over time, enabling the identification of key leverage points for policy intervention. To achieve this, the conceptual model derived from CLDs is transformed into a quantitative simulation model using SD software, specifically Stella Architect. This transformation involves establishing the mathematical relationships between the model variables and determining the simulation's time horizon. The requisite data for this case study is obtained from relevant statistics.

For the case study, empirical information is collected for Jelgava, a city in central Latvia with a population of approximately 55,000 people prone to spring floods. The insured assets considered in this study encompass residential buildings facing spring floods with high probability (10% or once every 10 years), average probability (1% or once in 100 years), and low probability (0.1% or once in 1000 years), along with associated losses and restoration costs outlined in Table 2.5.

Table 2.5

Disaster probability, damage, and restoration costs [177].

Flooding probability in 100 years, %	Flooded buildings area, m^2	Restoration costs per m^2
10%	103773	19.5
1%	547400	25.8
0.5%	695111	31.8

This statistical data serves as input for a stochastic-probabilistic simulation of spring flood hazard events implemented in the SD model through the RANDOM function, incorporating stochastic components and applying hazard probabilities with different return times [178]. The simulation involves a stochastic-probabilistic variable in the model and incorporates random sampling across 1000 simulation runs. This number of simulation runs is deemed sufficient to encompass a variety of potential combinations for disaster event occurrences over a 50-year period, utilizing the provided disaster input data from Table 2.5.

The function describing asset loss is determined based on a damage curve for buildings derived from the national flood risk assessment and management plans. For the insurance model, it is expressed in monetary units (EUR), with the damage defined as the damaged asset area in square meters (m^2). The resulting risk premium that insured assets must pay to the company in the model simulation is estimated for a 10-year period using equation 2.

$$RP = L_{average} + \sigma * P \quad (2)$$

Where:
RP – Risk premium,
$L_{average}$ – Loss associated with the average yearly loss per asset in the area subjected to disaster,
σ – Volatility of yearly loss per asset in the area subjected to disaster,
P – Premium charge in %.

Three scenarios are compared with the help of the developed SD model in a simulation for a time period of 50 years and a time step of one year. The scenarios are summarized in Table 2.6:

Table 2.6

Analysed scenarios with the developed SD model.

Case study scenario	Name	Risk premium	DRR measure	Flood risk reduction measure efficiency, %	Flood risk reduction measure cost, EUR
1.	Business-as-usual	Assessed every 10 years	No	-	-
2.	Investment in disaster risk reduction	Assessed every 10 years	Riverbed cleaning, coastal erosion prevention, and flow-through restoration	20.5	1 200 000
3.	Smart contract approach	Fixed	Riverbed cleaning, coastal erosion prevention, and flow-through restoration	20.5	1 200 000

The costs incurred by insurance companies, estimated as the total payouts to insured assets after the damage has occurred and the return on investment, serve as a basis for comparing the overall costs of transitioning from conventional insurance schemes to smart contracts in the BAU scenario. The comparison involves summing the damage to all assets in the area and the cost of disaster risk reduction measures, as based on [177].

The developed SD model enables the simulation of changes in the number of insured assets in the area. The assumption in the case study is an initial share of insured buildings in the area equal to 10%. In reality, fluctuations in the number of insured assets are influenced by factors such as risk perception and willingness to pay for risk. However, the model does not delve further into the study of risk perception. Changes in the willingness-to-pay-for-risk parameter are subjected to sensitivity analysis to comprehend their influence on the model's output.

Other assumptions in the model concerning the company's profit do not take into account payments for workers and other expenses related to administrative processes. Only risk premium payments are considered as income, with payouts and investment pay-offs as outcomes. The difference between income and outcome is regarded as the insurance company's profit. The study assumes that flood risk reduction measures impact not only the insured assets but also other assets in the area when such measures are implemented.

Model Testing and Validation

Multiple structure verification tests were conducted to validate and verify the developed System Dynamics model, encompassing: i) Content validation, ii) Extreme value test, and iii) Sensitivity analysis. The content validation procedure involved a panel of subject-matter experts in climate change, insurance, and system dynamics modeling. During this process, the experts assessed the model's structure, assumptions, and parameters in several stages. Initially, the model's Causal Loop

Diagrams (CLDs) were presented to the panel for review, soliciting feedback on the model's structure and assumptions. The panel provided input on key variables and interrelationships, suggesting changes to enhance the accuracy and robustness of the model. Subsequently, the panel reviewed the model parameters, offering feedback on their values and ranges suggesting changes based on their expert knowledge and available data.

The developed Stock and Flow model underwent validation through an extreme value test. In this test, the model was calibrated using historical data from the case study and then simulated with extremely high and low parameter values to assess if the model behavior aligns with the assumptions made in the CLD and SD Stock and Flow model under extreme conditions. Understanding the effects of uncertainty in data and identifying crucial variables impacting the model's output is crucial for practical model application.

Sensitivity analysis was employed to examine how the system responds to changes in the values of uncertain input parameters crucial for model output. This analysis is essential for assessing the robustness of the model. The results of the extreme value test and sensitivity analysis are elaborated further in Publication No. 1.

3. RESULTS AND DISCUSSION

This section of the doctoral thesis's summary presents the main results adhering to the methodological framework of the thesis. Thus, it serves as a comprehensive summary, highlighting the principal results and findings derived from the methodological steps and research methods outlined in Section 2 (refer to Figure 2.2). These details are in-depth presented in the ten scientific publications referenced in the introduction section.

3.1. Insurance premium calculation methods: main findings

This section presents the main outcomes in connection to the Approbation Publication No. 5, 6, 8 and 10. In particular, it reported key aspects of insurance premium calculation methods on socio-natural hazards and their potential practical application.

Traditional insurance scheme vs resilience approach

Approbation Publication No. 5 outlines the main characteristics of the so-called *resilience bonds*, highlighting, in particular, the reference values inherent to the risk that affect the insurance premium, if any, and the uncertainty related and inherent in the contract itself.

In the stylized quantitative model for a cost-benefit analysis, considering a traditional insurance scheme and a resilience approach, we may consider the opportunity of financing mitigative infrastructures [179].

The analysis has to be performed taking account of both the two viewpoints: one concerning the profit or loss account and the other the balance sheet, to which the mitigative infrastructures must be thought of as an additional value of the asset side.

Let's consider that the flood risk could be expressed by the distribution of the claim amount in a fixed time unit and that this risk must be faced throughout a fixed time horizon, at most even perpetual.

Let X be a function with a known density function and moments. Let's consider a risk assessment based only on the first two moments, thus having E[X] = m_1 and sigma[X] = m_2, such that insurance premium P is a function of these two parameters f(m_1, m_2) = P. A finite time horizon T (time units) or at least an infinite time horizon can be considered.

Assuming a fixed discount rate r and the relative discount factor $v = 1/r$, the actual total cost for flood risk insurance $C(T)$ can be calculated as reported in equation 3:

$$C(T) = \frac{P(1 - v^T)}{r} \tag{3}$$

Then, in case in case of infinite time horizon (i.e., perpetual payment), equation 4 could be characterized as:

$$C(\infty) = \frac{P}{r} \tag{4}$$

Let consider a mitigative infrastructure with cost K and a building time duration S. Let assume $S < T$. Let consider that after this infrastructure is built, the exposure to flood risk is reduced, i.e., we have a new claim Y with the first two moments $E[Y] = n_1$ and sigma$[Y] = n_2$, such that insurance premium is a function of these two parameters $f(n_1, n_2) = P_1$ for which it is $P_1 < P$.

A resilience bond is composed of two parts, one relative to the insurance aspect and the other relative to infrastructure financing.

We can assume that for the insurance side, the issuer has to pay a coupon equal to P, and for the financing side, an additional coupon of $Q = g(K)$ till time S, which can be the bond-maturity.

So the actual total cost in the case of a resilience bond approach, defined as a function D, over time can defined as expressed in equation 5:

$$D(T) = \frac{(P + Q)(1 - v^S)}{r} + \frac{P_1 v^S (1 - v^{(T-S)})}{r} \tag{5}$$

In the case of infinite time horizon (i.e., perpetual payment *P1* after time S), equation 6 can be characterized as:

$$C(\infty) = \frac{(P + Q)(1 - v^S)}{r} + v^S \left(\frac{P_1}{r}\right) \tag{6}$$

Therefore, the total cost for the two approaches, i.e., C and D, can be compared both for a finite and for an infinite time horizon. In this way, conducting a sensitivity analysis on the model parameters, namely X, Y, r, K, and others, is a straightforward task, even including refinement through continual updates with new data.

This allows for a comprehensive understanding of the cost-benefit analysis associated with the utilization of a traditional insurance scheme versus a more robust approach for funding the expenses during the initial time interval until the completion of the mitigative infrastructure, denoted as time S in our scheme. In this context, a resilience bond with a maturity matching the infrastructure timeline and a coupon rate contingent upon the initial risk assessed by premium P, along with the supplementary component tied to infrastructure cost K, emerges as a dual-purpose instrument. This bond serves not only as a means of risk coverage but also as a mechanism for financing the infrastructure, eventually including infrastructure for flood risk mitigation.

The final key point is to assess if the higher cost of a resilience bond, with the financing of mitigative infrastructures, could be convenient with respect to a traditional insurance approach, i.e., only facing claims payments for different time spans.

Risk Premium Evaluation in the Italian Context by Exceedance Probability

Approbation Publication No. 6 aims to elucidate the dynamics of insurance concerning catastrophic events and how insurance companies engage with insured parties (i.e., contractors) to craft tailored insurance policy contracts. The study mainly focuses on the regulatory landscape in the Italian context, serving as a key example of contractual challenges related to drafting insurance contracts against natural hazards.

Approbation Publication No. 6 identifies the drawbacks arising from information asymmetry between parties, encompassing critical elements of the policy agreement, such as the definition of overall risk, exposure, vulnerability, and the consequent insurance premium. A fictional application of the Exceedance Probability (EP) curve for risk and premium assessment by insurance companies is elucidated in the Paper No. 6. This method concentrates on crucial insurance parameters determining the premium and potential indemnity in the context of natural hazard-related risks.

The study introduces the potential connection between insurance dynamics and the new environmental, social, and governance (ESG) parameters for implementation in financial markets.

Publication No. 6 also focuses on normative aspects. The central theme is a systematic examination of insurance dynamics from the perspective of the company during contract elaboration. This analysis is specifically tailored to the Italian context, with a particular emphasis on the availability of data related to flooding events and extreme weather conditions.

The framework for insurance dynamics against natural hazards, particularly Catastrophe Models involving the application of Exceedance Probability, is outlined in the publication. Particularly, the second part of the study delves into the dissemination of insurance dynamics in Italy, with a specific focus on natural hazards. This section continues to concentrate on normative studies, elucidating general methods for calculating risk and premiums and offering an in-depth examination of insurance dynamics from the company's standpoint during contract formulation.

Moreover, Publication No. 6 highlights how a lack of transparency in contractual information poses a significant obstacle, hindering access to data crucial for risk calculations related to assets. Addressing this information gap is crucial for empowering individuals to use the data consciously.

A fictional case study of catastrophe scenarios in an area prone to flood hazards by implementing the curves of Average Annual Losses (AAL) and the probability of exceedance (EP) [180] is outlined in the Approbation Publication No. 6. The AAL, also known as "pure" or "claims report awards," can be incorporated into pricing alongside allowances for expenses and return on capital. The EP curve is commonly depicted as a graphical representation of the probability that a loss resulting from possible events, such as natural hazards, exceeds a certain amount [181]. Points on the curve offer varying interpretations in terms of the frequency and severity of losses.

These curves are invaluable for insurers and reinsurers in determining the magnitude and distribution of potential losses in their portfolios. The EP curve allows insurers to establish the Probable Maximum Loss (PML) for a portfolio of buildings within a specific timeframe due to the occurrence of a natural hazard. The insurer first defines an acceptable percentage risk and then checks the total loss amount for that specific probability level on the EP curve [182].

For the continuation of the discussion, it is crucial for the authors to address the theoretical questions described above through a table and a graph. This approach would partially clarify how insurance companies determine risk and pricing based on numerical foundations, specifically in determining the percentage of exceedance probability [88].

In the proposed practical example, it is assumed that there is a set of catastrophic events (Ei) that could pose a threat to a portfolio of immovable assets. Each event has an annual probability of occurrence (p_i) and an associated loss (L_i). Additionally, more than one event might occur in the same year. The table below assumes eight events, ordered by decreasing total losses (L). The sum of the probabilities of all events must equal 1 (see Table 3.1).

Table 3.1

Fictional EP curve definition.

E_i, step	P_i, %	L_i, €	EP (L_i), %	E [L] = p_i L_i, €
1	0.005	1000000	0.00500	5000
2	0.015	750000	0.01993	11250
3	0.02	500000	0.03953	10000
4	0.05	300000	0.08755	15000
5	0.1	200000	0.17880	20000
6	0.2	100000	0.34304	20000
7	0.25	50000	0.50728	12500
8	0.36	10000	0.68466	3600
Total:	**1.00**			**97350**

The variables included in Table 3.1 could be better explained as follows.

The expected or predicted loss in relation to a given event (E_i) over a timeframe equal to a year is:

$$E(L) = p_i \cdot L_i \tag{7}$$

The total expected losses for the entire set of events, defined as AAL, is given by the weighted sum of expected losses for each event and the probability that the event will occur (see equation 8).

$$AAL = \sum_{i=0}^{n} p_i \cdot L_i \tag{8}$$

If only one event takes place during the year, it is possible to determine the EP curve, i.e., the expressed loss value, as described in equations 9 and 10:

$$EP(L_i) = P(L > L_i) = 1 - P(L > L_i) \tag{9}$$

$$EP(L_i) = 1 - \prod_{i=1}^{n}(1 - p_i) \tag{10}$$

From equation 10, it can be deduced that the EP, as shown in the Figure 3.1 curve, is the annual probability that a loss exceeds a certain value, which is equal to 1, the probability that all other natural hazards below this value will not occur.

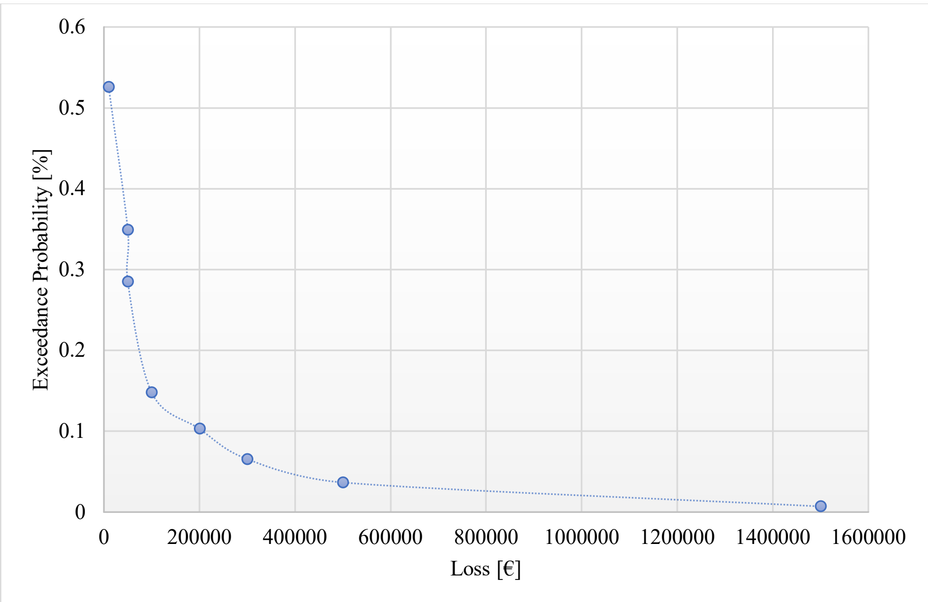

Figure 3.1. Fictional EP curve drafted according to Table 3.1.

Furthermore, the weaker party lacks assurance that the scrutiny applied to them and their assets is reciprocally conducted on the insurance company. The publication highlights the importance of incorporating new parameters, particularly Environmental, Social, and Governance (ESG) criteria [53], into contract and insurance instruments in the Italian context. This inclusion aims to enhance awareness, product safety, and rating reliability while mitigating the information asymmetry prevalent throughout the thesis methodology.

Many businesses lack comprehensive insurance reserves, impacting the amount of investment capital available. For instance, when examining the division between accrual basis and cash basis in detail, most statistical techniques used for reserve analysis rely on triangles and tables depicting insurance payments over various time periods. While there are numerous statistical methods, they all share a fundamental premise: losses accrued over time follow a consistent pattern.

It's essential to note that there is no additive division of business segments. Instead, when a line of business is subdivided, the same statistical method is applied to each component to estimate results. These individual estimates are then aggregated to estimate the overall line of business. However, this overall estimate rarely aligns with the estimate for the entire line of business obtained using the same statistical methodology. As per convention, the total of the parts of a line of business typically surpasses the reserve estimate made for the entire line of business.

Insurance in the context of flood risk: a multidisciplinary perspective

Approbation Publication No. 8 serves as a pivotal contribution to the implementation of the methodological approach outlined in the doctoral thesis. It underscores the imperative need for a multidisciplinary approach when addressing risk, particularly in the context of flood risk mitigation. The publication explores various concepts, including the resilience of Critical Infrastructure (CI), smart contracts, and blockchain technology. It delves into engineering considerations related to quantifying urban resilience and navigates through legal aspects associated with the integration of smart contracts supported by blockchain technology.

Expanding on the concepts of smart contracts and blockchain introduced in the paper, Publication No. 8 proposes an innovative actuarial model. This model incorporates a Bayesian adaptive design of the contract, a subject that will be thoroughly examined in section 3.2. The integration of these cutting-edge technologies not only enhances the understanding of risk but also contributes to the development of more sophisticated and adaptable risk mitigation strategies. The interdisciplinary nature of this research highlights the importance of converging insights from diverse fields to comprehensively address the complexities of risk management, particularly in the domain of flood risk.

Insurance mechanism facing adaptation measures to climate change

Approbation Publication No. 10 delves into understanding various adaptation measures implemented by insurance companies to address climate change, evaluating the beneficial aspect of a proactive role of insurance in potentially investing in risk reduction measures. Referring to 3.1.4.

Referring to insurance mechanisms facing adaptation measures to climate change, the paper emphasizes the inherent significance and connection between insurance companies, the obligatory interface they confront annually, and, notably, the myriad tools developed by these entities within the insurance and reinsurance sector to address natural hazards.

An interesting result in connection to this publication is a classification of adaptation measures in the insurance companies to climate change impact with reference to Dlugolecki [183] and Mills [34].

These are notable authors who have formulated classifications related to climate change adaptation. Dlugolecki's four-category classification covers risk reduction, damage control, product price adaptation, and risk transfer. Mills, with broader feedback, proposes a ten-category classification grounded in economic, financial, technical, and policy considerations [34]. Six of these categories specifically address climate change.

In the first category group, Mills observes that insurance companies actively promote understanding climate change through activities such as data collection, catastrophe modeling, and risk analysis. Beyond legal codes, insurers invest in research, forming teams, or outsourcing tasks [184]. For the second category, Mills notes insurance companies are "building awareness and participating in public policy" to inform policyholders about climate change impacts and long-term risk reduction possibilities.

The third category group, "aligning terms and conditions with risk-reducing behavior," aims to motivate policyholders to actively reduce risks. The subsequent category, "new insurance products and services," includes innovations like the Adjusted Gross Revenue (AGR), securing harvests in the USA by providing cash proportional to average income.

The last two Mills categories, "investment in climate change solutions" and "financing customer improvements" [185], involve insurers rebalancing portfolios for climate change opportunities. Emphasizing the need for joint efforts from the insurance and banking sectors, the author notes minimal efforts by all parties in this area.

Publication No. 10 focuses on the financial and economic support mechanisms employed by insurance companies in response to natural hazards. The potential insurance operations related to a natural hazard can significantly differ based on the country where the insurance company is headquartered and where the contract is stipulated.

The first distinction about insurance mechanism concerns the relationship between private insurance and public interventions that can be modulated on a range of different systems ranging from exclusive dependence on the market to complete public monopoly.

A second distinction in insurance mechanisms involves the types of risks covered, with three main categories: mono-linear coverage (focused on a single type of risk, like hurricanes or earthquakes), specific event coverage, and open coverage for any natural catastrophe. The cost of coverage is a crucial factor, varying based on insured capital, risk type, territory exposure, and public incentives to insurance companies [186]. The scope of damages covered is another differentiator, ranging from direct material damage to the potential inclusion of income loss from calamitous events. Spanish systems also consider personal injuries [187]. Insurance claims are subject to limits, with few systems offering unlimited coverage. Most have maximum limits for each damage type or event, alongside deductibles, to deter claims for irrelevant or unproven damages.

The bureaucratic aspect of obtaining an official natural disaster declaration is significant. While most systems require this declaration from a specific public body to open a claim, Spain does not necessitate it, and risk coverage is not contingent on the extent or amount of damage [188].

Lastly, variations in the financial reserves for guarantee distinguish insurance companies' approaches. Some countries encourage fund accumulation through favorable tax arrangements, while others adopt measures inherent to the financial market, such as contingent capital-related initiatives [189].

Table 1.3 in section 1.6 summarizes the overall findings, including descriptions, the social and economic functions, and the advantages and challenges associated with each financial insurance mechanism.

Publication No. 10 highlights important key aspects. The first pertains to the crucial significance of the established relationship between natural hazards and insurance companies. The second delves into the importance of how studies and adaptation classifications presented by various researchers and insurance companies can best interface with natural hazards. The last underscores criticism directed at the insurance industry for fostering general misinformation and a bias toward the financial world. While theoretically positive, this inclination results in the exclusion of a substantial portion of the population that is disconnected from financial dynamics.

3.2. Conceptual frameworks towards a new insurance tool: main findings

Flood risk insurance strategies for public administration

Approbation Publication No. 4 contributes to the economic and financial analysis and management of flood risk, expanding its scope to include hydrogeological risk considerations within the realm of public administration. As the primary entity responsible for mitigating these phenomena through territorial maintenance, public administration incurs the costs associated with restoring services damaged by such events. The assets requiring restoration encompass all public infrastructures (such as transportation, energy, water supply systems, and communication) and the damage suffered by private property if it impacts services guaranteed to the population.

Publication No. 4 proposes potential strategies that public administration can implement to address flood risk, examining three main approaches: absolute passivity, entailing payment for damages as they occur (business-as-usual scenario), a conventional insurance scheme, and a resilient, innovative insurance scheme. The economic and financial analyses in this work underscore how the assumption of a time horizon can influence the feasibility of each strategy compared to the others. This study emphasizes the crucial role of quantifying flood risk mitigation measures from an engineering perspective and explores potential challenges in pursuing these objectives within the regulatory framework of public administrations.

The potential use of Blockchain-based tools is proposed to enhance this synergy. The paper highlights the pivotal role that such IT data management platforms could play within risk analysis and management schemes, serving as both a data collection tool and a certification mechanism for the various steps necessary to complete the process.

More in specific Publication No. 4 emphasis how the effect of climatic phenomena causing damage varies across geographical areas and has been extensively addressed within the insurance market, including traditional products and mechanisms involving financial markets, such as *Catastrophe Bonds* (Cat-Bonds), which have seen a significant increase in the market in recent decades [190].

While the insurance market focuses on risk transfer and payments to other entities, public administration often bears the responsibility for managing these risks and addressing resulting damages. This poses a significant and growing economic challenge, particularly in dealing with upfront investments for adaptation or mitigation risk reduction solutions (UNISDR 2015).

One specific risk related to extreme climatic phenomena is flooding, both riverine and coastal, exacerbated by the rise in extreme climate events like heavy rains or storm surges. The impact on local assets depends on various factors, including the morphology of the territory, underlying hydrogeological risk, overall vulnerability of the population, and exposure of infrastructure to the hazard. Hydrogeological risk, in particular, affects not only private assets but also public infrastructures, such as transportation networks, energy and water distribution systems, and communication networks, incurring high restoration costs for public administration.

Approbation Publication No. 4 introduces a financial scheme for flood risk management from the perspective of public administration, offering a choice between different risk reduction strategies. The first involves a completely passive approach, with payments made as the damage occurs (business-as-usual scenario). The second is a traditional insurance scheme, while the third emphasizes urban resilience, evaluating the feasibility of upfront investments for risk mitigation through hazard-specific mitigation or adaptation projects. This aligns with the concept of resilience bonds, a financial structure first introduced in 2019 by the European Bank for Reconstruction and Development (EBRD).

The paper presents a comparative quantitative assessment model for the three strategies, employing a stochastic process to describe expectations regarding future damage levels. Similar quantitative-based approaches have been presented in previous papers by the same authors (see Approbation Publication No. 7 and No. 9) and Reguero [179], focusing on financing coastal resilience.

The analysis delves into the role of engineering competence in risk assessment and cost-benefit analysis of infrastructures used for risk management (e.g., embankments, dams, expansion tanks). Additionally, it outlines the regulatory framework, particularly within the European context, guiding public administrations in pursuing these objectives.

The findings of this publication are essential to delve into the System Dynamics model as proposed in sections 2.4 and 3.4.

The primary focus is on presenting a financial scheme encompassing three distinct strategies for public administration in managing flood risk. These strategies include:

1. **Passive Strategy**, which entails the payment of damages as they occur;
2. **Standard Insurance Strategy**, which involves determining a premium to shift a portion or the entirety of the compensation burden to the insurance market;
3. **Innovative Insurance as a Resilient Strategy**, which combines the standard insurance scheme with financing for mitigating infrastructures, ultimately reducing risk exposure upon completion.

The comparison will primarily focus on assessing the effectiveness of three distinct applications over a specified time horizon. It's essential to recognize that the benefits of the resilient strategy will materialize post-completion of mitigating infrastructures, incurring higher initial costs. While our approach aligns with Reguero [179], we introduce a stochastic framework for damages.

Enhancing urban resilience for flood risk reduction involves advancing mitigative infrastructures like hydraulic defense works, retaining dams, and expansion tanks. The process necessitates risk assessment through engineering modeling, encompassing pre- and post-mitigation project loss calculations and the overall costs and time for resilient infrastructure construction. This aspect is intricate, given site-specific engineering solutions and the nuanced nature of risk reduction assessments.

In the proposed model, the authors link flood risk to its primary source (i.e., rain levels and/or riverbed conditions in the exposed area). Establishing the statistical dependence of damages on this primary risk source poses a challenge due to the often-suboptimal quality of databases correlating damages with climate phenomena, especially in public administration archives. To maintain focus on the primary investigation, we omit this aspect, similar to the approach taken by Reguero [179], which doesn't reference any recorded loss databases for coastal damages.

Instead, we directly gathered historical damage data and organized it temporally (year, season, month). For simplicity and to mitigate seasonality effects in climatic events, we adopt an annual basis, a common assumption in many actuarial models. All subsequent quantities will be treated on an annual basis.

The exposure model can be defined as follows.

Let $X(h)$, i.i.d for $h = 1, 2, \dots$, represent the yearly random payment for flood damages in year h, with a distribution function $f(X)$, specifically $f(X) = f(X(h))\ \forall h$, his distribution can be estimated through the analysis of historical series of yearly damages, with moments $E[X^r]$ for $r = 1, 2, \dots$.

Assume an insurance premium function based on $f(X)$, denoted as $P = g(f(X))$, where $g : \mathbb{R} \to \mathbb{R}$. According to a standard assumption grounded in risk aversion principles, $P > E[X]$. Full coverage of damages by the insurance contract is assumed.

Suppose that, with a cost W and a completion time n, a mitigative infrastructure alters the random variable describing yearly damages for subsequent years to X_R, such that $E[X_R] < E[X]$ and $\sigma[X_R] < \sigma[X]$. Consequently, for the insurance premium with the same function g, $g(f(X_R)) = P_R < P$.

Assessing risk reduction through engineering expertise could be a challenging task, as it cannot be evaluated using a historical series of damages (given that the mitigative infrastructure did not exist before).

Since the comparison must be made in terms of current values, a generic annual discounting factor v corresponding to the rate of i must be fixed, that is, $v = (1 + i)-1$.

For the passive strategy (indicated with the subscript P in the following symbols), the random present value of the total payment by the public administration, fixed a generic time horizon of m years, $C_P(0,m)$, as reported in equation 11,

$$CP(0,m) = \sum_{h=1}^{m} X_h v^h \tag{11}$$

The expected value of X corresponds to a deferred annuity installment $E[X]$, expressed in equation 12.

$$E[C_P(0,m)] = \frac{1 - v^m}{i} E[X] \tag{12}$$

For the standard insurance strategy (denoted with subscript I in subsequent symbols), the current value of total expenditure for the public administration, deterministic in this case, forms a deferred annuity installment P, as stated in equation 13.

$$C_I(0,m) = \frac{1 - v^m}{i} P \tag{13}$$

In accordance with the risk aversion principle, wherein $P > E[X]$, we have:

$$E[C_P(0,m)] < C_I(0,m) \tag{14}$$

However, the passive strategy might incur annual compensation so high as to jeopardize the financial solidity of the public administration. In contrast, with the insurance strategy, the public administration can plan a constant yearly payment equal to P. The probability of very high compensation increases with the volatility of X, deducible from the historical series used to estimate its distribution $f(X)$.

The resilient strategy (indicated with subscript R) necessitates payment of insurance coverage P and financing of mitigating infrastructures with cost W for n years. After the completion time, the annual insurance cost decreases to P_R. Let Q be the annual installment for n years to finance the mitigating infrastructure, satisfying equation 15.

$$W = \frac{1 - v^n}{i} Q \tag{15}$$

This leads to the total expenditure, deterministic in this case, for the first n years incurred by the public administration, as reported in equation 16, and the following chain of inequalities, as presented in equation 17.

$$C_R(0, m) = \frac{1 - v^n}{i}(P + Q) \tag{16}$$

$$E[C_P(0, n)] < C_I(0, n) < C_R(0, n) \tag{17}$$

In terms of expected values, in the first n years, the passive strategy (though with a random result) is more cost-effective than the standard insurance strategy, which, in turn, is cheaper than the resilient one. Studying the break-even point problem in terms of time horizon is crucial to determine when the resilient strategy becomes more cost-effective, considering that for a generic value $m > n$, the present (deterministic) value of expenditure overall for this strategy is presented in equation 18.

$$C_R(0, m) = \frac{1 - v^n}{i}(P + Q) + v^n \frac{1 - v^{m-n}}{i} P_R \tag{18}$$

So, the break-even point concerning the standard insurance strategy will be m_I^*, the minimum value of the time horizon m $(> n)$ such that:

$$m_I^* = \min_{m=n+1,n+2,\ldots} C_R(0, m) < C_I(0, m) \tag{19}$$

While the break-even point concerning the passive strategy will be m_P^*, the minimum value of the time horizon m $(< n)$ such that:

$$m_P^* = \min_{m=n+1,n+2,\ldots} C_R(0, m) < E[C_P(0, m)] \tag{20}$$

Evaluating the cost W and completion time n of the mitigating work and quantifying risk reduction through engineering expertise can be a complicated objective, especially because there is no real feedback on the exposure to risk following the completion of the work. It is necessary to proceed only with hypotheses validated in contexts with some similarity.

A further development, based on such an ability to estimate through engineering skills, could be to evaluate a possible range of mitigating infrastructures, with costs and times given by pairs *W(j)* and *n(j)*, for the generic *j-th* option $(j = 1, 2, ..., J)$. From this, the ex-post risk exposure distribution is described by the random variable $X_R(j)$ and the corresponding reduced premium $P_R(j)$.

In this case, the problem of optimizing the choice of the mitigating work could concern the minimum $P_R(j)$ given a maximum level of infrastructure cost or the minimum in terms of the break-even point provided by the different choices, i.e., the minimum $m^*(j)$, with $J \in \{1, 2, ..., J\}$.

In comparing the convenience of the different strategies, the role of Blockchain tools underlying the concepts of smart contracts would be essential for the need for automatic contract passages from one phase to the next without wasting time, for example, from the completion of the mitigation infrastructure to the certification of risk exposure reduction. A smart contract can be defined as an automatic updating of contractual conditions upon the occurrence of certain conditions to be verified through Blockchain tools.

Presenting decision-making problems related to the selection of a risk mitigation strategy becomes intriguing when the distribution of random damage is known. Although no specific reference is made to an actual database of flood-related damage, we adopt a common assumption in the actuarial context, considering a lognormal distribution for random damage.

In particular, the authors aim to emphasize the potential significance of certain parameters in conducting a sensitivity analysis to assess the efficacy of resilient strategies compared to others. This assessment is based on the model introduced in the preceding section.

For the random variable representing damage, denoted as X, we assume a lognormal distribution characterized by parameters μ and σ. We further model the risk reduction after the completion of mitigative infrastructures within a specific timeframe. For the residual risk, X_R, we assume a lognormal distribution with parameters $\mu_R = (1 - d_1)\mu$ and $\sigma_R = (1 - d_2)\sigma$.

The insurance premium loading is hypothesized as a proportion α (> 0) of the volatility associated with random damage. Consequently, the total premium can be expressed as follows.

$$P = E[X] + \alpha\sigma[X] \tag{21}$$

Similarly, for the premium after the completion of the mitigative infrastructure.

$$P_R = E[X_R] + \alpha\sigma[X_R] \tag{22}$$

Considering a standard parameterization characterizing the original risk exposure and one after the construction of the mitigative infrastructure.

$$mu = 1, \sigma = 2, d_1 = 0.1, d_2 = 0.1, \alpha = 0.05 \tag{23}$$

It is important to note that:

$$E[X] = 20.08, \sigma[X] = 90.01, \qquad from\ which\ P = 24.58 \tag{24}$$

And

$$E[X_R] = 12.42, \sigma[X_R] = 38.09, \qquad from\ which\ P_R = 14.33 \tag{25}$$

Regarding the mitigation work and its financing (*W = 100*, *n = 5*, *i = 0.02*), from which *Q = 21.21* (to be paid over the planned n years of completion time). We proceed with a sensitivity analysis of the break-even points m_I^*, and m_P^*, according to (19) and (20). This analysis examines the time horizon at which the resilient strategy becomes advantageous compared to others, considering variations in the most significant parameters, including the volatility of the original risk and those related to the mitigative infrastructure. Disregarding the description of the volatility of the results and considering them only in terms of their expected values, the standard insurance strategy is consistently less convenient than the passive strategy (see equation 2).

It should be noted that as the volatility of the original risk increases, the breakeven point with respect to the standard insurance strategy constantly approaches, but there is no monotonous trend with respect to the passive strategy. The passive strategy's trend depends on the effect of loading the related insurance premium to this parameter, and the cost of the passive strategy, a function of the expected value alone, does not suffer in such a significant way. Of course, the higher the volatility of the original risk, the less safe the passive strategy is, as the probability of huge claims increases, potentially causing serious difficulties to the general economic situation of the public administration.

Table 3.2

Break-even point sensitivity with respect to the volatility of the original risk *σ*.

σ	m_I^*	m_P^*
2	16	27
2.1	13	24
2.5	7	22
3	6	89

Table 3.3

Break-even point sensitivity with respect to mitigative infrastructure costs *C*.

W	m_I^*	m_P^*
100	16	27
110	17	29
150	21	36
200	26	45

Table 3.4

Break-even point sensitivity with respect to risk reductions deriving from mitigative infrastructures measured by $d_1 = d_2$.

$d_1 = d_2$	m_I^*	m_P^*
0.1	16	27
0.11	15	25
0.15	13	20
0.2	12	17

Table 3.5

Break-even point sensitivity respect to mitigative infrastructures completion time *n*.

n	m_I^*	m_P^*
5	16	27
6	17	29
8	19	33
10	21	37

The results are largely as expected; the break-even point moves away as the cost of the mitigation work increases (see Tables 3.2-3.5). It could be interesting to analyze a model where, as the cost of mitigation works increases, their effectiveness in terms of risk reduction also increases, leading to a non-monotonous trend in the break-even point. However, a minimum level of abatement may need consideration to avoid making the break-even point the sole decision-making element in measuring the efficiency of the mitigating intervention.

Concerning the sensitivity to the reduction of risk derived from the mitigative infrastructure, we assume that the reduction rates of the parameters describing the original risk, μ and σ, have the same value ($d_1 = d_2$), while the effects of the mitigation works could impact these parameters in various ways, depending on the type of intervention.

It is interesting to note the effect of shortening the break-even point with increasing effectiveness, which is much more pronounced for the passive strategy than the insurance one.

Given the higher cost of the resilient strategy until the completion of the mitigation work, if this period is longer, it also entails an obvious shift in the break-even point, roughly the same magnitude compared to the standard insurance strategy and even more pronounced compared to the passive strategy.

Approbation Publication No. 4 introduces the potential use of innovative IT technology platforms, specifically Blockchain, within the insurance sector. Blockchain-based tools provide interfaces for real-time climate data collection and the recording of damages.

Regarding the potential (and in some cases effective) role of Blockchain in the insurance environment for various purposes (see Gatteschi [191] [135] and Approbation Publication No. 7 and 9).

Hence, a smart contract can be thought of as a multiphase contract, in which the steps to be controlled to proceed to the next phase are set at the beginning, which seems exactly the case of the mitigating process through the resilient strategy described in this work.

The various steps of the process are: the initial data collection relating to climatic phenomena (and their consequences in terms of flood phenomena) and the damage caused by them, for which the Blockchain can act in terms of certifying that the data comes from reliable sources; the stipulation of the contract both in the insurance part and in the financing part of the mitigation work; the certification of the timetable for the construction of the mitigation work (contractual clauses may be linked to any delays with respect to the settled timetable); the change in the regime of the insurance contract once the completion of the works has been certified, without the need for a new agreement on the actual exposure to risk, once this had been fixed at the signing of the contract (perhaps to be validated ex post by engineering expertise).

Note that since these mitigation processes should span various decades and trends in climate phenomena could be observed over such timeframes, the multiphase contract can consider refreshments in the assessment of some parameters of the model. For example, those describing the primary risk expressed by the distribution of random damage, with the consequent adjustment of the premium level for insurance coverage.

Publication No. 4 introduces an innovative approach that combines the effects of upfront risk reduction investments for public administration with resilient insurance mechanisms. The work presents a multidisciplinary analysis of potential flood risk coping strategies, offering a more comprehensive understanding of hydrogeological risk, an increasingly urgent concern for public administrations, particularly in light of the intensifying manifestations of extreme climatic phenomena in recent years.

The regulatory context, within which local public administrations can explore possible synergies at the European level (Covenant of Mayors) and in other geographical areas, is discussed. In addition to a conventional insurance approach, the paper describes an assessment scheme derived from a resilient approach. This resilient approach not only economically covers recorded damages but also includes the financing of risk mitigation works, a structure employed for so-called resilience bonds. The paper aims to provide a consistent approach to the application of international frameworks such as the Paris Agreement, the Sendai Framework for Disaster Risk Reduction, and the Agenda 2030 for Sustainable Development. Moreover, it is well integrated into the regulatory context of SECAP.

The construction of the quantitative model is emphasized to be based on engineering expertise, essential for both ex-ante and ex-post risk assessments and for designing the most effective mitigation works in terms of cost–benefit ratio. Given the additional cost of mitigation work, an appropriate indicator for comparing the resilient strategy to others is the break-even point, commonly used in investment evaluation contexts.

Financing for resilience using insurance adaptive schemes coping flooding risk

Approbation Publication No. 7 describes the initial attempt at a basic model for addressing flood risk, involving stakeholder choices (specifically, the public administration responsible for flood risk in a given area) among options such as no insurance, insurance, or insurance combined with investments in mitigative infrastructures.

In this subsection, we do not consider the role of new information collected after the choice time, which could be integrated into contract design. For example, considering trend variations in risk exposure, registered losses, and the comparison between the premium paid and registered losses over time could generate a potential surplus for investment in mitigative infrastructures. This model is refined in publication Approbation Publication No. 7 and utilized to formulate assumptions for the System Dynamics model outlined in sections 2.3 and 2.4.

A multiphase insurance adaptive scheme addressing flood risk in a specific area begins by considering a random variable Y that describes the risk level in the insured area. This variable could represent factors such as rainfall, water levels of rivers, or other indices measuring the primary source of flood risk. Historical series observations (y_i, $i=1,2...n$) allow us to estimate the distribution of the random variable Y (i.e., $F(Y)$).

Let X be the random variable describing random loss due to flood risk in a fixed unit of time in the insured area without any mitigative infrastructures. Historical series observations (x_i, with $i=1,2...n$) allow us to estimate the distribution of the random variable X (i.e., $F(X)$). Applying a premium principle based on the distribution of X enables us to determine a premium $P[X]$ per unit of time.

The insurance contractual conditions need to consider estimates related to the random variable X. It could be valuable to estimate a regression model between X and Y, directly linking contractual conditions to the original source of risk, especially in cases of data scarcity for losses. Hydraulic engineering expertise could help estimate the regression function between X and Y when various mitigative infrastructures are built.

Assuming C_i, with $i=1,2...m$, as an increasing sequence of infrastructure costs, we can determine the regression functions li (with $i=1,2...m$), describing decreasing risk exposure given the distribution of Y. So, let $P[Xi]$, $i=1,2...m$, be the premium per unit of time if infrastructure i is built. From the assumption of the efficiency of mitigative infrastructures, we have $P[X_i] < P[X_{i+1}]$ for each i.

If t_i is the time necessary to build up infrastructure i, let's assume that before the infrastructure is finished, the risk exposure remains the original one. Although a more detailed assumption about the evolution of risk exposure during the building time can be considered, we prefer to focus on a simplified version.

Let l be the regression function between X and Y without any mitigative infrastructures $X=l(Y)$. The fundamental choices for stakeholders, such as public administrations responsible for flood risk, include:

1. No insurance (and no resilience action), paying random losses (average $E[X]$ for each unit of time).
2. No insurance, taking resilience action through mitigative infrastructure i, and paying random losses (average $E[X]$ for each unit of time) plus the constant amount c_i/t_i.
3. Insurance and no resilience action, paying a constant amount $P[X]$.
4. Insurance and resilience action through mitigative infrastructures i, paying a constant amount $P[X] + c_i/t_i$ until time t_i; after that, the premium $P[X_i] < P[X]$ for each unit of time.

Considering there are m possible infrastructures, strategies *II* and *IV* have m different scenarios. The comparison between *I* and *III* depends on the randomness of future losses relative to the average value estimated for the past. A similar comparison can be made between *II* and *IV*, but since we don't have observations of the losses relative to r.v. Xi (for each $i=1,2...m$) due to historical series not considering risk mitigation by infrastructures i, estimation relative to r.v. X_i is based solely on engineering expertise.

Thus, the authors focus on the crucial choice between *III* (average is the same as *I*) and *IV* (average is the same as *II*) for each infrastructure i, with $i=1,2,...m$, choosing between no resilience and resilience. The present value (*PV*) of the total cost, with a discount rate r, is considered for a fixed time T, leading to the following expressions:

$$PV(III) = \sum_{j=1}^{T} P[X](1+r)^{-t_j} \tag{26}$$

$$PV(IV,i) = \sum_{j=1}^{i} \left(P[X] + \frac{c_i}{t_i}\right)(1+r)^{-t_j} + \sum_{j=i+1}^{T} P[X_i](1+r)^{-t_j} \tag{27}$$

In the given scenario outlined in the preceding subsection, let's consider a regular time grid s_i, where i=0,1,2,…,k, at which we reset the insurance contract accordingly. We initiate the process without any infrastructure, relying on engineering expertise estimations of infrastructure costs and their associated risk reduction effects. If P represents the constant total premium paid from s_i to s_{i+1} (with i=0,1,2,…,k-1), and $X\ (i,\ i+1)$ denotes the total loss incurred in the same interval, two distinct cases emerge. In the first case, P < $X\ (i,\ i+1)$, and in such instances, the insurance system covers the larger losses. Conversely, in the second case where there's a surplus P < $X\ (i,\ i+1)$, the adaptive contract design may allocate a portion of it, denoted by a in the range $(0,1)$, back to the insured.

These surpluses are aggregated, and the insured, typically the public administration, then has the choice of which kind of infrastructure to invest in. If the decision is to invest in infrastructure i, the stakeholder must wait to accumulate a total surplus equal to its cost, c_i. At the designated time, according to the regular grid introduced earlier, a new contract begins. The premium paid by the insured must be estimated using information collected up to that time for a contract of further duration t_i, representing the time necessary to build up infrastructure i. Following this additional duration, the insurance contract proceeds with a premium $E[X_i]$, considering the expected loss associated with infrastructure i.

It's worth noting that with this adaptive model, the starting premium P must be higher than the expected loss since it needs to generate the surplus required to finance the mitigative infrastructure. Only when the necessary surplus has been raised does the insurance premium become fair relative to expected losses. This design with a fixed premium and surplus distribution aligns with the legal framework of smart contracts. The new definition of the premium requires a renegotiation between the two counterparts, as stipulated by the same legal environment.

The optimization problem in this adaptive insurance scheme aims to determine the strategy that minimizes the total cost, as discussed in the preceding subsection. The optimal strategy is defined in terms of the pair P and infrastructure i. It's crucial to compare equivalent strategies, such as no insurance or only insurance (without resilience), within this optimization problem. The total cost for the strategy (P^*, i^*) is expressed as follows, where s_i represents the expected time at which the necessary surplus c_i is collected:

$$PV(P^*, i^*) = \sum_{j=1}^{i} P(1+r)^{-s_j} + \sum_{j=i+1}^{i+ti} P[X](1+r)^{-t_j} + \sum_{j=i+ti+1}^{T} P[X_i](1+r)^{-t_j} \tag{28}$$

This formulation captures the core of the optimization problem within the adaptive insurance scheme. It takes into account not only premiums, surpluses, and infrastructure costs over time but also delves into the identification of potential strategies for insurance companies. One such strategy involves allocating a portion of the surpluses to bolster investments in Disaster Risk Reduction (DRR) strategies. This, in turn, aims to raise awareness and encourage increased insurance coverage for both assets and civilians.

In essence, the optimization problem extends beyond the traditional scope of insurance dynamics. It explores how the adaptive model can be strategically leveraged to contribute to broader societal goals, such as enhancing disaster resilience. By channeling surpluses into DRR initiatives, insurance companies not only fulfill their financial objectives but also actively participate in fostering a more resilient and well-protected community. This approach aligns with the evolving role of insurance in comprehensive risk management strategies, transcending the conventional boundaries of financial compensation to become a proactive force in promoting overall societal well-being.

Flood risk insurance: from Blockchain to a Bayesian adaptive design contract

Approbation Publication No. 8 introduces an insurance contract designed to address flood risk in a multiperiodic scenario, employing an adaptive Bayesian scheme. The exploration delves into the opportunities and criticisms inherent in the perspectives of the disciplines involved, namely actuarial, engineering, and law. The intricate details related to the informatics aspects tied to blockchain technology are intentionally omitted, as this subject is best addressed in specialized informatics literature. It is noteworthy that the classical actuarial approach, specifically Bayesian adaptation facilitated by the accumulation of new reliable information on the considered risk, can be seamlessly integrated into a smart contract framework with the support of blockchain technology.

Publication No. 8 explores the interconnected relationship between smart contracting, blockchain technology, and the Bayesian adaptive design of contracts for flood risk insurance. The integration of quantitative tools for urban resilience assessment, coupled with innovative information technology (IT) tools and the processing of big data from GIS and satellite monitoring, underscores the need for more resilient insurance mechanisms supported by flexible contracting, such as smart contracts. This publication provides a comprehensive overview, covering general aspects of measuring and mitigating flood risk from an engineering perspective, conducting an in-depth analysis of legal aspects related to smart contracts over multiple periods, and presenting a Bayesian adaptive design of the contract within an actuarial framework.

Significantly, this publication is instrumental in paving the way and emphasizing the development of research directions for multidisciplinary research. The escalating concentration of human populations in urbanized areas has heightened exposure to flood recurrence times, posing challenges in implementing effective mitigation measures, especially concerning land availability in potential flood risk zones.

Critical Infrastructures (CI), among various assets experiencing increased risk due to heightened exposure, deserve specific attention. CI encompasses systems, networks, and assets crucial for society's functioning, public health and safety, and a nation's economy. These engineering and technological networks, including energy and water supply, transport services, oil and gas supply, banking and finance, and information and communication technology (ICT) systems, are critical for maintaining essential societal functions. Failures in these systems can significantly impact the population, economy, and national security [19, 20].

The complexity of urban systems, coupled with the increasing complexity of CI systems, necessitates strengthening interactions among people, activities, and properties [15]. This complexity heightens vulnerability, especially given the limitations in building new infrastructures in high-risk areas due to land constraints [20, 21]. Consequently, the intricate nature of infrastructures and urban systems restrains component activities during crisis periods. These observations underscore the critical attention of policymakers, economists, urban planners, engineers, insurance companies, and scientists. Their collective focus aims to develop innovative Risk Management frameworks that are more sustainable and resilient in addressing the effects of climate change and natural hazards.

Approbation Publication No. 8 underscores that flood risk assessment often revolves around estimating potential loss and damage costs. However, due to data scarcity, it is frequently impractical to conduct such assessments for each individual infrastructure or asset at risk. In response to this limitation, insurance companies commonly resort to using proxies in their databases to overcome data shortages.

From the presented perspective, there is a compelling need to shift towards a holistic risk reduction approach for areas prone to natural disasters. This approach should not only encompass engineering infrastructural systems but also consider social and territorial dimensions, including human, environmental, financial, and political systems, which collectively contribute to either enhancing or diminishing overall resilience. Consequently, it becomes crucial to evaluate how potential improvements in Critical Infrastructure (CI) infrastructure, encompassing both hard and soft measures, along with financial and insurance mechanisms, can optimize overall territorial resilience.

In the pursuit of enhancing infrastructural resilience from an engineering standpoint, it is essential to emphasize the spatial and time-dependent nature of preparation, resistance, and adaptation capacities to flood risk. These aspects highlight the need for new and innovative technologies to support an integrated Risk Management approach aimed at strengthening resilience at the urban level. Notably, recent advances in computing power, particularly in the processing of

Big Data, have been pivotal. However, challenges arise when analyzing and processing diverse datasets, such as environmental, flooding, geological, weather, satellite observations, topography, cadastral location, corporate, specific insurance, and socio-economic data, specifically tailored for flood risk evaluation [42].

Publication No. 8 underscores the findings from Rumson [42], emphasizing the imperative to enhance flood risk assessment through improved programming device capabilities to store, process, and analyze both aggregated and disaggregated data. This highlights the need for a holistic approach to data collection, analysis, and processing using various analytical tools, including Geographical Information Systems (GIS), probabilistic modeling, and the definition of damage curves. This multidisciplinary approach can support the development of proper insurance-based mechanisms as adaptive options to increase local resilience to flood risks.

In this context, blockchain technology emerges as a promising platform for mitigating risk and vulnerability in the collection and analysis of diverse data sources, such as Big Data related to GIS systems, environmental variables, exposure data, and social media data. Blockchain enables real-time risk assessment, leading to a more precise definition of risk-based pricing for insurance policies, addressing potential losses.

The technical definition of blockchain as a "*decentralized ledger and cryptographically secure transaction*" [64] is highlighted. It is not merely a tool for payment or exchange of goods and services but introduces a revolutionary capability, allowing the exchange of properties on the internet. Blockchain operates as an international safe register shared by all entities within a specific computer network, relying on peer-to-peer technology. Its decentralized nature eliminates the need for central repositories, fostering a peer-to-peer transactional network recorded in blocks, constituting the blockchain. All transactions are recorded and verified directly by the system and are only possible when approved by over 50% of the network nodes [65]. The European association of credit institutions has expressed a positive opinion on the reliability of the blockchain system, with its key characteristic being decentralization, as there is no central repository but a peer-to-peer transactional network among users.

Publication No. 8 underscores the capability of digitizing and representing the characteristics of any good or data through a code, enabling the storage and security of this information in a distributed register. This applies not only from a static perspective but also dynamically. Operations and agreements between network nodes can be tracked, and the execution can be automatically carried out by the Blockchain itself without the need for intermediaries. This capability is made possible by Smart Contracts, which, functioning as IT protocols, formalize agreement elements and automatically execute predefined terms when the specified conditions are met.

To provide a clear understanding of the operation of smart contracts, it is defined as a piece of code stored on a Blockchain, triggered by Blockchain transactions, and interacting with the Blockchain's database [52]. The rapid development and evolution of Smart Contracts have led to their increasing application. Open-source projects such as Ethereum, Counterparty, and Mastercoin have contributed to the creation of increasingly sophisticated Smart Contracts. Currently, these contracts are employed for the automatic execution of derivatives, futures, swaps, and options and even for building platforms for the sale of goods on the Internet without central authorities [53].

Regarding the specific focus of this paper, the state-of-the-art analysis, closely tied to the blockchain's current regulatory substrate, primarily explores dynamics within the insurance sector. In this sector, innovative forms of insurance utilizing Smart Contracts have emerged. Examples include Insure ETH, a UK startup specializing in airline reimbursements, and a pilot project by the

American International Group (AIG), IBM, and Chartered Bank collaborating on a Blockchain insurance Smart Contract for multinational coverage.

The paper identifies a significant implementation gap, suggesting a shift from a purely refund-based insurance blockchain to a big data management approach coupled with smart contracting. This transition enables the implementation not only of standard smart contracts but also multi-period contracts. In a multi-period implementation, the contractual structure, including the insurance premium, compensation amount, or risk percentage, can be modified periodically using blockchain technology and data from external certified sources.

In the context of natural disasters, the scanning of temporal phases in a multi-period contract allows essential elements to be changed or modified without terminating the contract or requiring a new agreement between the parties. The paper emphasizes that this approach enables the blockchain to be more than just a verifying agent of the insured event and transforms it into a powerful tool for storing and managing information from a multi-dimensional perspective.

The distinction between the one-dimensional perspective, where blockchain primarily verifies the insured event, and the multi-dimensional perspective, where blockchain facilitates the perpetuation and modification of the contract over time, is highlighted. In the latter, data relevant to insurance dynamics against natural hazards, such as rainfall, river height, and previous damage, serves not only to create a network of useful information but also to store this information securely using blockchain technology. The implementation of a multi-phase contract involves the continual modification of initial parameters based on the flow of data and the mutual consent of the parties involved.

Building upon the concepts of smart contracts and blockchain introduced in Paper No. 8, an actuarial model with a Bayesian adaptive design for the contract is proposed. Consider the set of data, denoted as $H(0)$, representing information collected at time 0, originating from time $-m$. Let the function W represent the premium to be paid for one unit of time until the first updating time, as detailed below.

$$W(0) = f(H(-m, 0) \equiv f(H(0)) \tag{29}$$

Within this dataset, we include information on damages resulting from the insured risk. Additionally, the dataset encompasses relevant details related to flood risk, mitigative infrastructures, and other pertinent factors. This information plays a crucial role in the comprehensive analysis and understanding of the risk landscape, allowing for a more nuanced evaluation of the effectiveness of mitigative measures and the overall resilience of the system in the face of potential hazards. The inclusion of these diverse data points facilitates a holistic examination of the complex interplay between insured risks and various contributing factors, contributing to a more robust and informed risk assessment framework.

Consider the sequence of updating times in the contract denoted as m_1, m_2, and so forth (i.e., m_i). At any given time, m_i, where i takes values from $1, 2,$ and beyond, the updated premium is determined by leveraging the information collected starting from $-m$, denoted as $H(-m, m_i)$. The calculation for the new premium that must be paid until the updating time m_{i+1} is defined by equation 30 as follows:

$$W(i) = f(H(-m, m_i) \equiv f(H(i)) \tag{30}$$

Let's assume that the collected information $H(0)$ comprises the historical series of damages, denoted as $x(i)$, where i takes values from $-m$ to 0 (i.e., $i = -m;-m+1, \ldots 0$), representing each time unit from $-m$ to the issue date 0 (refer to equation 31).

$$H(-m,0) = x(-m), x(-m+1), \ldots x(-1), x(0) \tag{31}$$

Let's assume $H_r(0)$, where $r = 1, 2, \ldots$, represents the estimate of the r-th moments of this random variable. If we adopt a premium principle based on a variance-style charge, our interest lies solely in $H_1(0)$, $H_2(0)$, and so on. The premium for a time unit starting from the issue date, denoted as $W(0)$, can be expressed as outlined in equation 32.

$$W(0) = f(K_1(0), K_2(0)) \tag{32}$$

Commencing from the issue date, the contract entails payments of the premium $W(0)$ for each unit of time until the first contract update at time m_1, triggered by the arrival of new information denoted as $H(1, m_1) = x(1); x(2) \ldots x(m_1)$.

At time m_1, leveraging all the information recorded in the interval $(-m, m_1)$, new estimates for $H_1(m_1)$ and $H_2(m_1)$ are obtained. Consequently, the premium is updated as articulated in equation 33.

$$W(m_1) = f(K_1(m_1), K_2(m_1)) \tag{33}$$

This premium must be paid for each time unit from $m_1 + 1$ to the next updating time m_2.

Now, let $n_i = m_i - m_{i-1}$, where i takes values from 1, 2, and so forth, representing the number of time units between mi and m_{i-1}. Consequently, the total premium paid in such an interval is $n_i W(i)$. The disparity between this total premium and the total claim in the same time interval, denoted as $C(i)$, is expressed in equation 34.

$$n_i W(i) - C(i) = U(i) \tag{34}$$

This represents either a profit or a loss for the insurance company. The contract may stipulate that in the case of a profit, i.e., when $U(i)$ is positive, a portion of the surplus earned by the company will be shared with the insured. This sharing can take the form of infrastructural investments aimed at risk mitigation. The assessment of the costs associated with mitigative infrastructures and their impact in terms of risk reduction requires an engineering analysis, as described in paragraph 1.

The influence of infrastructural investment on this numerical model can be introduced through a non-decreasing sequence of thresholds, denoted as $L(i)$, where i takes values from 1, 2, and so forth in the interval (m_{i-1}, m_i). These thresholds affect damages during the same time period: the higher $L(i)$, the lower the expected total damage $C(i)$.

The assessment of the relationship between surplus and threshold increase needs to be carried out using engineering considerations. It is reasonable to account for a delay between the emergence of the surplus and its impact on the threshold, owing to the time required to complete the infrastructures.

The role of blockchain technology lies in certifying the collected information and automating the changes in contractual terms (i.e., the premium level and surplus sharing) at each updating time.

This automation is central to the concept of smart contracting, involving the update of the contract without a new negotiation between the two parties. This approach has been of paramount importance for implementation in the System Dynamics model, as presented in section 3.4, and aligns with the principles outlined in Approbation Publication No. 1.

In Publication No. 8, the author initially highlights a notable regulatory gap within the insurance industry while exploring the potential advantages arising from the implementation of blockchain using a Bayesian quantitative approach. A pivotal focus in Publication No. 8 emphasizes that in Europe, specifically in Italy, a regulatory framework capable of accommodating the proposed smart contract exists. This is exemplified by the Fizzy Axa contract, which adopts blockchain technology for the insurance contractual framework, allowing for seamless real-time data flow [192].

Furthermore, Publication No. 8 presents crucial insights into the application of the proposed insurance premium calculation approach, extending its relevance to public administrations. It underscores the necessity for evaluating investments in mitigation, considering the potential future reduction in risk coverage costs within such a context.

Publication No. 8 underscores the imperative to reiterate the absolute need for a national or, preferably, a European platform to effectively operationalize the transfer of the described risk to financial markets [164]. Therefore, it is essential to emphasize that the legislative elements governing each step of this process should be agreed upon in a European context. This approach ensures compliance with the principles outlined in supranational treaties and the Covenant of Mayors [193], avoiding fragmented harmonization of national regulations.

Publication No. 8 underscores the potential applicability of the proposed premium risk calculation in developing a quantitative infrastructure resilience model. This aligns with the contemporary necessity, as mandated by national regulations, to conduct a mathematical study before arriving at significant political, business, and financial decisions, particularly those related to mitigating structures. This consideration extends to the development of contractual insurance structures, including what are commonly known as Resilience Bonds.

The discourse surrounding Resilience Bonds is currently grappling with the challenge of determining whether the increased cost associated with funding mitigation infrastructures is practical compared to a conventional insurance method [194]. This traditional approach typically involves addressing only claims payments over varying time periods.

Approbation Publication No. 8 underscores the significance of employing diverse alternative analytical methods in the strategic planning of insurance organizations. Break-even analysis and the assessment of income stability, serving as robust indicators, prove instrumental in addressing information asymmetry within insurance contracts. Moreover, these methods contribute to monitoring the key success factors crucial for the financial and economic development of insurance organizations. A well-balanced insurance portfolio and the potential for growth emerge as integral facets influencing an insurer's competitiveness.

A comprehensive examination of the insurance portfolio facilitates strategic planning for future periods, ensuring both the financial stability of insurance operations and the solvency of the insurance firm. Furthermore, it highlights the importance for insurance companies to possess the authority to determine client premiums, a task complicated by risk ambiguity, moral hazard, and associated uncertainties. The viability of catastrophic insurance relies on the existence of sufficient demand, with factors such as income levels, risk knowledge, risk perception, and the expectation of post-disaster public reimbursement influencing willingness to pay.

In a broader context, cultural, behavioral, and educational factors play a crucial role, as the demand for insurance is not solely governed by a logical trade-off between the price of the policy and its anticipated benefits. Finally, the presence of robust institutions and a clear regulatory framework emerge as indispensable for fostering the growth of competitive insurance markets.

Given the flood risk context, Approbation Publication No. 8 emphasizes that an automatic updating scheme of the contract could extend to include infrastructures tasked with risk mitigation. Furthermore, this component of the contract could be intricately linked to the certification approach facilitated by blockchain.

Future developments in this research could manifest in diverse directions. The engineering and actuarial approaches need to engage in a productive dialogue to render their respective analyses mutually beneficial. Simultaneously, the legal perspective must elucidate all aspects to ensure that the automatism provided by smart contracts in multiperiodic scenarios is not only conceivable in theory but also effective in practical applications.

A Multi-Disciplinary Approach in insurance contracts coping with Natural Hazards

As mentioned, the role of risk insurance in the context of socio-natural disasters is key for the effective execution of pre-disaster risk reduction strategies. This aspect is crucial in supporting comprehensive risk management efforts aimed at diminishing marginal risks. By empowering policyholders to transfer risk, this approach significantly alleviates the substantial financial burdens associated with costs incurred during the post-disaster recovery phase.

Publication No. 9 underscores a critical observation: the absence of an integrated risk insurance strategy for community resilience planning. This deficiency hampers the establishment of properly optimized holistic risk management. On the one hand, it reinforces pre-disaster risk mitigation measures, primarily relying on mitigative infrastructural solutions. On the other hand, it contributes to the better definition of risk prevention strategies, mainly associated with land planning and urban development.

This paper seeks to demonstrate the pivotal role that insurance markets can play in mitigating the economic consequences of natural and climate change disasters. It emphasizes the need to quantify more precisely the beneficial effects and costs of engineering-based mitigative solutions. In this context, a robust legal framework is essential for implementing the actuarial quantitative model, facilitating the creation of an integrated multidisciplinary approach. This approach holds the potential for implementation on a novel platform capable of collecting and processing information from various sources and dimensions, such as blockchain technology.

The scientific community is increasingly interested in employing blockchain technology to address issues related to the contractual dimension of natural disaster risk insurance, which can be conceptualized as a form of smart contracting. Through a comprehensive study involving law, environmental engineering, insurance, and IT, this paper proposes a specific multidisciplinary methodology. The goal of Publication No. 9 is to draft and implement a digital insurance contract on a blockchain platform tailored to mitigate natural hazards, advancing a quantitative concept to optimize the impact of catastrophe risk insurance on community resilience. It provides a key synergy for defining pre-disaster conditions and offers insights into a multidisciplinary approach that can contribute significantly to the field.

Governments, as well as legal entities, play a crucial role in the insurance landscape, exemplified by instances such as flood insurance. This type of insurance is intricately linked to land planning, investments in adaptation, and coverage for vulnerable assets [58]. Against the backdrop of an alarming rise in economic losses resulting from disasters, particularly in the context of climate change (most notable in non-insured losses) [195] [196], more precise risk assessments demand extensive data processing from diverse dimensions (e.g., environmental, geological, weather, insurance-specific, engineering, legal, socio-economic). Consequently, the adoption of proper data platforms and leveraging *Big Data* becomes imperative for pricing optimal insurance premiums [197]. This approach can effectively reduce the risk in hazard-prone communities, subsequently enhancing overall community resilience. It also provides an opportunity to allocate economic resources strategically, particularly to more vulnerable locations, addressing the challenge of non-insured assets [198].

In this context, emerging technologies such as *Blockchain* have garnered interest, especially in insurance applications. The feasibility of smart contracts in the insurance sector, particularly for instantaneous insurance, holds promise. The insurance industry is increasingly exploring blockchain technology, introduced by Nakamoto's milestone paper [199], as evidenced by documents from major insurance groups [200] [201] and consultancy firms [202] [203]. The establishment of the B3i in 2016, the first blockchain-centered insurance consortium [204], further underscores this trend.

While peer-to-peer insurance or reinsurance is a potential field for blockchain application [205], current models still rely on traditional insurance structures. However, smart contracts, considered an innovation, have been prototyped using the Ethereum blockchain [206].

This interconnection and multidisciplinary approach can bolster the development of insurance-based mechanisms for adaptation, contributing to increased local resilience against various disasters. Blockchain technology, in this regard, serves as a robust platform for mitigating risk and vulnerability through the collection and analysis of diverse data sources (e.g., Big data related to GIS systems, Environmental variables, Exposure data, Social media data). This enables real-time risk assessment and facilitates a more precise definition of risk-based pricing for insurance policies, considering potential losses. Publication No. 9 further emphasizes how the adoption of blockchain technology within a multidisciplinary framework can enhance overall community resilience to natural disasters, emphasizing the application of smart contracts in natural hazard insurance.

The evolution of smart contracts within blockchain technology has primarily focused on automating compensation mechanisms in the insurance industry [207]. However, there is a significant gap in implementation, pointing toward the need for a transition from purely refund-focused insurance blockchains to ones centered on big data management [208].

The current one-dimensional perspective of contracts primarily focused on a single period or contractual phase, is evident. Data entered into Blockchain technology undergoes a transformation into legal effects, such as compensation, within a single phase, lacking the ability to extend or modify the contractual structure. However, the future may see a shift toward a multi-phase contract involving periodic data scanning aimed not at contract termination but at evolution, change, and adaptation.

Paper No. 9 identifies the minimal and necessary features of a multi-phase contract, including onerousness, randomness (uncertainty), IT stipulation through an online platform using blockchain technology, the incorporation of blockchain technology, real-time data flow, and automatic renegotiation. These features, applied to insurance dynamics against natural hazards, can create and store a network of valuable information to counteract risk phenomena. The implementation involves the perpetuation of the contract, step by step, modifying initial parameters based on the consensus expressed by the parties.

The analysis of contracts with these characteristics within the Italian regulatory system can provide valuable insights. In terms of contract cost, the relationship between advantage and performance is pivotal, drawing parallels with examples from the Italian civil code, such as the sale of assets. The aleatory nature of the insurance contract is evident, given the uncertainty of the occurrence of a determined event, making it a perfect example in the context of this research.

The European association of credit institutions expresses a positive opinion about the reliability of the blockchain system, emphasizing its decentralized nature. Blockchain architecture, characterized by decentralization, eliminates the need for a central repository and operates on a peer-to-peer basis. In a standard blockchain structure, transactions are created and validated by active users, or nodes, in the network. Miners, also participants in the architecture, create blocks in the network.

Publication No. 9 expands on blockchain and smart contracting applications across sectors, including air flight delays and variable mortgages. It delves into the legal and technical aspects of connecting blockchain with smart insurance contracts, exploring the distinctions between Standard Smart Insurance Contracts and Multi-Period Contracts. Additionally, it discusses potential drawbacks for Smart Insurance Contracts in the context of natural hazards.

In its main findings, Publication No. 9 proposes a methodological approach, integrating engineering, insurance-actuarial, legal, and IT dimensions within a blockchain-supported platform. This multidisciplinary platform aims to optimize the interaction of regulatory, insurance, and engineering dimensions, facilitating the development of a tool capable of processing diverse information types. The use of blockchain technology in risk reduction strategies for natural hazards is highlighted.

Within this definition, a customized blockchain platform for "community" risks is proposed for environmental risks in specific geographical areas. This involves disciplines such as engineering (estimating accident probabilities, designing risk mitigation tools, and assessing potential damage), legal (legislation for public-private synergies and supervising the digital platform), actuarial (quantifying bonuses for potential damage coverage transfer), and IT (establishing a blockchain-based digital platform) (see Figure 3.2).

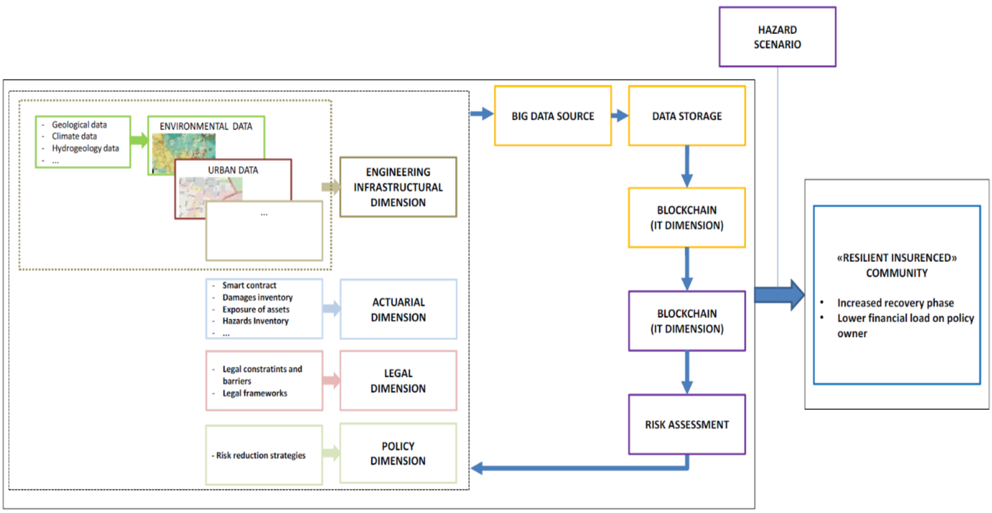

Figure 3.2. Novel multi-disciplinary approach for Blockchain implementation.

In this methodological approach, blockchain technology's role is to certify collected information and automate contractual term changes, which is essential for smart contracting. The automation, constituting the core of smart contracting, updates the contract without requiring a new negotiation between the parties.

The initial step involves creating an inventory of local hazards, assessing their occurrence, and gauging potential impacts on assets at risk. The method maps potential mitigation strategies applicable in a local context, emphasizing infrastructural dimensions and exploring the benefits of these strategies.

The proposed platform, based on this approach, could leverage open-source data and Big Data in a certified and validated manner. Blockchain, in premium computation and risk assessment, acts as a shared ledger recording individuals' and assets' histories [69]. This enables insurance companies to determine premiums automatically based on trustworthy data. The flexibility of blockchain and smart contracts allows policies and coverage to be activated or deactivated based on collected and validated data.

Blockchain has become a platform to mitigate risk and vulnerability, collecting and analyzing data from various sources. This enables real-time risk assessments and precise risk-based pricing of insurance policies, contributing to a more adaptive risk reduction tool. This approach enhances overall resilience and allocates financial resources effectively, particularly to vulnerable areas.

This methodology finds relevance in urban disasters, requiring innovative approaches to disaster management and building urban resilience. It aligns with sustainable development plans, especially within the framework of Sustainable Energy and Climate Action Plans (SECAPs) for Municipalities [71].

However, concerns exist, including scalability limitations, potential congestion, integration challenges between different blockchain platforms, and the inherent complexity for average users. These challenges may lead to skepticism and concerns about fraud associated with blockchain products. The methodological approach also includes a Bayesian calculation method, emphasizing the importance of multidisciplinary connections for technological implementations in the insurance field.

In summary, Publication No. 9 presents a comprehensive approach that integrates various scientific areas, leveraging blockchain to enhance risk reduction, resilience, and optimized insurance practices.

3.3. Case studies

Insurance mechanism for cultural heritage with Adjusted Gross Revenue

Natural hazards, particularly those exacerbated by climate change, have been causing an increasing number of catastrophic events, elevating the likelihood of damage also to cultural heritage. The escalation in both the frequency and economic consequences of hazards triggered by natural disasters propels the development of insurance tools and schemes as risk financing and management instruments.

The current status of the insurance market, especially in Italy concerning biological and natural disasters, depicts a general context where the assets of individuals are not adequately insured against the risks of disasters. In contrast, only a limited number of public entities and small to medium-sized companies are insured with specific policies covering earthquakes and floods. However, there has been a slight upward trend among medium to large companies in the last decade, as they have judiciously taken advantage of specific insurance policies. According to Porrini, the cause of the lack of penetration of insurance policies among individuals can be traced to the so-called "disaster *syndrome*", a state of shock and bewilderment common in the impact phase of disasters due to distortions on the demand side and insufficient supply of coping disaster resources [209].

Looking at the Italian context as an example of a country exposed to several socio-natural hazards, including biological hazards, and with exposed cultural heritage

The health emergency caused by COVID-19 immediately reverberated its effects on cultural heritage [5]. As of February 24, 2020, the Italian Ministry of Culture (MIBACT) had suspended free admission to museums and places of culture from Sunday, March 1, 2020. A decision preceded a few days before by the closure of museums, cinemas, and theaters in the areas most affected by the pandemic, which was followed, in the days immediately following, by the suspension throughout the national territory of the public opening services of institutions and places of culture [210]. In the following months, from May 2020, the opening service to the public of museums and other cultural institutes and places was allowed under certain conditions, and, from June 2020, the holding of shows open to the public in theatrical halls, concert halls, cinemas, and other spaces. Indeed, from November 6, 2020, the exhibitions and public opening services of museums and other cultural institutes and places have been suspended again [211]. Disaster prevention is essential to save cultural heritage. Management and investigations after a disaster are also very important to define the extent of damage to movable and immovable cultural heritage [212]. This represented a massive impact on the incomes of such economic activities.

Within this context, the Italian experience with the Department of Civil Protection (CPD) and the Ministry of Civil Protection seems appropriate also for the European context. In fact, setting up a special Committee that has recently disseminated, released, and published behavioral models compiled by specially trained teams after an earthquake seems a consistent approach. These models allow a description of the damage, calculate vulnerability indexes, and estimate the cost of the intervention [55].

These preventive measures, in the general context of hazards, regardless of their nature, are typically sorted into two categories: structural and non-structural. Structural measures are challenging to materialize in the case of cultural heritage protection because they are mostly visible, disturbing, and often not cost-effective [213].

The Approbation Publication No. 2 is part of a broader research effort by the authors, building upon assumptions and results obtained in the context of a case study involving the assets of *Villa Adriana* and *Villa D'Este*. The objectives of Approbation Publication No. 2 focus on unveiling an innovative strategy for an *ex-ante* (prevention and mitigation) and *e-post* (recovery and adaptation) risk mitigation. This strategy is aimed at economic heritages vulnerable to damage and losses, particularly those, like the Covid-19 pandemic, that can impact profitability broadly.

The paper specifically addresses cultural heritage exposed to socio-natural hazards, emphasizing the irreversible damage and destruction caused by long-term climate effects and disasters. This is also indicated by the European Parliament: "*Prolonged climate impacts and other disasters occasionally lead to irreversible damage to cultural heritage or the complete destruction of entire areas of cultural heritage, including both movable and immovable elements*" [214]. The study shifts attention to the financial impact of Covid-19 on a specific heritage: *Villa D'Este* and *Villa Adriana* in Tivoli, Rome Province, chosen due to their significant income loss during the pandemic.

Villa Adriana and *Villa D'Este* in Tivoli are among Italy's most significant UNESCO-designated cultural sites [215]. Although the cultural site is now viewed as a whole, the assets were initially divided, with *Villa Adriana* being designated as a World Heritage Site in 1999 and *Villa D'Este* as a World Heritage Site in 2001. The grounds of the Villae include an amazing concentration of fountains, nymphaea, grottoes, water themes, and an organ that produces audible effects created by water. The choice of the site of the two Villae underlies a multiplicity of factors and motivations [210].

A cultural asset, in this case, *Villa Adriana* and *Villa d'Este*, should be subject to an economic risk assessment in the event of a catastrophe of any kind, including environmental (in the sense of climatic events and their consequences, such as a flood), seismic, fire, or health-related (such as the pandemic). Different hazards have distinct effects on specific budget items, both on the revenue and expenditure sides. The Italian context was selected to illustrate how the pandemic impacts ticket sales by decreasing them.

As mentioned in the introduction, the paper fits into the context of broader scientific research on the relationship between biological hazards and cultural heritage. In particular, this section refers to the sum of the losses from non-incomes suffered by the cultural heritage mentioned in the case study, specifically *Villa Adriana* and *Villa D'Este*, during the pandemic outbreak from Covid-19.

However, unlike a pandemic, a fire or a flood in some of the structure's spaces would likely lead to the site's temporary closure and negatively impact ticket sales. Moreover, unlike a pandemic, this scenario probably involves significant costs to restore the structure's full efficiency [216].

Both engineering-structural prospective analyses are required to assess the effects of these costs or lost profits. From the forecast of non-income losses from ticket sales [209], it might be possible to evaluate the potential use of insurance coverage to deal with the risks described above, considering a flexible component of the periodic cost based on the ongoing registered claims experience. In the next part, a case study is proposed, starting with a quantification of the premium with a flexible insurance approach.

Consider a random variable X that describes the theoretical amount of compensation in the time unit (for example, one year), from which an insurance premium P can be calculated. In traditional insurance, this premium is considered constant for each period of coverage and is a function of the distribution of X. The variable X encompasses all damages [149].

The flexible approach involves recording the suitable compensation amount during the period preceding a recalculation and redefinition date (t) from the inception (start) of the insurance coverage, which can be fixed as time 0, representing the compensation for t years, denoted as $Y(0,t)$. The frequency of recalculation must be contractually determined and outlined annually or at a different specified frequency.

Let $Y(0,t)$ represent the total amount compensated by the insurance company, and P denote the sum of premiums paid by the insured within the same time frame. The flexibility lies in providing a *bonus-malus* scheme based on different predefined levels, as described in Equation 35 below:

$$Y(0,t) - P = D(t) \tag{35}$$

Should $D(t)$ exceed a certain threshold, meaning more compensation than premiums paid, the flexibility scheme might increase the premium until the next recalculation. On the other hand, if $D(t)$ is negative, there could be a decrease in the premium sum until the next recalculation or retrocession of part of $D(t)$ to the insured party, perhaps to be linked to risk mitigation works. More specifically, the potential progression of risk mitigation works, to be financed independently and/or through these hypothetical insurance retrocessions, may gradually decrease the total amount of insurance coverage, provided that the sum of the actual and effective damage is positively affected (i.e., reduced) by mitigation; otherwise, this flexibility scheme would end up generating positive $D(t)$ levels, consequently increasing the premium.

This section presents a real case study based on the methodology and calculation methods aligned with the Doctoral thesis and the approbation Publication No. 2. As highlighted earlier, cultural heritage has traditionally been considered a static element whose value is represented by the intrinsic value of the assets that compose it and the cost of reconstruction. Over time, companies have adopted traditional forms of risk mitigation and reconstruction insurance without the desirable diffusion for such a decisive and important issue for public welfare. Initially, insurance coverage focused on *ex-post* protection, involving the disbursement of equal sums, theoretically for the reconstruction of damaged assets. More recently, attempts have been made to provide ex-ante protection, allowing the constant disbursement of the insurance premium to allocate part of it to the construction of risk mitigation structures.

The author's idea in the possible development of a different approach lies in the notion that economic cultural heritages can no longer be understood solely as public assets, whose value is outlined by the cost of the immovable asset itself. Cultural heritage, exemplified by *Villa D'Este* and *Villa Adriana*, must be considered economic activities and industries exposed to the risk of natural hazards and business risk. Public entities, while not subject to insolvency rules, are susceptible to market rules and fluctuations in cash flow. Unravelling doubts about the systematic classification of economic cultural heritage as public industries, it seems appropriate to assess whether some form of insurance, initially used for other areas, could be useful for heritage when incomes are affected due to hazards, losses, and negative fluctuations.

To mitigate the catastrophe risk from natural hazards regarding financial losses, the author suggests evaluating the option of adopting a particular form of insurance, widespread above all in the USA in the agricultural field: protection derived from the Adjusted Gross Revenue (AGR). AGR insurance is a non-traditional insurance plan that allows the risk management of the entire company. It is a compelling product that could serve as a model for possible application in Italy and other European Union countries. AGR is a policy that insures company revenues, using the historical gross revenues of an agricultural company as a reference parameter, obtainable from tax data (average of the last 5 years) reported by the parties. This insurance product is applicable to any production sector.

Although closely related to the paper, the AGR Policy offers, among other features, insurance coverage for losses of gross revenues due to natural disasters or calamities. Using the data obtained from the paper on the calculation of Covid-19 losses for the heritage of *Villa D'Este* and *Villa Adriana*, the following calculations are reported after proceeding to the calculation table for the elaboration of the insurance premium and respective disbursement.

The data inventory necessary to calculate the AGR for the presentation of the case study is proposed in the table below with a reference to the years 2017-2019 (i.e., before Covid-19).

Table 3.6

Data inventory for the case study of Villa d'Este and Villa Adriana [210]

	2017	**2018**	**2019**
Tax charges, €	316491.81	31500.00	55905.12
Charges for active workers of service, €	229136.30	215000.00	161517.36
Purchase of goods of consumption and services, €	710067.95	801500.00	1209335.69
Recovery, restoration, adjustment, and maintenance of the immaterial assets (software/hardware) and material movable and immovable assets.	1237997.60	975000.00	1343449.73
Purchase of goods of consumption and services, €			
Ministerial and state grants: concession assets, €	200000.00	400000.00	199744.81
Ticket sales, €	3350822.12	4000000.00	4869535.94

According to Table 3.6, the eligible income for 2017 amounted to € 3,333,123.66, calculated as:

$$3350822.12 + 1237997.60 - 710067.95 - 229136.30 - 316491.81 = 3333123.60 \quad (36)$$

Once the eligible income has been determined for each year, the AGR is calculated by incorporating increases or decreases, as outlined in Table 3.7.

Table 3.7

Calculation of AGR

Year	Eligible Incomes, €	Increase/Decrease, %
2017	3333123.66	
2018	4327000.00	4327000.00/3333123.66 = 1.2981
2019	4985972.31	4985972.31/4327000.00 = 1.1522

The average eligible income is computed using the equation below.

$$\frac{(3333123.66 + 4327000.00 + 4985972.3)}{3} = 4215365.12\ € \quad (37)$$

The average percentage increase/decrease is derived from Equation 38.

$$\frac{(1.2981 + 1.1522)}{4} = 1.22 \quad (38)$$

The adjusted gross revenue can be calculated as:

$$4215365.32 \cdot 1.488 = 6274149.74\ € \quad (39)$$

The value is verified by the AIP (Approved Insurance Provider), which then utilizes it to calculate the insurance coverage. The insurance program offers different levels of income coverage. The insured individual may choose the package that best suits their needs. The packages offered include:

- 80/75 or 80/90 = coverage level of 80% with the payment of a rate of 75% or 90%;
- 75/75 or 75/90 = coverage level of 75% with the payment of a rate of 75% or 90%;
- 65/75 or 65/90 = coverage level of 65% with the payment of a rate of 75% or 90%.

Publication No. 2 envisages the introduction of an insurance policy known as Agricultural Risk Insurance (AGR). The study strongly advocates for the implementation of AGR, highlighting its potential benefits in curbing macroeconomic and financial repercussions, minimizing losses, and mitigating risks associated with natural calamities.

In order for insurance programs to operate optimally, they must satisfy a range of criteria, particularly in terms of their capacity to quantify risks and provide extensive coverage. The study accentuates the critical necessity of cultivating a comprehensive understanding of socio-natural hazards. This depth of understanding serves as a fundamental prerequisite for devising effective mitigation strategies aimed at preserving and safeguarding urban cultural heritage assets.

The effectiveness of insurance initiatives hinges on meeting specific prerequisites, notably the ability to quantify risks and provide comprehensive coverage. This study places significant emphasis on the imperative of acquiring a thorough understanding of socio-natural hazards. Such comprehension serves as a foundational requirement for the development of robust mitigation strategies tailored to protect urban cultural heritage assets.

This proposed approach offers advantages in terms of constraining macroeconomic and financial impacts, minimizing losses, and diminishing risks associated with natural hazards. This perspective aligns with a resilience and risk management strategy. The introduction of AGR not only has the potential to naturally introduce new operational dynamics to the insurance market but is also designed to alleviate the adverse consequences of a hazard. This is achieved, at the very least, by constraining costs and financial damages associated with such events.

Furthermore, the implementation of AGR represents a proactive step towards enhancing the overall resilience of the economic system in the face of natural calamities. By providing a financial safety net and reducing the economic fallout, AGR contributes to a more robust risk mitigation framework. This approach not only addresses the immediate financial impacts of natural disasters but also fosters a culture of preparedness and long-term resilience within the insurance industry and the broader economic landscape.

Socio-natural disaster effect in cultural heritage during COVID-19: losses estimation

The approbation Publication No. 3 focuses specifically on cultural heritage vulnerable to socio-natural hazards, emphasizing the irreversible damage caused by long-term climate effects and disasters. The European Parliament acknowledges that "*prolonged climate impacts and disasters can occasionally result in irreversible damage to cultural heritage, even leading to the complete destruction of entire areas, encompassing both movable and immovable elements*" [32].

The study then shifts its focus to the financial repercussions of Covid-19 on specific heritage sites, namely *Villa D'Este* and *Villa Adriana* in Tivoli, Rome Province, selected due to the significant income loss they experienced during the pandemic. Both sites are integral to Italy's cultural landscape and are recognized by UNESCO as among the most important cultural sites in the country [215].

The selection of these sites is motivated by several factors. Firstly, their inclusion in the UNESCO list underscores their qualitative importance on a national and international scale. Secondly, the entrepreneurial and economic management methods applied to these assets align with the criteria set by UNESCO. Thirdly, the ease of retrieving fiscal and economic balance sheets for the years 2017–2020 facilitates data analysis. Lastly, the geographical location of the sites and the unfavorable economic situation resulting from the severe Covid-19 outbreak in 2020 further justify their selection.

The collected information is summarized in Tables 1.2 and 1.3. Table 1.2, based on the 2017–2020 extracted financial statements, examines macro-data related to budget items in four areas: fixed (mandatory payments and non-recursive ones), variable costs, and fixed and variable revenues.

In Table 1.3, the authors analyze the most relevant values of the indicators from Table 1.2 over the last three years to assess any negative impact of hazards. Additionally, Table 1.4 in the Approbation Publication No. 3 reports several government provisions that limit or prevent the opening of Cultural Heritage sites, exacerbating their economic condition.

The paper underscores the need for an economic risk assessment for cultural assets exposed to risks, evaluating the impact of cost reductions and potential multihazard scenarios, such as combinations of extreme weather events or biological pandemics. To evaluate the impact of these costs, historical data series are essential for extrapolating estimates of economic risk related to various balance sheet items affected by a catastrophic scenario.

Based on the investigated case study, the reduction in ticket revenue during catastrophic events can be evaluated. Utilizing the daily average of incomes b (assuming a constant flow without seasonality) from previous years, derived from annual total receipts *B(t)* with *t = 2019, 2018, …*, and considering *m* annual revenue figures, the following descriptive equation can be derived.

$$b = (B(2019) + B(2018) + \cdots + B(2019 - m + 1)) \cdot \left(\frac{1}{m}\right) \cdot \left(\frac{1}{365}\right) \tag{40}$$

Based on the equation it could be assessed the impact of a forced lockdown, such as the one in 2020 due to the pandemic (as indicated in Table 1.3 and 1.4), and compare the estimate of the reduction in collection with the years before (i.e., 2017-2019). To illustrate this with a numerical example using the data in Table 1.3 for collections in 2017–2019, it can be determined that

$$b = (3350822 + 4000000 + 4869535) \cdot \left(\frac{1}{3}\right) \cdot \left(\frac{1}{365}\right) = 11.160 \tag{41}$$

Then, assuming a forced lockdown of *n = 130 days* in 2020, there would be an estimated loss of €1 450 818, which is then compared with the difference between the average takings in 2017–2019 (€ 4 073 452) and the total ticketing income in 2020.

Paper No. 3 underscores the vulnerability and economic instability of cultural sites, exemplified by the impact of the Covid-19 pandemic on cash flow in 2020. The simple mathematical equations calculate the average income losses, considering the three-year period (2017–2019) as the baseline and factoring in the days the site was closed.

Key findings include the disproportionately high management costs of cultural sites, even when closed, the exposure to risks without effective mitigation measures, and the lack of insurance coverage in financial records related to natural events. Additionally, the study emphasizes the following aspects:

- Public administrations, including the examined cultural heritage, are exposed to hazards without adequate preventive and remedial countermeasures. The hazard of Covid-19 revealed a lack of measures despite not causing direct damage to assets and people.
- The second key aspect concerns the inconsistency of provisional balance sheets drawn up before the pandemic outbreak and the inability, both generally and specifically, to address it at an entrepreneurial level.
- The third aspect highlights the total absence, as per balance sheets, of any insurance coverage related to natural events, emphasizing the need for insurance that maintains the flow of money to avoid worsening direct and indirect consequences.

3.4. Smart insurance mechanism analysis by System Dynamics approach

The functioning of the insurance mechanism studied and implemented in the System Dynamics (SD) model for the defined case study is best elucidated through Causal Loop Diagrams (CLDs). The conceptual model, developed with CLDs for three case study scenarios and outlined in Table 2.6, identifies the key variables and their interrelationships within the studied system. By employing reinforcing and balancing loops in CLDs, the conceptual model introduces a dynamic problem of the system and a dynamic hypothesis of the model. This is based on a thorough review of the literature and the expert knowledge of the selected system under study.

The simulation results of the Stock and Flow model, which is based on CLDs and delineates three case study scenarios, are analysed by comparing model variables such as Risk Premium, Area of Assets Insured, Insurance Company Profit, Insurance Companies' Expenditure, and Total Costs of Disaster. These variable results facilitate a comprehensive comparison of different aspects of the performance of the proposed smart insurance mechanism in the analysed scenarios. A more detailed analysis of the results is available in the Approbation Publication No. 1.

Scenario 1 model

The problem explored in Case Study Scenario 1 revolves around the notion that, in a business-as-usual insurance mechanism, the total risk premium payments escalate with an increased number of insurance contracts due to heightened risk perceptions linked to climate change. The hypothetical behavior in this scenario is depicted in Figure 3.3, illustrating risk premium payments and insurance payout flows over a 10-year period.

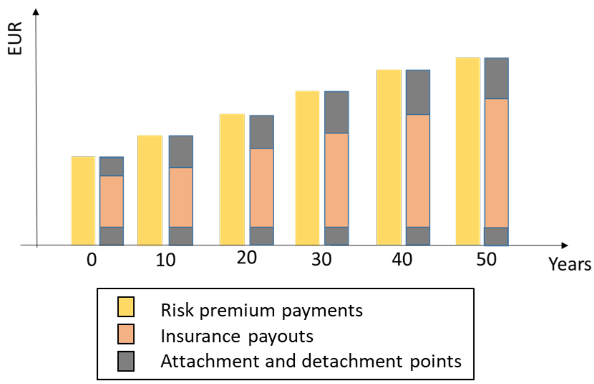

Figure 3.3. Illustration of insurance companies' payment flows in case study Scenario 1.

The attachment point signifies the loss level at which the insurance company intervenes to cover excess losses, while the detachment point indicates the loss level at which the insurance company ceases coverage. The sum between the attachment and detachment points of insurance is utilized for payouts to insured assets, indicating that the risk associated with these points is not covered.

For Case Study Scenario 1, a Causal Loop Diagram (CLD) is formulated and presented in Figure 3.4. The main components of the CLD are two feedback loops and variables: Damage to assets and Extreme weather events. The relationships between the variables suggest that assuming all other factors remain constant, an increase in the extreme weather event variable will lead to a rise in the value of damaged assets. Similarly, a surge in asset damage will result in an increase in the cost of risk premiums after the reassessment of risk premiums in contracts within a 10-year period. The time delay between accounted damage to assets over the period for which the risk premium is assessed is represented by the two stripes on the connector between damage to assets and risk premium.

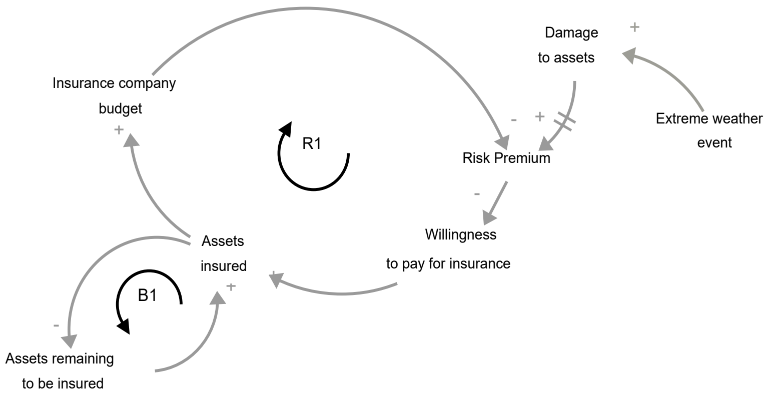

Figure 3.4. CLD for case study Scenario 1.

Risk premium, willingness to pay for insurance, assets insured, and insurance company budget are the variables linked in the reinforcing loop R1. The values of the variables related to the reinforcing loop R1 increase in a closed loop, following the reinforcing loop definition. This loop illustrates the dynamic issue of the rising risk premium over time due to increasing asset damage, resulting in rising insurance company budgets and a subsequent decline in the risk premium, as seen in Figure 3.3. In this case, the supply-demand elasticity function determines the extent to which the risk premium value will decline. The number of assets in the area determines the growth of loop R1, and the CLD is complemented by balancing loop B1, which includes variables Assets insured and Assets remaining to be insured. The empirical model structure, known as a stock and flow model, simulates the system's behavior based on developed CLDs. The results of the empirical model simulation for Case Study Scenario 1 are presented and discussed more comprehensively in the Approbation Publication No. 1.

Scenario 2 model

In accordance with the approaches outlined in Scenario 2 and Scenario 3, the government would invest in Disaster Risk Reduction (DRR), thereby enhancing the safety of the covered assets. The underlying concept of these scenarios is that the insurance firm takes on the responsibility to reimburse the government's investment through bonds, thereby positioning the insurance industry proactively as a driver for risk reduction and preventive measures. The government is envisaged as the local area's representative responsible for DRR development, thereby expressing interest in progressing towards investment in DRR, ultimately repaid by the insurance firm through bonds. This strategy assumes that effective DRR implementation will lead to a reduction in risk, subsequently resulting in diminished insurance payouts due to fewer incidents causing asset damage. Scenario 2 elaborates on this case, as depicted in Figure 3.5.

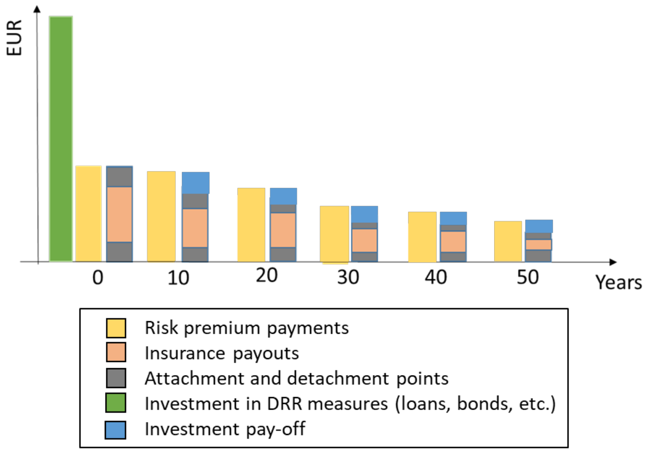

Figure 3.5. Illustration of insurance companies' payment flows with Investment in disaster risk reduction (Scenario 2) [217].

Investment in disaster risk mitigation constitutes one of the two additional feedback loops introduced in Scenario 2 (Figure 3.6). The loop R2 delineates how an intelligent contract investment in Disaster Risk Reduction (DRR) measures can diminish asset damage, reduce risk premiums, and ultimately elevate insurance willingness, insured assets, and the budget of insurance companies. The reinforcing loop R2 is counterbalanced by loop B2, ensuring that the budget of insurance firms does not grow indefinitely.

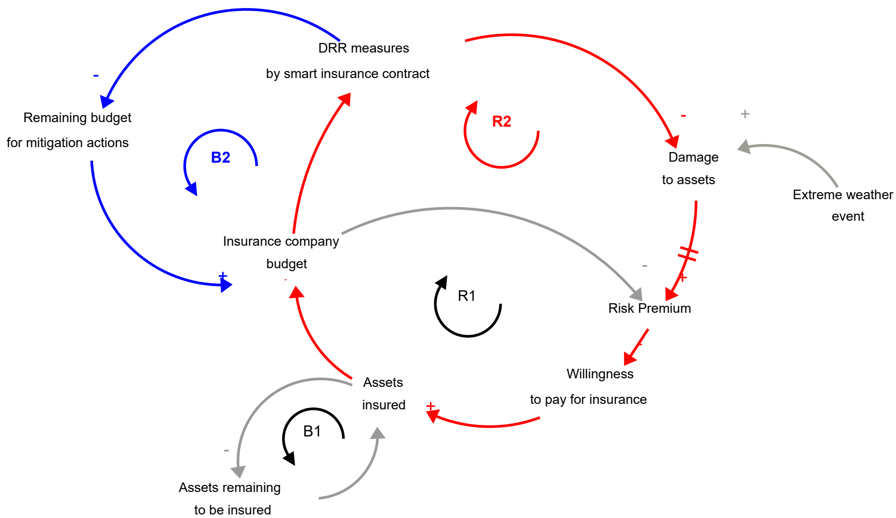

Figure 3.6. CLD for Investment in disaster risk reduction (Scenario 2) [217].

While this approach is geared towards diminishing disaster risk, there exists the possibility of a negative balance in an insurance company's budget. This can occur due to a reduction in risk premium payouts resulting from a decrease in disaster events, making it challenging to recover the initial investment in disaster risk reduction. Consequently, the introduction of a fixed premium price becomes necessary. The empirical model structure, known as a stock and flow model, simulating the system's behavior, is established based on developed Causal Loop Diagrams (CLDs) for Case Study Scenario 2. The results of the model simulation are presented and elucidated in the Approbation Publication No. 1.

Scenario 3 model

In Scenario 3, referred to as the "Smart Contract approach," a fixed premium concept is considered. Under this methodology, the disparity between insurance payouts and the established risk premium or a percentage of the insurance company's profits is utilized to reimburse the initial government bond investment in disaster risk reduction measures.

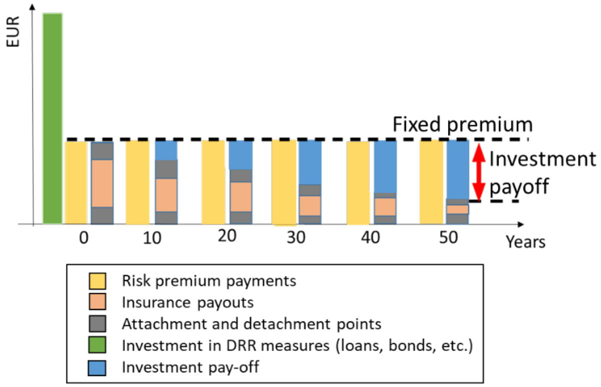

Figure 3.7. Illustration of insurance companies' payment flows with Smart contract approach (Scenario 3) [217].

To counteract the effects of loop R2 in the insurance system model provided, it becomes essential to introduce a fixed premium that is not contingent on asset damage. This fixed premium is determined based on historical data at the time of fixation. Consequently, the Causal Loop Diagram (CLD) for the smart contract technique in Figure 3.8 does not incorporate the connection between asset damage and risk premium. The proposed CLD underwent scrutiny and received approval for further utilization in a System Dynamics (SD) stock and flow model by a panel of experts in SD and insurance.

The total expenditure of the company in Scenario 1 differs from the approaches in Scenarios 2 and 3, where insurance firms' expenditure encompasses both the pay-off of investments and payouts to insured assets after damage occurs. The costs incurred by insurance companies, estimated as the total in the SD model, can be utilized to compare the overall costs of transitioning from conventional insurance schemes to smart contracts in the Business-As-Usual (BAU) scenario. Evaluating the total disaster costs involves summing up the damage to all assets in the area and the expenditure on Disaster Risk Reduction (DRR) measures to assess the overall efficacy of the analyzed scenarios.

The study indicates that implementing flood risk reduction measures may expose other assets in the vicinity to risk beyond the insured assets. Investing in DRR using this strategy can lead to reduced risk and risk premiums, thereby increasing people's willingness to pay for insurance. The System Dynamics (SD) model allows the simulation of changes in the localized insured asset count. Only payments for risk premiums and payouts from investment gains are recorded as income and results, respectively. Profit for insurance firms is defined as the difference between income and results. The simulation results for Scenario 3 are presented and discussed in Approbation Publication No.1.

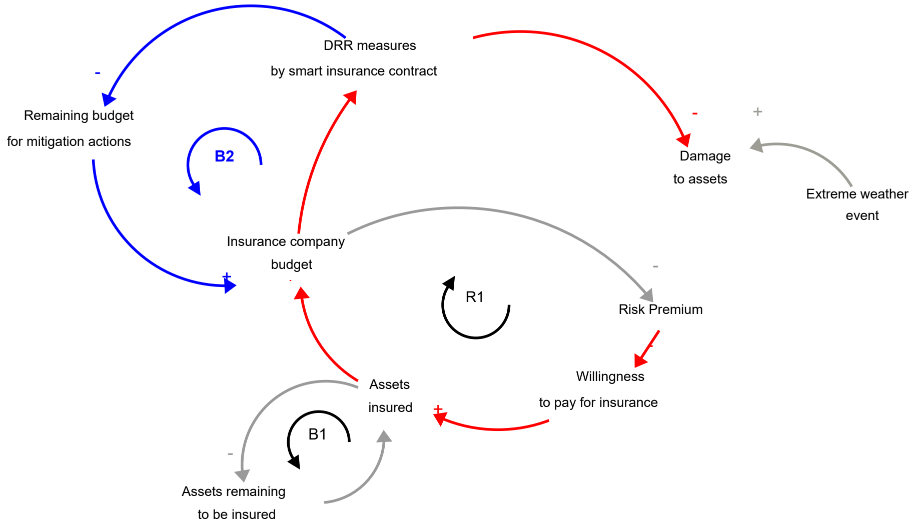

Figure 3.8. CLD for Smart contract approach (Scenario 3) [217].

Comparison of scenarios

In this section, a comparative analysis of the statistics obtained from 1000 simulation runs for each scenario is presented. These statistics shed light on the behavior of the following parameters: insured assets area, insurance company profit, insurance company expenditure, and total costs of disasters. The selected parameters for comparative analysis allow us to comprehend the differences in each insurance mechanism and their impact on insurance companies' business.

The statistics of the insured asset area are depicted in Table 3.8. In Scenario 1, the mean insured asset area for all simulation runs is approximately 2.48E+05 m^2. The minimum insured asset area is 1.09E+05 m^2, while the maximum is significantly larger, at 4.93E+05 m^2. Scenario 2 presents a different picture, with the mean insured asset area notably higher, at 5.11E+05 m^2. The standard deviation in Scenario 2, equal to 3.51E+04 m2, is much smaller than in Scenario 1, suggesting that simulation results for the insured asset area are more tightly clustered around the mean.

Table 3.8.

Statistics of insured asset area

Statistic	Scenario 1	Scenario 2	Scenario 3
Mean of insured assets area	2.48E+05	5.11E+05	N/A
Std. Dev. of insured assets area	8.86E+04	3.51E+04	N/A
Min of insured assets area	1.09E+05	3.33E+05	N/A
25% Percentile of insured assets area	2.03E+05	4.76E+05	N/A
75% Percentile of insured assets area	3.05E+05	5.33E+05	N/A
Max of insured assets area	4.93E+05	5.33E+05	N/A

*N/A – not applicable

In contrast to the other scenarios, Scenario 3 exhibits unique characteristics as the risk premium value is set constant; hence, the insured asset area in all simulations is equal to 4.63E+05 m2. Scenario 2 presents a higher average insured asset area, while Scenario 1 shows a lower average insured asset area than Scenario 3. This tendency is well presented by histograms in Figure 3.9, where, for Scenario 1, the graph is skewed towards lower insured asset area values; for Scenario 2, the graph is skewed towards higher insured asset area values. And for Scenario 3, the insured asset area is the same for all simulation runs.

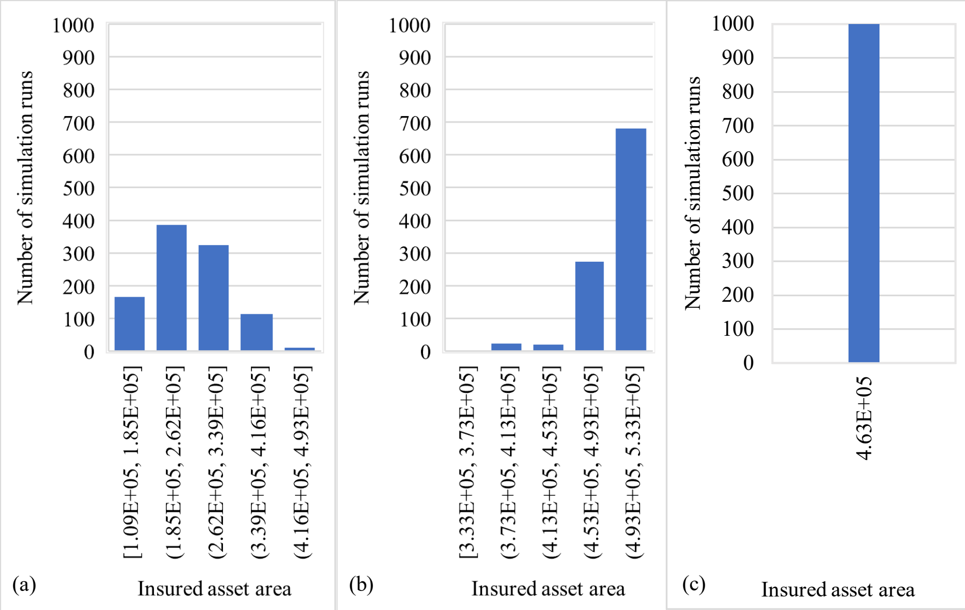

Figure 3.9. Histograms for insured asset area in Scenario 1(a), Scenario 2(b) and Scenario 3(c).

The statistics for the profitability of insurance companies across three scenarios are shown in Table 3.9. In Scenario 1, the mean insurance company profit is EUR 34.6 million, with a standard deviation of EUR 13.5 million, indicating a considerable range in profit levels based on simulation-run hazard occurrences. The lowest profit value is EUR -34.9 million, suggesting a probability that the insurance business could suffer a loss. About EUR 42.4 million represents the 75th percentile, indicating that 25% of simulation runs show profits higher than this value. The highest profit in all simulations is EUR 98.1 million.

Scenario 2 exhibits different statistical values. In comparison to Scenario 1, the average insurance company profit is noticeably larger, at about EUR 67 million, indicating a better degree of profitability. However, the standard deviation is EUR 30.8 million, showing that profit levels can vary significantly compared to Scenario 1. The minimal profit recorded is EUR -20.5 million, pointing to a reduced potential loss for the insurance firm. In 25% of simulation runs, the company will produce earnings higher than the ones shown by the 75th percentile, about EUR 89.9 million. In all simulation runs, a maximum profit of EUR 146 million was recorded.

Table 3.9

Statistics of Insurance company profit

Statistic	**Scenario 1**	**Scenario 2**	**Scenario 3**
Mean	3.46E+07	6.70E+07	2.79E+07
Std. Dev.	1.35E+07	3.08E+07	4.55E+06
Min of Insurance company profit	-3.49E+07	-2.05E+07	5.15E+06
25% Percentile of Insurance company profit	2.72E+07	4.55E+07	2.55E+07
75% Percentile of Insurance company profit	4.24E+07	8.99E+07	3.08E+07
Max of Insurance company profit	9.81E+07	1.46E+08	3.08E+07

The mean average insurance company profit in Scenario 3 is EUR 27.9 million, which is less than Scenario 2 but more than Scenario 1. In comparison to the other scenarios, Scenario 3's standard deviation of EUR 4.55 million is relatively low, indicating less fluctuation in profit levels among simulation runs. The minimal profit that has been recorded is roughly EUR 5.15 million. The documented maximum profit is EUR 30.8 million, which also represents the 75th percentile. Corresponding to the statistics in Table 3.9 above, Figure 3.10 shows the histograms for insurance company profit in three scenarios. The largest average profit is found in Scenario 2. Despite having a lower average profit, Scenario 3 has the lowest profit variability, suggesting a more stable and predictable scenario for the insurance company, while Scenario 1 shows lower average profitability and greater profit level variability.

The three separate scenarios from the perspective of companies' spending are represented in Table 3.10. In Scenario 1, the mean value of expenditure in the total number of simulation runs is EUR 1.36 million. In Scenario 2, it is EUR 26.2 million, and in Scenario 3, it is EUR 4.10 million. A higher standard deviation indicates greater variability in spending in Scenario 2, equal to EUR 12.3 million, while for Scenario 1 and Scenario 3, it is EUR 1.41 million and EUR 4.55 million, respectively. The minimum expenditure is 0, while in Scenario 3, it is EUR 1.20 million.

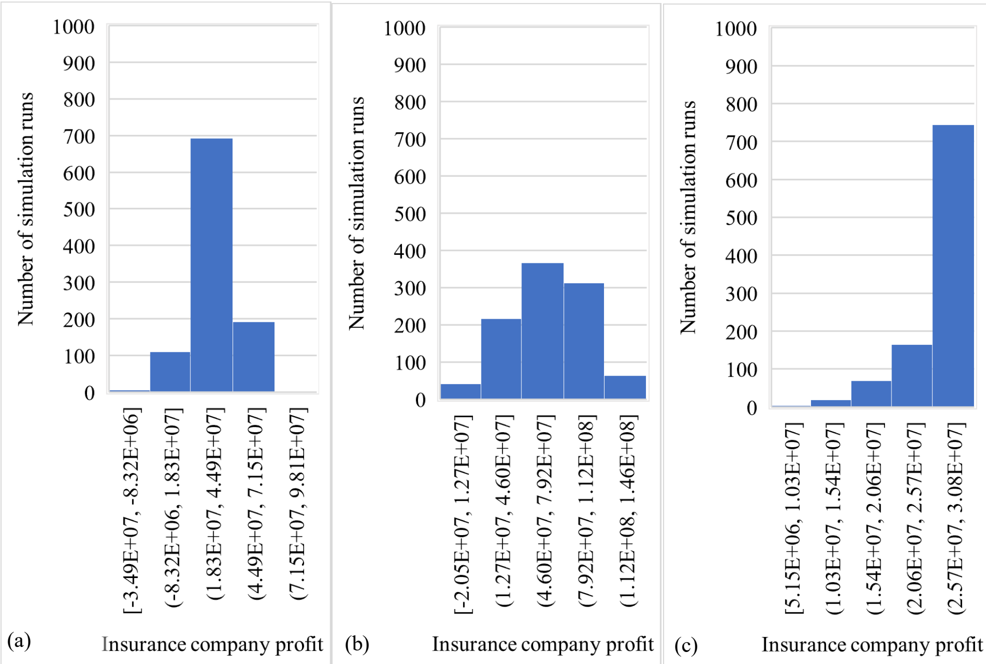

Figure 3.10. Histograms for insurance company profit in Scenario 1(a), Scenario 2(b), and Scenario 3(c).

Table 3.10.

Statistics of Insurance company expenditure

Statistic	Scenario 1	Scenario 2	Scenario 3
Mean of Total insurance company expenditure	1.36E+06	2.62E+07	4.10E+06
Std. Dev. of Total insurance company expenditure	1.41E+06	1.23E+07	4.55E+06
Min of Total insurance company expenditure	0.00E+00	0.00E+00	1.20E+06
25% Percentile of Total insurance company expenditure	0.00E+00	1.76E+07	1.20E+06
75% Percentile of Total insurance company expenditure	1.89E+06	3.39E+07	6.49E+06
Max of Total insurance company expenditure	7.12E+06	6.83E+07	2.69E+07

According to the statistics presented in Table 3.10 and the histograms in Figure 3.11 for insurance company expenditure, there is significantly higher expenditure expected for the insurance company in Scenario 2 compared to Scenarios 1 and 3. Similarly, as for insurance company profit, Scenario 3 has a different distribution pattern for insurance company expenditure. In Scenario 3, the proportion of simulation runs with lower expenditure is much higher than for Scenarios 1 and 2, appearing as a skewed histogram graph towards lower values.

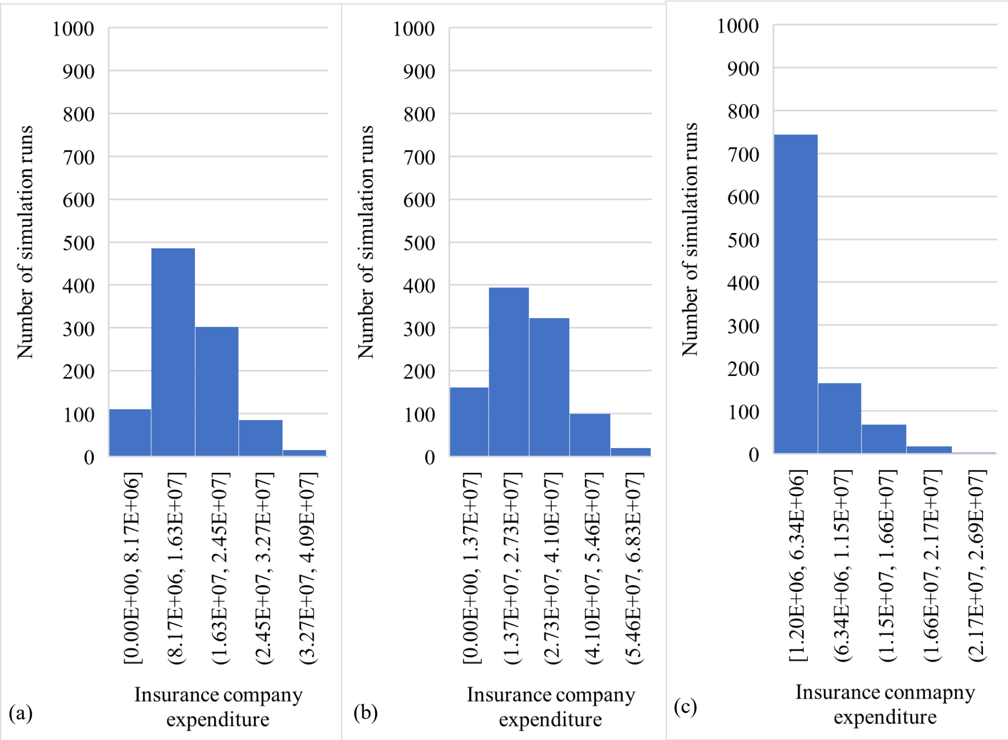

Figure 3.11. Histograms for insurance company expenditure in Scenario 1(a), Scenario 2(b), and Scenario 3(c).

Finally, the total costs of the disaster are compared among the analyzed scenarios in Table 3.11. Scenario 2 and Scenario 3 show similar statistical outputs, as the applied disaster risk measures considered in these scenarios have the same effect on reducing disaster risk and, consequently, the damage costs. Both Scenario 1 and Scenario 3 exhibit significantly lower mean and maximum values of total disaster costs compared to Scenario 1. This information is consistent with the histogram graphs shown in Figure 3.12, where Scenario 2 and Scenario 3 have similar skewed graphs towards lower values in the total cost of disaster.

Table 3.11.

Statistics of the total costs of disaster

	Scenario 1	Scenario 2	Scenario 3
Mean of Total costs of disasters	6.99E+07	7.90E+06	7.34E+06
Std. Dev. of Total costs of disasters	3.02E+07	1.12E+07	1.05E+07
Min of Total costs of disasters	0.00E+00	0.00E+00	0.00E+00
25% Percentile of Total costs of disasters	4.92E+07	0.00E+00	0.00E+00
75% Percentile of Total costs of disasters	8.99E+07	1.79E+07	1.36E+07
Max of Total costs of disasters	1.58E+08	5.86E+07	5.38E+07

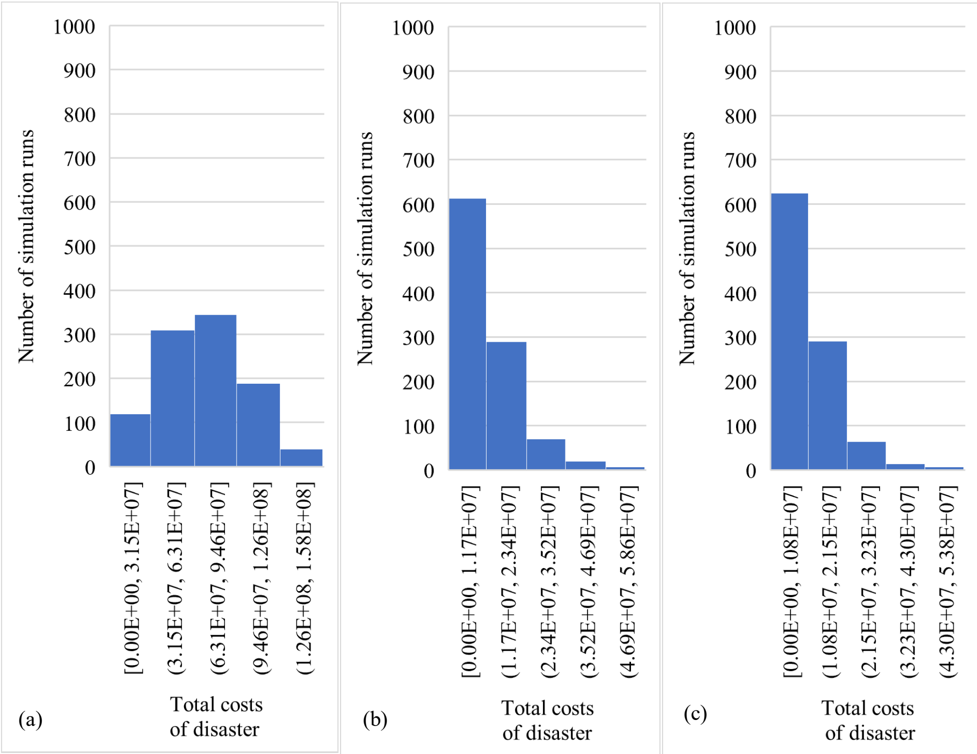

Figure 3.12. Histograms for total costs of disaster in Scenario 1(a), Scenario 2(b), and Scenario 3(c).

Summarizing the comparison of the selected model parameters among the defined scenarios, the results indicate that Scenario 1 has a lower number of insured assets with higher total disaster costs compared to Scenarios 2 and 3. Therefore, Scenario 1 can be considered less desirable for local communities. Scenario 2 proved to be the most profitable among the analyzed scenarios; however, Scenario 3 exhibited more consistency in profitable outcomes. Moreover, Scenario 3 did not show any cases of negative values in profit, unlike the other two scenarios. Such differences between scenarios are also reflected in the statistics of the insurance company's expenditure.

CONCLUSIONS AND RECCOMANDATIONS

This Doctoral thesis aimed to fill the knowledge gap on how new insurance instruments embedded in a proactive role of the insurance sector can be used for co-financing disaster resilience projects as mitigation and adaptation strategies enhancing community resilience against weather-related hazards.

The Doctoral thesis wanted to demonstrate the effectiveness of integrating Smart Insurance Contracts to be substantial to enhance the resilience of communities and reduce the socio-economic impact of natural disasters and socio-natural hazards, leading to more sustainable and adaptive disaster risk management strategies. A novel mechanism based on a Bayesian adaptive insurance scheme addressing flooding risk directed toward public administration has been proposed. This mechanism incorporates Smart Contracts and is further applied in developing a System Dynamics-based urban assessment tool for socio-natural hazards, with a specific focus on floods in the Latvian context.

This doctoral research underscores the pivotal role played by insurance mechanisms in mitigating climate change-related disasters and safeguarding lives, livelihoods, and critical infrastructure. By deploying a comprehensive approach involving robust risk assessment, innovative insurance mechanisms, incentives for risk reduction, capacity building, stakeholder collaboration, and continuous monitoring and evaluation, the outputs of the Doctoral thesis are relevant, enhancing community resilience and propelling sustainable development amid the complex challenges posed by climate change. Recognizing the evolving nature of climate risks, this Doctoral thesis demonstrated how fostering innovation towards the effectiveness and accessibility of insurance mechanisms in the ever-changing landscape provides policy support toward DRR strategies and planning.

This Doctoral thesis represents a comprehensive study presenting fundamental insights and strategic recommendations for stakeholders, particularly public administrations, insurance companies, policymakers, and disaster risk managers. I particularly bedside the innovative Bayesian Adaptive Insurance mechanisms implementing Smart Contracts. This study highlights the usefulness of the System Dynamics modelling approach for examining the feedback loops that govern the behavior of complex systems related to the insurance mechanism of disaster insurance. The study aims to solve an existing problem in conventional disaster insurance mechanisms, which aims only to provide financial safety for asset recovery after a disaster event and not to decrease the risk of disaster itself. This problem is especially becoming topical with climate-related disaster risk increases and can lead only to higher damage costs in the long term.

The analysis of results unfolds key conclusions and offers a set of crucial recommendations, harmonizing diverse perspectives for effective risk reduction and resilience enhancement presented as follows.

Conclusions

- The study advocates for a novel multidisciplinary approach, recognizing the importance of legislative, engineering, and actuarial dimensions. This approach aims to create a comprehensive assessment tool for the insurance sector, specifically designed to quantify the benefits of mitigative risk reduction measures against socio-natural hazards.
- The thesis highlights the escalating economic challenge faced by public administrations in managing risks and addressing damages in the insurance market, particularly with the upfront

investments required for adaptation and mitigation solutions. It introduces a novel financial scheme for flood risk management, emphasizing a resilient approach that combines upfront risk reduction investments with insurance mechanisms. This aligns with the concept of resilience bonds, offering a choice between passive, traditional insurance, and proactive urban resilience strategies.

- The analysis of results underscores the crucial role of engineering competence in risk assessment, cost-benefit analysis, and the design of effective mitigation works. The regulatory framework, especially in the European context, guides public administrations in pursuing these objectives.
- There is a focus on integrating innovation, such as Blockchain technology, into insurance mechanisms. This technology is proposed as an innovative tool for real-time climate data collection, damage recording, and smart contract implementation. The proposed smart contract is a multiphase contract type designed to adapt over decades, taking into consideration climate trends and adjusting parameters for risk assessment.
- The thesis emphasizes the potential of blockchain technology in mitigating risk and vulnerability by enabling real-time risk assessment. The necessity for automatic updating schemes of contracts linked to certification, facilitated by blockchain, is highlighted. This facilitates more precise risk-based pricing for insurance policies, setting the stage for utilizing various innovative technologies (e.g., Big Data processing, GIS, and probabilistic modeling). These technologies form an integrated Risk Management approach aimed at enhancing urban resilience. This approach addresses spatial and time-dependent preparation, resistance, and adaptation capacities to flood risk.
- The study underscores the potential of blockchain technology in mitigating risk and vulnerability by enabling real-time risk assessment. It emphasizes the need for automatic updating schemes of contracts linked to certification facilitated by blockchain, providing more precise risk-based pricing for insurance policies.
- Insurance companies are encouraged to consider strategic allocation of surpluses towards Disaster Risk Reduction (DRR) strategies, contributing to broader societal goals and enhancing disaster resilience.
- The study emphasizes the crucial role of multidisciplinary research in addressing the interconnected relationship between smart contracting, blockchain technology, and Bayesian adaptive design for flood risk insurance. The escalating concentration of human populations in urbanized areas amplifies the need for resilient insurance mechanisms supported by flexible contracting tools.
- The research underscores the significance of the System Dynamics modeling approach in comprehensively examining the intricate feedback loops governing the behavior of complex systems, specifically within the realm of disaster insurance mechanisms. Addressing a critical gap in conventional disaster insurance paradigms, focused primarily on post-disaster financial recovery. The study aims to tackle the fundamental issue of reducing the inherent risk of disasters. This becomes particularly relevant in the context of escalating climate-related disaster risks, which, if left unaddressed, could result in escalating long-term damage costs.
- The System Dynamics model addresses the limitations of conventional disaster insurance mechanisms by proposing a new model that not only financially safeguards asset recovery post-disaster but also actively works to decrease the risk of disasters. This innovative approach becomes especially pertinent with the increasing threat of climate-related disasters.
- In response to the limitations identified in conventional insurance models, the research introduces a novel insurance mechanism. This paradigm shift aims to counteract the inherent inefficiencies of existing models in dealing with the mounting threats posed by disasters. Applied in a local case study, the proposed insurance mechanism operates on a dynamic hypothesis, envisioning a smart

insurance contract. This innovative contract not only supports investments in disaster risk mitigation measures, thereby reducing damage costs and safeguarding insured assets but also facilitates the attraction of new assets through a more effective insurance scheme. The net result is a system that yields even higher benefits for the insured assets, showing the potential benefits of a proactive role of the insurance sector for co-financing disaster resilience projects and enhancing community resilience against weather-related hazards. Results from the SD model, including the Smart contract approach, demonstrate the consistent benefit of such mechanisms in providing both disaster cost reduction and revenue for insurance companies. The case study utilizing the developed System Dynamics model demonstrates the effectiveness of the innovative insurance mechanism. It confirms that fixing risk premiums for insurance companies is a crucial step in decreasing overall disaster costs when investing in Disaster Risk Reduction (DRR) measures. The Smart contract approach, as compared to business-as-usual or conventional mechanisms, consistently shows better results in terms of disaster costs and revenue for insurance companies.

- The proposed insurance mechanism, incorporating a dynamic hypothesis and a smart insurance contract supporting investment in disaster risk mitigation measures, aims to reduce damage costs and attract new assets to be insured. The model developed holds promise in advancing the practical application of innovative insurance mechanisms in diverse regions. By providing valuable insights for insurance companies, policymakers, and disaster risk managers, the model offers information on the most beneficial scenarios for local communities and other stakeholders. The proposed paradigm shift in insurance mechanisms has the potential to reshape disaster risk management strategies, steering them toward more effective, sustainable, and community-centric approaches.
- The proposed premium risk calculation is recommended for developing a quantitative infrastructure resilience model. This aligns with national regulations mandating mathematical studies before significant decisions related to mitigating structures, including Resilience Bonds.
- The research encourages a proactive role for insurance companies in promoting overall societal well-being by channeling surpluses into DRR initiatives, aligning with the evolving role of insurance in comprehensive risk management strategies.
- The complexity of urban systems and CI necessitates a holistic risk reduction approach, considering both engineering and social dimensions. Policymakers, economists, urban planners, engineers, insurance companies, and scientists are urged to collaboratively develop innovative and sustainable Risk Management frameworks.
- The methodology proves particularly relevant in the context of urban disasters, where innovative approaches are crucial for effective disaster management and building urban resilience. Its alignment with sustainable development plans, especially within the framework of Sustainable Energy and Climate Action Plans (SECAPs) for Municipalities, emphasizes its applicability to contemporary challenges. Engaging stakeholders, including insurance companies, policymakers, and disaster risk managers, is crucial for the successful implementation of innovative insurance mechanisms. Collaborative efforts can foster resilience and contribute to sustainable development goals in the face of climate-related challenges.

Recommendations

- Future developments involving Monte Carlo simulation to address variability in results, emphasizing the need for real-world data to validate the theoretical model, as demonstrated by the study on flood risk, could be addressed.

- The proposed approach, applicable to various risks and mitigation strategies, should be further developed based on the quality of data available in feasibility studies for resilient processes in moe real cases.
- Future developments should involve a productive dialogue between engineering and actuarial approaches. The legal perspective must clarify aspects to ensure the practical effectiveness of smart contracts in multiperiodic scenarios.
- Insurance organizations are encouraged to employ diverse alternative analytical methods, such as break-even analysis and income stability assessment, for strategic planning. These methods address information asymmetry within insurance contracts, contribute to monitoring key success factors, and enhance an insurer's competitiveness.
- Consideration of cultural, behavioral, and educational factors is crucial in understanding the demand for insurance. The study emphasizes that factors beyond a logical trade-off between policy price and benefits, including income levels, risk knowledge, risk perception, and post-disaster public reimbursement expectations, influence willingness to pay.
- The proposed multidisciplinary approach should be further refined through continuous collaboration between legislative, engineering, and actuarial professionals. This collaboration is essential for the ongoing development and improvement of the assessment tool for the insurance sector with the aim of creating an assessment tool for the insurance sector in order to quantify the benefit of mitigative risk reduction measures coping against natural hazards.
- The study aligns with sustainable development plans, and future research should explore ways to seamlessly integrate blockchain-based risk mitigation tools with existing frameworks, such as SECAPs for Municipalities. This integration ensures a holistic and coordinated approach to urban resilience.
- The proposed methodology should undergo further validation and real-world application to assess its effectiveness and reliability. This could involve pilot projects or partnerships with insurance organizations to implement and evaluate the practical implications of the blockchain-based risk mitigation tool.
- Future research should focus on validating the proposed innovative insurance mechanism in various contexts and regions. Continuous refinement and validation of the System Dynamics model will enhance its applicability and reliability, providing a robust tool for decision-makers.

This PhD thesis lays the groundwork for transformative advancements in the realm of disaster risk management, emphasizing the critical role of innovative insurance mechanisms in building resilient communities within the continuously evolving challenges of climate change. The insights and methodologies presented herein contribute to a growing body of knowledge with practical implications for diverse stakeholders involved in the complex landscape of disaster resilience and sustainable development.

The integration of these conclusions and recommendations provides a roadmap for stakeholders, policymakers, and researchers to navigate the complexities of flood risk management, leveraging innovative technologies and collaborative approaches for a resilient and sustainable future.

REFERENCES

[1] C. Suykens, S. J. Priest, W. J. van Doorn-Hoekveld, T. Thuillier, and M. van Rijswick, "Dealing with flood damages: Will prevention, mitigation, and ex post compensation provide for a resilient triangle?," *Ecol. Soc.*, vol. 21, no. 4, 2016, doi: 10.5751/ES-08592-210401.

[2] Swiss Re-Sigma, "Natural catastrophes and man-made disasters in 2013: large losses from floods and hail; Haiyan hits the Philippines," *Swiss Re*, no. 1, p. 52, 2014, [Online]. Available: http://www.pacificdisaster.net/pdnadmin/data/original/SwisRe_2014_Natural_Catastrophes_sigma1_2014_en.pdf%0Afile:///K:/guilherme.mohor/OneDrive/Referencias/Referencias-artigoMario/2014 Swiss Re sigma1_2014_en.pdf.

[3] United Nations Office for Disaster Risk Reduction, *Global Assessment Report on Disaster Risk Reduction 2022: Our World at Risk: Transforming Governance for a Resilient Future*, no. April. 2022.

[4] H. Hoff, L. Bouwer, G. Berz, W. Kron, and T. Loster, "Risk Management in Water and Climate: The Role of Insurance and Other Financial Services," no. November, p. 42, 2003, [Online]. Available: http://www.germanwatch.org/klak/dwc2003.htm.

[5] S. Paleari, "Disaster risk insurance: A comparison of national schemes in the EU-28," *Int. J. Disaster Risk Reduct.*, vol. 35, no. October 2018, p. 101059, 2019, doi: 10.1016/j.ijdrr.2018.12.021.

[6] J.-F. Wahlin, "Du partenariat entre les assureurs privés et les Régions en ce qui concerne les dégâts provoqués par des catastrophes naturelles aux risques simples assurés. Le cas des inondations des 14 au 16 juillet 2021," *Bull. des Assur.*, vol. 417, no. 4, pp. 452–462, 2021.

[7] Assuralia, "Principaux chiffres du secteur des assurances : tendances et inondations juillet 2021," 2021. .

[8] L. Bevere and F. Remondi, "Natural catastrophes in 2021: the floodgates are open," *Swiss Re Inst.*, no. 1, 2022.

[9] Ipcc.ch., "Mitigation of Climate Change, Working Group III — IPCC," 2018. https://www.ipcc.ch/working-group/wg3/?idp=456 (accessed Jul. 30, 2019).

[10] C. Quinto, *Insurance Systems in Times of Climate Change, Schulthess Juristische Medien AG, Zurich*. Basel - Geneva, 2011.

[11] A. Galderisi and G. Limongi, "A comprehensive assessment of exposure and vulnerabilities in multi-hazard urban environments: A key tool for risk-informed planning strategies," *Sustain.*, vol. 13, no. 16, 2021, doi: 10.3390/su13169055.

[12] G. Marin, M. Modica, S. Paleari, and R. Zoboli, "Assessing disaster risk by integrating natural and socio-economic dimensions: A decision-support tool," *Socioecon. Plann. Sci.*, vol. 77, no. December 2020, p. 101032, 2021, doi: 10.1016/j.seps.2021.101032.

[13] S. Paleari, "Disaster risk insurance: A comparison of national schemes in the EU-28," *Int. J. Disaster Risk Reduct.*, vol. 35, no. December 2018, p. 101059, 2019, doi: 10.1016/j.ijdrr.2018.12.021.

[14] T. Altun and N. Güldiken, "Natural disaster insurance: public-private sector partnership," *J. Hum. Sci.*, vol. 16, no. 4, pp. 1084–1095, 2019, doi: 10.14687/jhs.v16i3.5843.

[15] F. Le Quesne *et al.*, "The Role of Insurance in Integrated Disaster and Climate Risk Management: Evidence and Lessons Learned," no. 22, p. 68, 2017.

[16] R. S. Roberts, "Economic Strategies for Coastal Disaster Risk-Reduction: A Case Study of Exmouth (Ph.D.), Murdoch University, Western Australia," 2012.

[17] P. Nowak and M. Romaniuk, "Pricing and simulations of catastrophe bonds," *Insur. Math. Econ.*, vol. 52, no. 1, pp. 18–28, 2013, doi: 10.1016/j.insmatheco.2012.10.006.

[18] N. Gatzert and R. Kellner, "The influence of non-linear dependencies on the basis risk of industry loss warranties," *Insur. Math. Econ.*, vol. 49, no. 1, pp. 132–144, 2011, doi: 10.1016/j.insmatheco.2011.02.005.

[19] S. R. Chikabvumbwa, N. Salehnia, R. Manzanas, C. Abdelbaki, and A. Zerga, "Assessing the effect of spatial–temporal droughts on dominant crop yield changes in Central Malawi," *Environ. Monit. Assess.*, vol. 194, no. 2, pp. 1–16, 2022, doi: 10.1007/s10661-021-09709-4.

[20] M. Mededjel, G. Belalem, F. Z. N. Benadda, and S. Kadakelloucha, "A Blockchain Application

Prototype for the Internet of Things," *J. Commun. Softw. Syst.*, vol. 18, no. 2, pp. 124–136, 2022, doi: 10.24138/JCOMSS-2021-0129.
[21] F. De Masi and D. Porrini, "Climate Change Remedies," *Encycl. Law Econ.*, pp. 1–8, 2021, doi: 10.1007/978-1-4614-7883-6_616-2.
[22] T. J. Ogbu, S. E. Scales, M. M. de Almeida, J. A. F. van Loenhout, N. Speybroeck, and D. Guha-Sapir, "Predictors of exceeding emergency under-five mortality thresholds using small-scale survey data from humanitarian settings (1999 – 2020): considerations for measles vaccination, malnutrition, and displacement status," *Arch. Public Heal.*, vol. 80, no. 1, pp. 1–2, 2022, doi: 10.1186/s13690-022-00916-0.
[23] S. Zanardo and J. L. Salinas, "An introduction to flood modeling for catastrophe risk management," *Wiley Interdiscip. Rev. Water*, vol. 9, no. 1, pp. 1–9, 2022, doi: 10.1002/wat2.1568.
[24] Vision of Humanity, "Trend of disaster events by disaster type (I), 1990-2019. Total number of disasters, by type (II), 1990-2019," 2019. https://www.visionofhumanity.org/global-number-of-natural-disasters-increases-ten-times/#:~:text=From 1990 to 2019%2C a,disasters in this time period.
[25] United Nations Global Assessment Report on Disaster Risk Reduction, "2019 Global Natural Disaster Assessment Report," *Wonderful Wastel. other Nat. disasters*, pp. 46–47, 2020, [Online]. Available: https://www.emdat.be/.
[26] CRED, "Climate in action Executive Summary," *EM-DAT | Int. disasters database*, p. 8, 2022, [Online]. Available: https://www.emdat.be/.
[27] Our World in Data, "Deaths from natural disasters as a share of total deaths, 2019." https://ourworldindata.org/grapher/share-deaths-from-natural-disasters.
[28] K. Jacobs and S. Williams, *Natural disaster preparation and response: Issues for state housing authorities*, no. 131. 2009.
[29] Our World in Data, "Deaths from natural disasters by type, World, 1900 to 2022." https://ourworldindata.org/grapher/number-of-deaths-from-natural-disasters.
[30] M. Garcia, E. Koebele, A. Deslatte, K. Ernst, K. F. Manago, and G. Treuer, "Towards urban water sustainability: Analyzing management transitions in Miami, Las Vegas, and Los Angeles," *Glob. Environ. Chang.*, vol. 58, no. June 2018, p. 101967, 2019, doi: 10.1016/j.gloenvcha.2019.101967.
[31] Prevention Web, "Relationship between hazards/people/losses in last three years." Relationship between hazards/people/losses in last three years.
[32] T. Carr, "Focus on alternatives: Catastrophe bonds explained," no. September 2002, pp. 1–4, 2011.
[33] United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP), *The Disaster Riskscape Across Asia-Pacific*. 2019.
[34] E. Mills, "Climate change, insurance and the buildings sector: Technological synergisms between adaptation and mitigation," *Build. Res. Inf. - Build. RES Inf.*, vol. 31, 2003, doi: 10.1080/0961321032000097674.
[35] A. Saha *et al.*, "Modelling multi-hazard threats to cultural heritage sites and environmental sustainability: The present and future scenarios," *J. Clean. Prod.*, vol. 320, no. April, p. 128713, 2021, doi: 10.1016/j.jclepro.2021.128713.
[36] M. Ravankhah *et al.*, "A multi-hazard platform for cultural heritage at risk: The STORM risk assessment and management tool," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 949, no. 1, 2020, doi: 10.1088/1757-899X/949/1/012111.
[37] World Meteorological Organization (WMO), *WMO Statement on the Status of the Global Climate in 2019*, no. 1248. 2020.
[38] K. Kraehnert *et al.*, "Insurance against Extreme Weather Events: An Overview," *Rev. Econ.*, vol. 72, no. 2, pp. 71–95, 2021, doi: 10.1515/roe-2021-0024.
[39] G. Forzieri *et al.*, "Escalating impacts of climate extremes on critical infrastructures in Europe," *Glob. Environ. Chang.*, vol. 48, pp. 97–107, 2018, doi: https://doi.org/10.1016/j.gloenvcha.2017.11.007.
[40] S. Landini, "Credit in Agriculture : In the Perspective of Banking Law , Financial Market Law and Insurance Law," vol. 266, no. 4, pp. 801–816, 2021.

[41] Food and Agriculture Organization of the United Nations, “The impact of disasters and crises on agriculture and food security: 2021,” 2021. doi: 10.4060/cb3673en.
[42] EM-DAT, “Weather, Climate & Catastrophe Insight,” 2020. [Online]. Available: https://de.statista.com/statistik/daten/studie/1260862/umfrage/verteilung-der-naturkatastrophen-weltweit-nach-art-der-katastrophen/.
[43] B. A. Jafino, B. Walsh, J. Rozenberg, and S. Hallegatte, “Revised Estimates of the Impact of Climate Change on Extreme Poverty by 2030: Poverty and Shared Prosperity 2020 Background Paper,” no. September, 2020, [Online]. Available: http://www.worldbank.org/prwp.
[44] European Environment Agency, “Annual economic damage caused by weather and climate-related extreme events in the EU Member States,” 2023. [Online]. Available: https://www.eea.europa.eu/ims/economic-losses-from-climate-related.
[45] I. P. Canlas, “Three decades of disaster risk reduction education: A bibliometric study,” *Nat. Hazards Res.*, 2023, doi: https://doi.org/10.1016/j.nhres.2023.02.007.
[46] E. Commission, J. R. Centre, L. Feyen, F. Dottori, and L. Alfieri, *Task 7, river floods : : JRC PESETA III project*. Publications Office, 2018.
[47] B. De Botselier, “How the EU Covenant of Mayors and climate-adapt strenghten local climate policy-making. A Case Study of the City of Bruges,” 2019.
[48] T. Venturini, K. De Pryck, and R. Ackland, “Bridging in network organisations. The case of the Intergovernmental Panel on Climate Change (IPCC),” *Soc. Networks*, 2022, doi: https://doi.org/10.1016/j.socnet.2022.01.015.
[49] O. Edenhofer and K. Seyboth, “Intergovernmental Panel on Climate Change (IPCC),” in *Encyclopedia of Energy, Natural Resource, and Environmental Economics*, J. F. Shogren, Ed. Waltham: Elsevier, 2013, pp. 48–56.
[50] A. Ismail-Zadeh, “Natural hazards and climate change are not drivers of disasters,” *Nat. Hazards*, no. 0123456789, 2021, doi: 10.1007/s11069-021-05100-1.
[51] H. Treiblmaier and R. Beck, *Business transformation through blockchain: Volume II*, vol. I. 2018.
[52] A. J. Pagano, M. Feofilovs, and F. Romagnoli, “The relationship between insurance companies and natural disaster risk reduction : overview of the key characteristics and mechanisms dealing with climate change .,” *Environ. Clim. Technol.*, vol. 00, 2018.
[53] S. Cosma, S. Principale, and A. Venturelli, “Sustainable governance and climate-change disclosure in European banking: the role of the corporate social responsibility committee,” *Corp. Gov. Int. J. Bus. Soc.*, no. September 2021, 2022, doi: 10.1108/cg-09-2021-0331.
[54] AXCO, “AXCO Non-life insurance market reports: Country report 2020s; OECD 2015, 2016, 2018; EU JRC 2012.”
[55] EC and WB, “Economics for Disaster Prevention and Preparedness - Financial Risk and Opportunities to Build Resilience in Europe,” 2021, [Online]. Available: https://civil-protection-humanitarian-aid.ec.europa.eu/what/civil-protection/european-disaster-risk-management/economics-disaster-prevention-and-preparedness_en.
[56] A. J. Pagano, F. Romagnoli, and E. Vannucci, “Insurance against Natural Hazards: Critical Elements on the Risk Premium Evaluation in the Italian Context,” *Environ. Clim. Technol.*, vol. 24, no. 3, pp. 373–386, 2020, doi: 10.2478/rtuect-2020-0110.
[57] B. A. Antwi-Boasiako, “It’s beyond my control: The effect of locus of control orientation on disaster insurance adoption,” *Int. J. Disaster Risk Reduct.*, vol. 22, pp. 297–303, 2017, doi: https://doi.org/10.1016/j.ijdrr.2017.02.014.
[58] S. Surminski and D. Oramas-Dorta, “Flood insurance schemes and climate adaptation in developing countries,” *Int. J. Disaster Risk Reduct.*, vol. 7, pp. 154–164, 2014, doi: 10.1016/j.ijdrr.2013.10.005.
[59] J. de Boer, W. J. Wouter Botzen, and T. Terpstra, “More Than Fear Induction: Toward an Understanding of People’s Motivation to Be Well-Prepared for Emergencies in Flood-Prone Areas,” *Risk Anal.*, vol. 35, no. 3, pp. 518–535, 2015, doi: https://doi.org/10.1111/risa.12289.
[60] P. Lujala, H. Lein, and J. K. Rød, “Climate change, natural hazards, and risk perception: The role of proximity and personal experience,” *Local Environ.*, vol. 20, pp. 1–21, 2014, doi: 10.1080/13549839.2014.887666.
[61] G. Setten and P. Lujala, “Climate change and natural hazards - the geography of community

resilience," *Nor. Geogr. Tidsskr.*, vol. 74, pp. 133–134, 2020, doi: 10.1080/00291951.2020.1778782.
[62] U. Habiba and R. Shaw, "24 - Improvement of responses and recovery approaches for cyclone hazards in coastal Bangladesh," in *Science and Technology in Disaster Risk Reduction in Asia*, R. Shaw, K. Shiwaku, and T. Izumi, Eds. Academic Press, 2018, pp. 409–430.
[63] A. Reynaud, C. Aubert, and M.-H. Nguyen, "Living with Floods: Protective Behaviours and Risk Perception of Vietnamese Households," *Geneva Pap. Risk Insur. - Issues Pract.*, vol. 38, no. 3, pp. 547–579, 2013, doi: 10.1057/gpp.2013.16.
[64] J. S. Carlton *et al.*, "The effects of extreme drought on climate change beliefs, risk perceptions, and adaptation attitudes," *Clim. Change*, vol. 135, no. 2, pp. 211–226, 2016, doi: 10.1007/s10584-015-1561-5.
[65] S. Z. Walelign and P. Lujala, "A place-based framework for assessing resettlement capacity in the context of displacement induced by climate change," *World Dev.*, vol. 151, p. 105777, 2022, doi: https://doi.org/10.1016/j.worlddev.2021.105777.
[66] G. Wachinger, O. Renn, C. Begg, and C. Kuhlicke, "The risk perception paradox--implications for governance and communication of natural hazards.," *Risk Anal.*, vol. 33, no. 6, pp. 1049–1065, Jun. 2013, doi: 10.1111/j.1539-6924.2012.01942.x.
[67] A. Dlugolecki, "The Cost of Extreme Events in 2030. A Report for United Nations Framework Convention on Climat," 2007.
[68] E. Mills, "Insurance in a Climate of Change," *Science (80-.).*, vol. 309, no. 5737, pp. 1040–1044, 2005, doi: 10.1126/science.1112121.
[69] A. Buzási and A. Csizovszky, "Urban sustainability and resilience: What the literature tells us about 'lock-ins'?," *Ambio*, vol. 52, no. 3, pp. 616 – 630, 2023, doi: 10.1007/s13280-022-01817-w.
[70] N. Kapucu, Y. 'Gurt' Ge, Y. Martín, and Z. Williamson, "Urban resilience for building a sustainable and safe environment," *Urban Gov.*, vol. 1, no. 1, pp. 10–16, 2021, doi: 10.1016/j.ugj.2021.09.001.
[71] V. Assumma, M. Bottero, G. Datola, E. De Angelis, and R. Monaco, "Dynamic models for exploring the resilience in territorial scenarios," *Sustain.*, vol. 12, no. 1, pp. 1–19, 2020, doi: 10.3390/su12010003.
[72] M. Zhang, C. Peng, J. Shu, and Y. Lin, "Territorial Resilience of Metropolitan Regions: A Conceptual Framework, Recognition Methodologies and Planning Response—A Case Study of Wuhan Metropolitan Region," *Int. J. Environ. Res. Public Health*, vol. 19, no. 4, 2022, doi: 10.3390/ijerph19041914.
[73] S. Shamsuddin, "Resilience resistance: The challenges and implications of urban resilience implementation," *Cities*, vol. 103, no. May, 2020, doi: 10.1016/j.cities.2020.102763.
[74] N. Komendantova, A. Scolobig, A. Garcia-Aristizabal, D. Monfort, and K. Fleming, "Multi-risk approach and urban resilience," *Int. J. Disaster Resil. Built Environ.*, vol. 7, no. 2, pp. 114–132, 2016, doi: 10.1108/IJDRBE-03-2015-0013.
[75] G. Büyüközkan, Ö. Ilıcak, and O. Feyzioglu, "A review of urban resilience literature," *Sustain. Cities Soc.*, vol. 77, p. 103579, 2021, doi: 10.1016/j.scs.2021.103579.
[76] M. Mola, M. Feofilovs, and F. Romagnoli, "Energy resilience: research trends at urban, municipal and country levels," *Energy Procedia*, vol. 147, pp. 104–113, 2018, doi: https://doi.org/10.1016/j.egypro.2018.07.039.
[77] M. Bottero, G. Datola, and R. Monaco, "Fuzzy cognitive maps: A dynamic approach for urban regeneration processes evaluation," *Valori e Valutazioni*, vol. 2019, no. 23, pp. 77–90, 2019.
[78] J. G. Carter, "Climate change adaptation in European cities," *Curr. Opin. Environ. Sustain.*, vol. 3, no. 3, pp. 193–198, 2011, doi: 10.1016/j.cosust.2010.12.015.
[79] S. Bueno, V. A. Bañuls, and M. D. Gallego, "Is urban resilience a phenomenon on the rise? A systematic literature review for the years 2019 and 2020 using textometry," *Int. J. Disaster Risk Reduct.*, vol. 66, p. 102588, 2021, doi: https://doi.org/10.1016/j.ijdrr.2021.102588.
[80] W. Zhu, "Ambiguity aversion and an intertemporal equilibrium model of catastrophe-linked securities pricing," *Insur. Math. Econ.*, vol. 49, no. 1, pp. 38–46, 2011, doi: 10.1016/j.insmatheco.2011.02.001.
[81] H. Kaushalya, G. Karunasena, and D. Amarathunga, "Role of Insurance in Post Disaster

Recovery Planning in Business Community,” *Procedia Econ. Financ.*, vol. 18, no. September, pp. 626–634, 2014, doi: 10.1016/S2212-5671(14)00984-8.
[82] A. Rahman and C. Fang, “Appraisal of gaps and challenges in Sendai Framework for Disaster Risk Reduction priority 1 through the lens of science, technology and innovation,” *Prog. Disaster Sci.*, vol. 1, p. 100006, 2019, doi: https://doi.org/10.1016/j.pdisas.2019.100006.
[83] F. Toseroni, F. Romagnoli, and F. Marincioni, “Adapting and Reacting to Measure an Extreme Event: A Methodology to Measure Disaster Community Resilience,” *Energy Procedia*, vol. 95, pp. 491–498, 2016, doi: https://doi.org/10.1016/j.egypro.2016.09.074.
[84] United Nations, “Report of the world conference on natural disaster reduction,” *World Conf. Nat. Disaster Reduct.*, vol. 37604, no. 23-27 May, pp. 1–49, 1994.
[85] “UN General Assembly, Resolution 69/283 of 23 June 2015, Sendai framework for disaster risk reduction 2015–2030, 2015.”
[86] A. Wilkins *et al.*, “Challenges and opportunities for Sendai framework disaster loss reporting in the United States,” *Prog. Disaster Sci.*, vol. 10, p. 100167, 2021, doi: https://doi.org/10.1016/j.pdisas.2021.100167.
[87] “Global Earthquake Model Foundation - Methods and Tools Innovation for Seismic Risk Assessment,” 2018.
[88] A. Subramanian and J. Wang, “Reinsurance versus securitization of catastrophe risk,” *Insur. Math. Econ.*, vol. 82, pp. 55–72, 2018, doi: 10.1016/j.insmatheco.2018.06.006.
[89] Y. Zhao and M. T. Yu, “Measuring the liquidity impact on catastrophe bond spreads,” *Pacific Basin Financ. J.*, vol. 56, no. February, pp. 197–210, 2019, doi: 10.1016/j.pacfin.2019.06.006.
[90] F. T. Gizzi, D. Porrini, and F. De Masi, “Building a natural hazard insurance system (Nhis): The long-lasting Italian case,” *Sustain.*, vol. 13, no. 21, 2021, doi: 10.3390/su132112269.
[91] T. Götze and M. Gürtler, *Risk transfer beyond reinsurance: the added value of CAT bonds*, vol. 47, no. 1. Palgrave Macmillan UK, 2022.
[92] J. P. Newman *et al.*, “Review of literature on decision support systems for natural hazard risk reduction: Current status and future research directions,” *Environ. Model. Softw.*, vol. 96, pp. 378–409, 2017, doi: 10.1016/j.envsoft.2017.06.042.
[93] A. Braun, “Pricing catastrophe swaps: A contingent claims approach,” *Insur. Math. Econ.*, vol. 49, no. 3, pp. 520–536, 2011, doi: 10.1016/j.insmatheco.2011.08.003.
[94] J. D. Daron and D. A. Stainforth, “Assessing pricing assumptions for weather index insurance in a changing climate,” *Clim. Risk Manag.*, vol. 1, pp. 76–91, 2014, doi: 10.1016/j.crm.2014.01.001.
[95] S. Landini, “From Environmental insurance to Environmental derivatives?,” *Eur. Energy Environ. Law Rev.*, vol. 22, no. 6, pp. 228–234, 2013, [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84891681374&partnerID=40&md5=a301f3bc39e1e4f084a217b409f46a0f.
[96] Z. Zhao, “Natural catastrophe risk, insurance and economic development,” *Energy Procedia*, vol. 5, pp. 2340–2345, 2011, doi: 10.1016/j.egypro.2011.03.402.
[97] Y. C. Wu and S. L. Chung, “Catastrophe risk management with counterparty risk using alternative instruments,” *Insur. Math. Econ.*, vol. 47, no. 2, pp. 234–245, 2010, doi: 10.1016/j.insmatheco.2010.04.002.
[98] A. Steynor, L. Pasquini, and K. Waagsaether, “The Psychology of Decision Making Under Uncertainty (USAID),” 2019.
[99] A. Steynor, L. Pasquini, A. Thatcher, and B. Hewitson, “Understanding the Links Between Climate Change Risk Perceptions and the Action Response to Inform Climate Services Interventions,” *Risk Anal.*, vol. 41, no. 10, pp. 1873–1889, 2021, doi: 10.1111/risa.13683.
[100] S. A. Bokadarov, A. S. Kravchenko, A. N. Peregudov, N. G. Kulakova, and A. V. Kalach, “Disaster Insurance Decision Support System,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 459, no. 5, 2020, doi: 10.1088/1755-1315/459/5/052060.
[101] J. Froestad *et al.*, *Climate change at the city scale: Impacts, mitigation and adaptation in Cape Town*, vol. null. 2012.
[102] O. O. Olarewaju and B. C. Nomlala, “Climate Change and Insurance Business in Developing Economies,” no. June, 2021, pp. 190–201.
[103] S. Fankhauser, C. Gennaioli, and M. Collins, “The political economy of passing climate change

legislation: Evidence from a survey," *Glob. Environ. Chang.*, vol. 35, pp. 52–61, 2015, doi: https://doi.org/10.1016/j.gloenvcha.2015.08.008.
[104] A. Hu and I. Demir, "Real-time flood mapping on client-side web systems using hand model," *Hydrology*, vol. 8, no. 2, 2021, doi: 10.3390/hydrology8020065.
[105] E. Segal, M. Negev, E. Feitelson, and D. Zaychik, "Devising 'policy packages' for seismic retrofitting of residences," *Nat. Hazards*, vol. 89, 2017, doi: 10.1007/s11069-017-2978-0.
[106] Z. Bakaki, T. Böhmelt, and H. Ward, "The triangular relationship between public concern for environmental issues, policy output, and media attention," *Env. Polit.*, vol. 29, pp. 1–21, 2019, doi: 10.1080/09644016.2019.1655188.
[107] U. Ranke, *Natural disaster risk management: Geosciences and social responsibility*. 2016.
[108] J. Gallagher, "Learning about an Infrequent Event: Evidence from Flood Insurance Take-Up in the United States," *Am. Econ. J. Appl. Econ.*, vol. 6, no. 3, pp. 206–233, 2014, doi: 10.1257/app.6.3.206.
[109] R. E. Dumm, D. L. Eckles, C. Nyce, and J. Volkman-Wise, "The representative heuristic and catastrophe-related risk behaviors," *J. Risk Uncertain.*, vol. 60, no. 2, pp. 157–185, 2020, doi: 10.1007/s11166-020-09324-7.
[110] M. Z. Nain, S. A. Bhat, and J. A. Bhat, "ESG investments, bear periods and adaptive resilience: evidence from India using a DBEKK-MGARCH," *J. Soc. Econ. Dev.*, 2023, doi: 10.1007/s40847-023-00273-w.
[111] A. Martini, "Socially responsible investing: from the ethical origins to the sustainable development framework of the European Union," *Environ. Dev. Sustain.*, vol. 23, no. 11, pp. 16874–16890, 2021, doi: 10.1007/s10668-021-01375-3.
[112] H. Alibašić, *Strategic Resilience and Sustainability Planning. Management Strategies for Sustainable and Climate-Resilient Communities and Organizations*, no. February. 2022.
[113] D. Struck, "Insurance in the Time of ESG," *Board Leadersh.*, vol. 2023, pp. 1–8, 2023, doi: 10.1002/bl.30245.
[114] I. Khovrak, "ESG-driven approach to managing insurance companies' sustainable development," *Insur. Mark. Co.*, vol. 11, pp. 42–52, 2020, doi: 10.21511/ins.11(1).2020.05.
[115] P. Wrede, C. Phily, J. J. Wipf, C. Tatin-Jaleran, and D. Garand, "Pricing for microinsurance: a technical guide," pp. 1–162, 2016, [Online]. Available: http://www.impactinsurance.org/sites/default/files/MI Pricing Guide FINAL.pdf.
[116] A. Thomas and R. Leichenko, "Adaptation through insurance: Lessons from the NFIP," *Int. J. Clim. Chang. Strateg. Manag.*, vol. 3, no. 3, pp. 250–263, 2011, doi: 10.1108/17568691111153401.
[117] M. Dell'ovo, F. Dell'anna, R. Simonelli, and L. Sdino, "Enhancing the cultural heritage through adaptive reuse. A multicriteria approach to evaluate the Castello Visconteo in Cusago (Italy)," *Sustain.*, vol. 13, no. 8, pp. 1–29, 2021, doi: 10.3390/su13084440.
[118] Freeman P.K. and S. K., "Comparative analysis of large-scale catastrophe compensation schemes, Catastrophic Risks and Insurance – Policy Issues in Insurance, 8 ed, OECD, Paris, 2005, pp. 187–234."
[119] V. Buterin, "A Next-Generation Smart Contract and Decentralized Application Platform," *https://github.com/ethereum/wiki/wiki/White-Paper*, 2014.
[120] D. Macrinici, C. Cartofeanu, and S. Gao, "Smart contract applications within blockchain technology: A systematic mapping study," *Telemat. Informatics*, vol. 35, no. 8, pp. 2337–2354, 2018, doi: 10.1016/j.tele.2018.10.004.
[121] M. Giancaspro, "Is a 'smart contract' really a smart idea? Insights from a legal perspective," *Comput. Law Secur. Rev.*, vol. 33, no. 6, pp. 825–835, 2017, doi: 10.1016/j.clsr.2017.05.007.
[122] G. Greenspan, "Beware of the Impossible Smart Contract," *http://www.theblockchain.com/2016/04/12/beware-of-the-impossible-smart-contract*, 2016.
[123] A. J. Pagano, F. Romagnoli, and E. Vannucci, "Implementation of Blockchain Technology in Insurance Contracts against Natural Hazards: A Methodological Multi-Disciplinary Approach," *Environ. Clim. Technol.*, vol. 23, no. 3, 2019, doi: 10.2478/rtuect-2019-0091.
[124] A. Hassan, M. I. Ali, R. Ahammed, M. M. Khan, N. Alsufyani, and A. Alsufyani, "Secured Insurance Framework Using Blockchain and Smart Contract," *Sci. Program.*, vol. 2021, pp. 1–11, 2021, doi: 10.1155/2021/6787406.

[125] F. Loukil, K. Boukadi, R. Hussain, and M. Abed, "Ciosy: A collaborative blockchain-based insurance system," *Electron.*, vol. 10, no. 11, pp. 1–15, 2021, doi: 10.3390/electronics10111343.
[126] F. Casino, T. K. Dasaklis, and C. Patsakis, "A systematic literature review of blockchain-based applications: current status, classification and open issues," *Telemat. Informatics*, vol. 36, no. May 2018, pp. 55–81, 2018, doi: 10.1016/j.tele.2018.11.006.
[127] F. Sabz Ali Pour, "Application of a Blockchain Enabled Model in Disaster Aids Supply Network Resilience," Old Dominion University, 2021.
[128] A. Gaur, "Conceptual Blockchain Analysis for Disaster Management," 2023, pp. 163–178.
[129] N. Szabo, "The Idea of Smart Contracts," *http://szabo.best.vwh.net/idea.html*, 1997.
[130] S. F. Fahmy, "Blockchain and its uses," 2018.
[131] AXA - Comunicato Stampa, "AXA Is Using Ethereum's Blockchain for a New Flight Insurance Product This website uses cookies," 2019.
[132] S. Landini, "Assicurabilità e indennizzabilità dei rischi catastrofali ambientali," *Assicurazioni*, 2013.
[133] "Italian AXA Paper del climatico La governance dell ' ambiente come bene pubblico globale : oggi , per il domani."
[134] A. J. Pagano, F. Romagnoli, and E. Vannucci, "Implementation of blockchain technology in insurance contracts against natural hazards : a methodological multi-disciplinary approach," *Environ. Clim. Technol.*, vol. 23, no. 3, pp. 211–229, 2019, doi: 10.2478/rtuect-2019-0091.
[135] V. Gatteschi, F. Lamberti, C. Demartini, C. Pranteda, and V. Santamaría, "Blockchain and smart contracts for insurance: Is the technology mature enough?," *Futur. Internet*, vol. 10, no. 2, pp. 8–13, 2018, doi: 10.3390/fi10020020.
[136] J. Park, S. Jeong, and K. Yeom, "Smart Contract Broker: Improving Smart Contract Reusability in a Blockchain Environment," *Sensors*, vol. 23, p. 6149, 2023, doi: 10.3390/s23136149.
[137] R. Feng, "Traditional Insurance," 2023, pp. 85–117.
[138] A. Borselli, "Smart Contracts in Insurance: A Law and Futurology Perspective," 2020, pp. 101–125.
[139] A. J. Pagano, F. Romagnoli, and E. Vannucci, "Quantitative and Financial Aspects of Resilience Bonds in the Context of Recursive Insurance Contracts. A Cost Benefit Analysis," *Environ. Clim. Technol.*, vol. 24, no. 3, pp. 387–402, 2020, doi: 10.2478/rtuect-2020-0111.
[140] H. Kantur, C. Bamuleseyo, and O. Mansour, "How smart contracts can change the insurance industry: Benefits and challenges of using Blockchain technology," no. May, 2018, [Online]. Available: https://www.diva-portal.org/smash/record.jsf?pid=diva2:1214254.
[141] S. Ferrazzi, "The Notion of 'Cultural Heritage' in the International Field: Behind Origin and Evolution of a Concept," *Int. J. Semiot. Law*, vol. 34, no. 3, pp. 743–768, 2021, doi: 10.1007/s11196-020-09739-0.
[142] UNESCO, "Protocol to the Convention for the Protection of Cultural Property in the Event of Armed Conflict," 1954.
[143] A. Jagielska-Burduk, M. Pszczyński, and P. Stec, "Cultural heritage education in unesco cultural conventions," *Sustain.*, vol. 13, no. 6, 2021, doi: 10.3390/su13063548.
[144] R. Maio, T. M. Ferreira, and R. Vicente, "A critical discussion on the earthquake risk mitigation of urban cultural heritage assets," *Int. J. Disaster Risk Reduct.*, vol. 27, no. October 2017, pp. 239–247, 2018, doi: 10.1016/j.ijdrr.2017.10.010.
[145] ICOMOS, "The wise use of heritage: abstracts from the World Congress of the Conservation of Cultural Heritage during ICOMOS 12th General Assembly," 1999.
[146] UNESCO, "Convention Concerning the Protection of the World Cultural and Natural Heritage (Paris)," 1972.
[147] F. Donato, "Cultura, patrimonio culturale e creatività nelle politiche della ricerca europee," *CAPITALE Cult. Stud. Value Cult. Herit.*, vol. 24, pp. 1–30, 2021.
[148] ANIA, "Associazione Nazionale tra le Imprese Assicuratrici. Italian insurance 2016–2017," 2017.
[149] A. J. Pagano, F. Romagnoli, and E. Vannucci, "Non-Incomes Risk Mitigation Mechanisms for Cultural Heritage: Role of Insurances Facing Covid-19 in the Italian Context," *Environ. Clim. Technol.*, vol. 26, no. 1, pp. 871–882, 2022.
[150] E. Apchain *et al.*, "Efficiency and durability of protective treatments on cultural heritage copper

corrosion layers," *Corros. Sci.*, vol. 183, no. February, 2021, doi: 10.1016/j.corsci.2021.109319.
[151] A. Bedate, L. C. Herrero, and J. Á. Sanz, "Economic valuation of the cultural heritage: Application to four case studies in Spain," *J. Cult. Herit.*, vol. 5, no. 1, pp. 101–111, 2004, doi: 10.1016/j.culher.2003.04.002.
[152] S. Kishor Patel, S. Mukherjee, and A. Nanda, "Importance of Insurance Mechanisms in Natural Disasters' Risk Mitigation: A case study in Indiav," *J. Disaster Emerg. Res.*, vol. 4, no. 1, pp. 38–51, 2021, doi: 10.18502/jder.5664.
[153] M. Vecco and F. Imperiale, "Cultural Heritage : Values and Measures. What Insurance Value ?," *J. Multidiscip. Res.*, vol. 9, no. 1, pp. 7–22, 2017.
[154] D. P. Alyakina and G. F. Khisamova, "Methodology for Rating of Insurance Portfolio," *Mediterr. J. Soc. Sci.*, no. November 2014, 2014, doi: 10.5901/mjss.2014.v5n24p137.
[155] A. J. Pagano, E. Vannucci, and F. Romagnoli, "Flood risk: financing for resilience using insurance adaptive schemes," *Int. J. Plant Chem. Soil Sci. Plant Nutr. Univ. Pisa*, 2019.
[156] C. Arrighi *et al.*, *Multi-risk assessment in a historical city*, no. 0123456789. Springer Netherlands, 2022.
[157] P. Grossi and H. Kunreuther, "The role of uncertainty on alternative disaster management strategies," *International Geology Review*, vol. 43, no. 5. pp. 391–400, 2001.
[158] J. P. Lee and M. T. Yu, "Valuation of catastrophe reinsurance with catastrophe bonds," *Insur. Math. Econ.*, vol. 41, no. 2, pp. 264–278, 2007, doi: 10.1016/j.insmatheco.2006.11.003.
[159] W. J. W. Botzen, J. . Bergh, and J. M. Van Den Bergh, "Monetary valuation of insurance against climate change risk," *Work. Manuscr. ...*, vol. 53, no. May, pp. 1–6, 2012, doi: 10.1111/j.1468-2354.2012.00709.x.
[160] D. Petersen, "Automating governance: Blockchain delivered governance for business networks," *Ind. Mark. Manag.*, vol. 102, no. November 2021, pp. 177–189, 2022, doi: 10.1016/j.indmarman.2022.01.017.
[161] X. Wang, W. Yang, S. Noor, C. Chen, M. Guo, and K. H. Van Dam, "Blockchain-based smart contract for energy demand management," *Energy Procedia*, vol. 158, pp. 2719–2724, 2019, doi: 10.1016/j.egypro.2019.02.028.
[162] G. De Gregorio, *Il contratto di assicurazione*. Giuffrè, 1987.
[163] S. Landini, "Reticenze dell'assicurato e annullabilità del contratto," *Resp. civ. e prev*, 2011.
[164] H. C. Kunreuther and E. O. Michel-Kerjan, "The Development of New Catastrophe Risk Markets," *Annu. Rev. Resour. Econ.*, vol. 1, no. 1, pp. 119–137, 2009, doi: 10.1146/annurev.resource.050708.144302.
[165] Actuaries Institute, "The Impact of Big Data on the Future of Insurance," 2016.
[166] A. Bellieri dei Belliera, M. Galeotti, A. J. Pagano, G. Rabitti, F. Romagnoli, and E. Vannucci, "Flood risk insurance : the Blockchain approach to a Bayesian adaptive design of the contract .," in *Afir ERM*, 2019, no. May, pp. 1–19.
[167] N. Kapucu, Y. 'Gurt' Ge, Y. Martín, and Z. Williamson, "Urban resilience for building a sustainable and safe environment," *Urban Gov.*, no. October, 2021, doi: 10.1016/j.ugj.2021.09.001.
[168] Y. Paudel, W. J. W. Botzen, and J. C. J. H. Aerts, "Estimation of insurance premiums for coverage against natural disaster risk: An application of Bayesian Inference," *Nat. Hazards Earth Syst. Sci.*, vol. 13, no. 3, pp. 737–754, 2013, doi: 10.5194/nhess-13-737-2013.
[169] D. Serre and C.Heinzlef, "Assessing and mapping urban resilience to floods with respect to cascading effects through critical infrastructure networks. International Journal of Disaster Risk Reduction," *Int. J. Disaster Risk Reduct.*, 2018.
[170] D. Bruneau, "A framework to quantitatively assess and enhance the seismic resilience of communities," *EERI Spectra*, pp. 733–752, 2003.
[171] N. R. Dalezios, "Environmental Hazards Methodologies for Risk Assessment and Management," *Water Intell. Online*, vol. 16, no. February, p. 9781780407135, 2017, doi: 10.2166/9781780407135.
[172] A. Blumberga *et al.*, *System Dynamics for Environmental Engineering Students*, 1st editio. Riga: RTU Izdevniecība, 2011.
[173] J. Forrester, "Some basic concepts in system dynamics," *Sloan Sch. Manag. ...*, pp. 1–17, 2009.
[174] J. D. Sterman, "Learning in and about complex systems," *Syst. Dyn. Rev.*, vol. 10, no. 2–3, pp.

291–330, 1994, doi: 10.1002/sdr.4260100214.
[175] D. Kurnianingtyas, B. Santosa, and N. Siswanto, "A System Dynamics for Financial Strategy Model Assessment in National Health Insurance System," in *Proceedings of the 2020 2nd International Conference on Management Science and Industrial Engineering*, 2020, pp. 44–48, doi: 10.1145/3396743.3396754.
[176] M. Chen, C.-T. Hsiao, G. C. Lai, and P.-L. Chang, "A System Dynamics Model of Development and Business Strategy in Taiwan Life Insurance Industry," *J. Risk Manag. Insur.*, vol. 13, no. 1, pp. 23–30, 2009.
[177] G. A. M. LATVIAN CENTER FOR ENVIRONMENT, "Preliminary flood risk assessment for 2019 -2024," 2019.
[178] M. Feofilovs and F. Romagnoli, "Dynamic assessment of urban resilience to natural hazards," *Int. J. Disaster Risk Reduct.*, vol. 62, p. 102328, 2021, doi: https://doi.org/10.1016/j.ijdrr.2021.102328.
[179] B. G. Reguero *et al.*, "Financing coastal resilience by combining nature-based risk reduction with insurance," *Ecol. Econ.*, vol. 169, p. 106487, 2020, doi: https://doi.org/10.1016/j.ecolecon.2019.106487.
[180] E. N. Gurenko, "Climate Policy," in *Climate Change and Insurance: Disaster Risk Financing in Developing Countries*, 2006.
[181] P. Grossi and H. Kunreuther, "An Introduction to Catastrophe Models," in *Catastrophe modelling: a new approach to managing risk*, 2005.
[182] S. Surminski, L. M. Bouwer, and J. Linnerooth-Bayer, "How insurance can support climate resilience," *Nature Climate Change*, vol. 6, no. 4. 2016, doi: 10.1038/nclimate2979.
[183] A. Dlugolecki, "Climate Change and the Insurance Sector," *Geneva Pap. Risk Insur. Issues Pract.*, vol. 33, no. 1, pp. 71–90, 2008.
[184] M. Wilkins, "The Need for a Multi-Level Approach to Climate Change—An Australian Insurance Perspective," *Geneva Pap. Risk Insur. - Issues Pract.*, vol. 35, no. 2, pp. 336–348, 2010, doi: 10.1057/gpp.2010.8.
[185] E. Mills, R. Roth, and E. Lecomte, "Availability and Affordability of Insurance Under Climate Change. A Growing Challenge for the U.S," *J. Insur. Regul.*, vol. 25, 2005.
[186] R. Schwarze and G. G. Wagner, "The political economy of natural disaster insurance: lessons from the failure of a proposed compulsory insurance scheme in Germany," *Eur. Environ.*, vol. 17, no. 6, pp. 403–415, 2007, doi: https://doi.org/10.1002/eet.456.
[187] J. McAneney, D. McAneney, R. Musulin, G. Walker, and R. Crompton, "Government-sponsored natural disaster insurance pools: A view from down-under," *International Journal of Disaster Risk Reduction*, vol. 15. 2016, doi: 10.1016/j.ijdrr.2015.11.004.
[188] M. Bof, "Terremoti: Generali, costi non possono piu' gravare su collettivita," *Il Sole 24 Ore*, 2012.
[189] A. Coviello, "Profili e principali approcci alle coperture dei rischi catastrofali," in *Calamità Naturali e coperture assicurative*, Dario Flaccovio, Ed. 2013, pp. 29–82.
[190] Munich Re, "Economic consequences of natural catastrophes: Emerging and developing economies particularly affected – Insurance cover is essential," 2013.
[191] V. Lamberti, F.; Gatteschi, V.; Demartini, C.; Pranteda, C.; Santamaria, "Blockchain or not blockchain, that is the question of the insurance and other sectors. IT Prof. 2017, doi:10.1109/MITP.2017.265110355."
[192] E. Vannucci, A. J. Pagano, and F. Romagnoli, "Climate change management: a resilience strategy for flood risk using Blockchain tools," *Decis. Econ. Financ.*, vol. 44, pp. 177–190, 2021, doi: 10.1007/s10203-020-00315-6.
[193] S. Berghi, "Energy use in Urban Transport sector within the Sustainable Energy Action Plans (SEAPs) of three Italian Big Cities," *Energy Procedia*, vol. 126, pp. 414–420, 2017, doi: 10.1016/j.egypro.2017.08.193.
[194] S. Trémolet, B. Atwell, K. Dominique, N. Matthews, M. Becker, and R. Muñoz, "Chapter 15 - Funding and financing to scale nature-based solutions for water security," in *Nature-based Solutions and Water Security*, J. Cassin, J. H. Matthews, and E. L. Gunn, Eds. Elsevier, 2021, pp. 361–398.
[195] A. G. Rumson, A. P. Garcia, and S. H. Hallett, "The role of data within coastal resilience

assessments: an East Anglia, UK, case study," *Ocean Coast. Manag.*, vol. 185, p. 105004, 2020, doi: https://doi.org/10.1016/j.ocecoaman.2019.105004.
[196] E. Stoeckli, C. Dremel, and F. Uebernickel, "Exploring characteristics and transformational capabilities of InsurTech innovations to understand insurance value creation in a digital world. Electron. Mark. 1–19," 2018.
[197] Actuaries Institute, "The Impact of Big Data on the Future of Insurance," no. November, pp. 1–36, 2016, [Online]. Available: https://actuaries.asn.au/Library/Opinion/2016/BIGDATAGPWEB.pdf.
[198] H. Kunreuther, E. Michel-Kerjan, and G. Tonn, "Insurance, Economic Incentives and Other Policy Tools for Strengthening Critical Infrastructure Resilience: 20 Proposals for Action 56.," 2016.
[199] S. Nakamoto, "Bitcoin: A Peer-to-Peer Electronic Cash System; 2008, Available online: https://bitcoin.org/bitcoin.pdf," 2008.
[200] S. Higgins, "Insurance Giant Allianz France Exploring Blockchain Potential," 2016. https://www.coindesk.com/markets/2015/12/21/insurance-giant-allianz-france-exploring-blockchain-potential/.
[201] Insurance Times, "AXA leads $55m investment in blockchain," 2016. https://www.insurancetimes.co.uk/axa-leads-55m-investment-in-blockchain/1417270.article.
[202] M. Ramada, "For insurers blockchain is the new black," 2017. http://blog.willis.com/2016/12/for- insurers-blockchain-is-the-new-black.
[203] A. Shelkovnikov, "Blockchain Applications in Insurance," London, 2016.
[204] S. Higgins, "European Insurance Firms Launch New Blockchain Consortium," 2016. https://www.coindesk.com/markets/2016/10/19/european-insurance-firms-launch-new-blockchain-consortium/.
[205] BanklessTimes, "Friendsurance brings P2P concept to insurance," 2023. https://www.banklesstimes.com/news/2015/08/30/friendsurance-brings-p2p-concept-to-insurance/.
[206] J. Davis, "Peer to peer insurance on an Ethereum blockchain. General Consideration of the Fundamentals of Peer to Peer Insurance," 2017.
[207] "L'Assicurazione dei Rischi. Calamità Naturali. Insuring Natural Catastrophe Risks," 2000.
[208] W. Viriyasitavat and D. Hoonsopon, "Blockchain characteristics and consensus in modern business processes," *J. Ind. Inf. Integr.*, no. June, pp. 0–1, 2018, doi: 10.1016/j.jii.2018.07.004.
[209] F. Gizzi, D. Porrini, and F. De Masi, "Building a Natural Hazard Insurance System (NHIS): The Long-Lasting Italian Case," *Sustainability*, vol. 13, no. 21, p. 12269, 2021, doi: 10.3390/su132112269.
[210] A. J. Pagano, F. Romagnoli, and E. Vannucci, "COVID-19 Effects on Cultural Heritage : The Case of Villa Adriana and Villa D ' Este," *Environ. Clim. Technol.*, vol. 25, no. 1, pp. 1241–1252, 2021.
[211] D. Agostino, M. Arnaboldi, and A. Lampis, "Italian state museums during the COVID-19 crisis: from onsite closure to online openness," *Museum Manag. Curatorsh.*, pp. 362–372, 2020, doi: 10.1080/09647775.2020.1790029.
[212] M. Munasinghe and C. Clarke, "Disaster Prevention for Sustainable Development-Economic and Policy Issues," *Int. Decad. Nat. Disaster Reduct.*, 1994.
[213] Ministère de l'Intérieur, "Plan ORSEC et Plans Particuliers d'Intervention [Online]. [Accessed 12.11.2021]. Available: https://www.gouvernement.fr/risques/dispositif-orsec."
[214] M. Drdácký, L. Binda, I. Herle, and L. Lanza, "Protecting the cultural heritage from natural disasters," *Adv. Res. Cent. Cult. Herit.*, no. February, p. 100, 2007, [Online]. Available: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Protecting+the+cultural+heritage+from+natural+disasters#3%5Cnhttp://www.europarl.europa.eu/activities/committees.
[215] B. Miller, L. Dixon, and N. Clancy, "Reasonable and Risk-Based? Replacing NFIP Generally Subsidized Rates with a Means-Tested Subsidy," *South. Econ. J.*, vol. 85, no. 4, pp. 1180–1195, 2019, doi: https://doi.org/10.1002/soej.12329.
[216] Europa Nostra, "COVID-19 & Beyond: Challenges and Opportunities for Cultural Heritage," no. October, pp. 1–30, 2020, [Online]. Available: https://bit.ly/3jaWHCB.
[217] M. Feofilovs, A. J. Pagano, M. Spiotta, E. Vannucci, and F. Romagnoli, "Climate change-related

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1. M. Feofilovs, **A. J. Pagano**, E. Vannucci, M. Spiotta, and F. Romagnoli. Climate change-related disaster risk mitigation through innovative insurance mechanism: a System Dynamics model application for a case study in Latvia International. *Risks*, 2024 (in review).

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3. **A. J. Pagano**, F. Romagnoli, and E. Vannucci. COVID-19 Effects on Cultural Heritage: The Case of Villa Adriana and Villa D'Este. *Environ. Clim. Technol.*, 2021, Vol. 25, no. 1, pp. 1241-1252.

4. **A. J. Pagano**, F. Romagnoli, and E. Vannucci. Climate change management: a resilience strategy for flood risk using Blockchain tools. *Decis. Econ. Financ.*, 2021, Vol. 44, pp. 177-190.

5. **A. J. Pagano**, F. Romagnoli, and E. Vannucci. Quantitative and Financial Aspects of Resilience Bonds in the Context of Recursive Insurance Contracts. A Cost Benefit Analysis. *Environ. Clim. Technol.*, 2020, Vol. 24, no. 3, pp. 387-402.

6. **A. J. Pagano**, F. Romagnoli, and E. Vannucci. Insurance against Natural Hazards: Critical Elements on the Risk Premium Evaluation in the Italian Context. *Environ. Clim. Technol.*, 2020, Vol. 24, no. 3, pp. 373-386.

7. **A. J. Pagano**, E. Vannucci, and F. Romagnoli. Flood risk: financing for resilience using insurance adaptive schemes. *International Journal of Plant Chemistry, Soil Science and Plant Nutrition of the University of Pisa, The Effects of Climate Change Agrochimica - Special Issue*, 2019, pp. 305-322.

8. A. Bellieri dei Belliera, M. Galeotti, **A. J. Pagano**, G. Rabitti, F. Romagnoli, and E. Vannucci. Flood risk insurance: the Blockchain approach to a Bayesian adaptive design of the contract. In *Afir ERM*, 2019, pp. 1-19.

9. **A. J. Pagano**, F. Romagnoli, M. Spiotta, and E. Vannucci. Implementation of Blockchain Technology in Insurance Contracts against Natural Hazards: A Methodological Multi-Disciplinary Approach. *Environ. Clim. Technol.*, 2019, Vol. 23, no. 3, pp. 211-229.

10. **A. J. Pagano**, M. Feofilovs, and F. Romagnoli. The relationship between insurance companies and natural disaster risk reduction: overview of the key characteristics and mechanisms dealing with climate change. *Energy Procedia*, 2018, Vol. 147, pp. 566-572.

Publication 1

Climate change-related disaster risk mitigation through innovative insurance mechanism: a System Dynamics model application for a case study in Latvia

Climate change-related disaster risk mitigation through innovative insurance mechanism: a System Dynamics model application for a case study in Latvia

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***Abstract* – This study explores how the System Dynamics modelling approach can help to deal with the problem of conventional insurance mechanisms by studying the feedback loops governing complex systems connected to the disaster insurance mechanism. Instead of addressing the disaster's underlying risk, the traditional disaster insurance strategy largely focuses on providing financial security for asset recovery after a disaster. This constraint becomes especially concerning as the threat of climate-related disasters grows since it may result in rising long-term damage expenditures. A new insurance mechanism is suggested as a solution to this problem in order to lower damage costs while safeguarding insured assets and luring new assets to be protected. A local case study utilizing a System Dynamics stock and flow model is created and validated by examining the model's structure, sensitivity analysis and extreme value test. The case study results performed on a city in Latvia highlight the significance of effective disaster risk reduction strategies in lowering overall disaster costs applied within the innovative insurance mechanism. The logical coherence seen throughout the analysis of simulated scenario results strengthens the established model's plausibility. The case study's findings support the innovative insurance mechanism's dynamic hypothesis and show that they can be used in various settings. The information this study provides and the model can help insurance firms, policy planners, and disaster risk managers make decisions that will benefit local communities and other stakeholders regarding climate-related disaster risk mitigation.**

***Keywords* – Disaster risk reduction, damage probabilities, dynamic model, probabilistic approach, Causal loop diagrams, Investment, Natural hazard**

1. Introduction

Climate change has increased the frequency and intensity of natural disasters, including floods, hurricanes, wildfires, and extreme weather events and it poses significant risks to communities, ecosystems, and economies worldwide. Within the last 2 decades (i.e. 2000-2019), the Emergency Events Database (EM-DAT) [1] depicted a strong increase in disaster events (more than 7 300), with more than 1.2 million deaths and more than 4 billion people affected [2].

According to statistics on natural disasters in Europe, floods and storms, followed by severe temperatures, account for most disaster incidents. According to a Swiss Re analysis, [3] the

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recurrence rates of similar flood occurrences have dramatically increased across South and Eastern Europe. Changes in forestry and agricultural land use, population expansion, and urbanisation are thought to have contributed to the growing flood risk. In addition, a research by [4] found that from 1960 to 2010, the distance in Europe across which multiple rivers flood simultaneously increased by roughly 50%, contributing to large-scale flood impacts.

In the study of [5], which suggests that land-use changes, urbanisation, and climate change were reported as contributors to increasing flood risk, similar findings about an increase in the frequency of extreme events such as floods, heatwaves, droughts, windstorms, and wildfires across Europe are found.

According to [6], urbanisation and climate change, which will affect social and economic factors, will provide more difficulties for European cities in the near future. According to EEA, earthquakes came in second with losses of about EUR 29 billion, while flooding and storms were the most expensive hazards in Europe from 1998 to 2009, with losses totaling up to about EUR 52 billion for floods and EUR 44 billion for storms [7].

Large portions of Europe were hit by droughts, according to the Munich Re report for 2018. Droughts are thought to cause over EUR 3.3 billion in damage to forests and agriculture. Overall damages from two significant winter storms in Europe totaled EUR 3.1 billion, and tropical storms caused EUR 310 million in property damage. Strong wind gusts in coastal areas have caused EUR 3 billion in damage [8].

One of the biggest risks associated with the climate in Latvia is flooding. Due to the spring's quick snowmelt, riverine flooding occurs every year in Latvia and can become disastrous. According to the event's severity, the return rate is expected to range from once per 10 to 200 years. Together, these incidents result in the destruction of structures, loss of land and natural resources, interruptions to energy provision, and problems with the water management system. This circumstance demonstrates that some settlements in Latvia are not sufficiently "resilient" to natural disasters, so research must be done to give a more comprehensive understanding of the issue associated with riverine floods [9].

The yearly rise in storm surge damage to buildings in all coastal cities in Latvia between 2040 and 2070 may be close to EUR 1.5 million per year, according to the Latvian Adaptation Plan to Climate Change for Time Period to 2030 [10]. Damage in the years 2070 to 2100 could possibly top EUR 3 million annually. In addition, as a result of climate change, increased rainfall and snowmelt could result in yearly economic losses of EUR 40 000–50 000 in the years 2020–2040 and EUR 160 000–210 000 in the years 2070–2100 [9].

Building urban resilience is crucial to reducing the effects of natural disasters in Latvia, according to the current condition and anticipated future effects, and it must be carefully taken into account when used in local policy planning. Local governments (i.e., municipalities) might greatly benefit from a tool that aids in the evaluation of the consequences of various urban resilience methods and fills in knowledge gaps about long- and short-term tradeoffs in urban resilience planning.

These disasters threaten human lives, infrastructure, and the environment. In this context, insurance mechanisms play a vital role in mitigating the impacts of climate change-related disasters by providing financial protection and promoting risk reduction measures, and innovative insurance mechanisms have emerged as essential tools to mitigate and manage the risks associated with climate change.

Projects mitigating the effects of hazards on communities can now be financed using a wide range of financial and insurance mechanisms. Event-linked instruments, including *Catastrophe Bonds*, have increased in popularity in recent years [11].

A wide range of financial tools is emerging to finance projects reducing hazard impacts on communities. In recent years, event-linked securities such as catastrophe bonds have expanded. For example catastrophe bonds can bed used to transfer risks related to the possibility of disasters to the financial markets (2021), [12] or like *Resilience Bond* created to support resilient infrastructure initiatives lowering large-scale risks in potential disasters [13], [14].

Due to the interaction of these factors, it is necessary to increase resilience through hazard mitigation techniques. Resilience is defined as the capacity to anticipate, withstand, recover from, or more successfully adapt to actual or potential unfavourable events [15], [16]. A community's capacity to withstand and recover from disasters can be improved by making proactive investments in hazard mitigation measures that assist in reducing catastrophic losses and damages.

However, financial resources are frequently allocated disproportionately to support recovery initiatives after a disaster, rather than using the few resources to finance pre-disaster mitigation activities. According to research, disaster mitigation investing is cost-effective because it typically generates $6 in savings for every $1 invested [17].

This proactive role could be played by insurance companies, implemented in different type of mechanisms. Insurance mechanisms offer indispensable tools to manage the risks associated with climate change [12]. By facilitating risk transfer, encouraging risk reduction measures, promoting collaboration, and fostering innovation, these mechanisms contribute to building resilience and ensuring sustainable development in the face of climate challenges. Policymakers, insurers, and communities must work together to enhance the accessibility, affordability, and effectiveness of insurance mechanisms, ultimately safeguarding societies against climate change-related risks and supporting a more resilient future [18].

2.1. Role of insurance sector in mitigating and adapting to climate change-related risks

The insurance sector has a proactive role in mitigating and adapting to climate change-related risks. Insurance mechanisms begin with a comprehensive risk assessment to effectively mitigate climate change-related risks. This involves analyzing historical disaster data, studying climate projections, and evaluating vulnerability assessments considering factors such as historical data, climate models, vulnerability assessments, and exposure analysis. Insurance providers can accurately price policies and determine coverage levels by understanding the frequency, severity, and spatial distribution of risks. Proper risk pricing ensures that policyholders pay premiums commensurate with the level of risk they face, thereby incentivizing risk reduction measures [19], [20]. Through risk management advice and guidelines, insurers also encourage policyholders to implement measures that mitigate climate-related risks, thus fostering resilience.

Insurance mechanisms have the potential to incentivize risk reduction and adaptation measures. Insurers can offer reduced premiums or additional coverage benefits to policyholders who adopt climate adaptation strategies, invest in resilient infrastructure, or implement sustainable practices. By encouraging proactive measures, insurance mechanisms contribute to building climate resilience, reducing vulnerability, and promoting long-term sustainability [21].

Parametric or index-based insurance products have emerged as innovative mechanisms to enhance the efficiency and effectiveness of climate risk mitigation. These products utilize predetermined triggers, such as wind speed, rainfall levels, or temperature thresholds, to determine the payout amounts. By removing the need for complex claims processing and assessments, parametric insurance enables faster response and timely financial support to affected policyholders. It also reduces administrative costs for insurance providers, enabling them to offer coverage to more individuals and businesses in high-risk areas [22].

By offering lower premiums or other benefits, such as deductible discounts or specialized coverage options, insurance providers encourage policyholders to implement climate adaptation and mitigation strategies insurance mechanisms can play a pivotal role in incentivizing risk reduction measures. These measures may include constructing resilient infrastructure, adopting sustainable land management practices, implementing early warning systems, or investing in disaster-resistant building materials. Insurance mechanisms foster a proactive approach to risk reduction through such incentives and enhance overall community resilience [18], [23].

Effective risk communication and education are essential components of state-of-the-art insurance mechanisms. Insurers engage with policyholders, urban communities, and local authorities to raise awareness about climate change risks, insurance options, and risk reduction measures [24]. Through educational campaigns, workshops, and community forums, stakeholders are empowered to make informed decisions, enhance their risk perception, and actively participate in building urban resilience [25].

Successful implementation of insurance mechanisms to mitigate climate change-related disasters requires collaboration among various stakeholders. Government agencies, non-governmental organizations, insurance providers, local communities, and academic institutions must work together to develop comprehensive solutions. By pooling resources, knowledge, and expertise, stakeholders can create integrated approaches to disaster risk reduction and ensure that insurance mechanisms align with broader climate change adaptation strategies [19].

Monitoring and evaluating the effectiveness of insurance mechanisms is crucial to their long-term success. By continuously assessing changes in risk profiles, insurance uptake rates, claims experience, and the overall resilience of insured assets, stakeholders can identify areas for improvement and make necessary adjustments. This iterative process helps refine the insurance mechanisms, enhance their efficiency, and adapt to evolving climate change risks [26].

Insurance mechanisms can incentivize the development of green and resilient infrastructure in urban areas. Insurers encourage risk reduction and resilience-building practices by offering lower premiums or tailored coverage options to policyholders who implement climate adaptation measures, such as green roofs, permeable pavements, or flood-resistant constructionv[11], [27]. These incentives protect insured assets and contribute to the overall sustainability and climate resilience of urban environments.

Insurance mechanisms against climate change risks require continuous innovation and research [11], [18], [27]. Insurers need to stay abreast of emerging climate science, technological advancements, and risk modeling techniques. By investing in research and development, insurers can improve risk assessment accuracy, develop tailored coverage options, and adapt to changing climate dynamics Innovations such as parametric triggers, data analytics, and remote sensing technologies contribute to the effectiveness and efficiency of insurance mechanisms.

Governments play a vital role in supporting insurance mechanisms against climate change risks [28]. Policymakers can facilitate the development and implementation of supportive regulations, tax incentives, and risk-sharing frameworks. Public-private partnerships foster collaboration between insurers and governments, enabling the design of comprehensive insurance solutions that address the unique challenges of climate change and promote inclusive coverage [23], [29].

2.2 Aim of the paper

Considering the overall concern towards climate change and the need to mitigate natural hazards' risks, new and more proactive insurance tools may be key soon. However, there is limited research on the use and implementation of resilience financial tools implemented with the insurance sector to perform integrated research to evaluate the dynamics towards a more favorable and pro-active role of the insurance system.

This constraint raises concerns because it could result in growing long-term damage costs as the threat of climate-related calamities increases. To address this issue and reduce damage costs while protecting insured assets, a novel insurance method is proposed in this study.

To fill in this knowledge gap and assess the usefulness and efficiency of new insurance instruments embedded in a proactive role of the insurance sector as driver for risk mitigation and prevention measure the core question of the proposed case study is "*to what extend the applications of a novel insurance mechanism can be used for co-financing disaster resilience projects by mitigation and adaptation strategies enhancing community resilience against weather-related hazards*"?

The aforementioned issues will influence the business strategies and upcoming advancements of insurance businesses. A variety of intricate and dynamic elements brings on the occurrences and issues. These elements depend on one another since they are connected and have causal connections. This study wants to represent a first step to create a proactive business development model for insurance companies in the climate-related risk reduction field. Thus, a case study for the Latvian context will be made to identify issues linked to business operation through a system dynamics modelling.

This study explores the role of insurance mechanisms in safeguarding against climate change-related risks and highlights their importance in promoting resilience and sustainable development with help of insurance bonds for financing the disaster risk reduction (DDR) measures.

A new insurance mechanism is suggested as a solution to this problem in order to lower damage costs while safeguarding insured assets and luring new assets to be protected. A local case study utilizing a System Dynamics stock and flow model is created and validated by examining the model's structure, sensitivity analysis and extreme value test.

Two different insurance mechanism are analyzed as potential option when a risk reduction financing come from a governmental risk mitigation strategy: (i) a declining risk premium in connection to the risk reduction from a governmental risk mitigation strategy (ii) a fix risk premium where the savings from reduced premiums can partly cover the initial investment in risk reduction measure or support it.

Developing a System Dynamics model to analyze insurance mechanisms aimed at declining and mitigating climate change-related disasters in the urban context can provide valuable insights into the complex dynamics and feedback loops involved.

System Dynamics model requires expertise in system dynamics modeling techniques, climate science, urban planning, and insurance practices. It is crucial to gather relevant data, consult domain experts, and refine the model iteratively based on feedback and validation.

2. METHODOLOGY

The study uses System Dynamics (SD) modelling to investigate the complex and dynamics problem of insurance policies aiming to helping local communities dealing with climate-related disasters impacts on their real estate assets. This section presents the description of SD method and steps performed for development of system dynamics model and conducting a case study, including the definition of the dynamic problem and hypothesis, creation of causal loops that explain the behaviour of studied system, necessary data inputs, model validation, and scenarios used to determine the effects of various policy interventions.

The SD is a methodology developed by Forrester et.al. in the 1950s at the Massachusetts Institute of Technology (MIT). This approach is particularly useful for studying dynamic systems that exhibit feedback loops, delays, and non-linear relationships. The fundamental principle of system dynamics is that the behaviour of a system arises from the interactions of its various components rather than the components themselves. These components could be physical elements, entities, or variables that influence each other and produce changes in the overall system behavior [30].

Key concepts in system dynamics modeling include [31]:

- Stocks and flows: stocks represent accumulations of resources or quantities within the system (e.g., inventory, population), while flows represent the rates at which these resources move between stocks.
- Feedback loops: feedback loops occur when the output of a system component influences its own behavior or that of other components in the system. There are two types of feedback loops: positive feedback loops, which amplify changes in the system, and negative feedback loops, which tend to stabilize the system.
- Delays: delays in system dynamics refer to the time it takes for an action or change in one part of the system to have an effect on other parts. Delays can lead to oscillations or non-intuitive behaviors in the system.
- Causal Loop Diagrams: causal loop diagrams are graphical representations used to visualize the relationships between the variables in a system and the direction of influence. They help identify feedback loops and understand the underlying dynamics.
- Simulation: SD models are typically implemented using computer simulation software. These models allow analysts to experiment with different scenarios and policies, helping them understand how the system responds to changes over time.

System dynamics modelling is widely used in various fields, including business management, economics, public policy, environmental studies, and engineering. It helps decision-makers gain insights into the behaviour of complex systems, identify potential challenges, and test policies and strategies before implementing them in the real world. By understanding the dynamic nature of systems, it enables better planning, decision-making, and problem-solving [32].

SD has been implemented in several complex problem sectors connected to insurance mechanisms [33], [34], this represents a good background for the purpose of this study.

2.1. System Dynamics: Building Causal Loops Diagrams

System's behaviour is represented by a diagrams known as causal loops [30]. The causal loops are a crucial part of the system dynamics approach as they present the studied system's dynamic problem and give insight into how to deal with the problem. The causal loop diagrams (CLDs) show interaction of variables in SD model by the connections between them symbolized by arrows. The arrows are symbolised by plus sign for positive relationships among variables, whereas negative relationships are symbolized by minus sign. This relationship in CDLs is considered under assumption *Ceteris paribus,* meaning "all other things being equal". This means that the connected variables symbol is signifying only the change in the link of the two variables, without looking at the whole systems change.

The connected variables can be linked in a loops, known as feedback loops in SD model. The feedback loops strongly influence a system's behaviour and are used to examine the potential effects of various policy interventions, which address the dynamic problem. The feedback loops can include a dynamic hypothesis, which aims to show how systems behaviour can be improved to deal with the dynamic problem. The dynamic interaction within CLDs is shown by reinforcing loops and balancing loops. Each type of loop can have positive or negative effect of other loops in the system:

- Reinforcing loops amplify changes within a system and may cause exponential growth or decline and is marked with letter *R* in CLD. Reinforcing loops embedded in the system are often the cause of the problematic behaviour.
- Balancing loops have the opposite of the reinforcing loops. Balancing loops tend to restore equilibrium or maintain stability within a system due to their counter interaction with the effect in the changes of initial variable in the loop. Balancing loops are marked with letter *B* in CLD.

Through the use of reinforcing and balancing loops within CLDs a dynamic problem of system and dynamic hypothesis of the model is introduced. The dynamic problem in this study is that existing disaster insurance mechanisms allow covering the costs of disaster, but do not allow to prevent the risk of future damage causes, which are increasing due to climate change impact resulting as an increase in frequency and intensity of extreme weather events. The dynamic hypothesis is that advanced insurance mechanisms implemented by smart insurance contract can help to reduce damage costs by supporting investment in disaster risk mitigation measures, thus protecting insured assets, and at the same time attracting new customers due to a more effective insurance scheme.

To address the dynamic problem and implement the hypothesis in the SD model in scenarios, CLDs are constructed based on a review of the literature and expert knowledge of the selected system under the study. Once the key variables and their interrelationships are identified in the conceptual model developed with CLDs, the empirical model structure that simulates the system's behaviour is created.

2.2. Setting up System Dynamics Stock and Flow Model

System dynamics stock and flow models are used to simulate the behaviour of complex systems over time [30]. In a stock and flow model, variables are represented by:

i) stocks, which accumulate or deplete over time, and by
ii) flows, which represent the rate at which variables enter or exit a stock.

The interactions between stocks represent feedback loops and flows, and the mathematical relationships between the stocks determine the behaviour of the system over time and flows. This makes the system dynamics approach particularly useful for modeling complex social-ecological systems, as it allows for the representation of multiple feedback loops and nonlinear relationships between variables. The use of stock and flow models also allows for the exploration of the dynamic behaviour of a system over time, and the identification of key leverage points for policy intervention.

The conceptual model from CLDs is translated into a quantitative simulation model using the system dynamics software Stella Architect. This involves defining the mathematical relationships between the model variables and the simulation's time horizon. The data in this case is gathered from statistics for a specific case study.

2.3. Defining a Case study

The developed stock and flow models is applied for a case study exploring the scenarios of conventional and smart contract insurance. These scenarios are designed to test the effectiveness of smart insurance contract for real estate assets in mitigating the impacts of climate change related extreme weather events. The empirical data is collected for a local case study of Jelgava city, which is located in the central Latvia and has population around 55 thousand inhabitants. The city is subjected to yearly natural hazard of spring floods and the insured assets considered in this study are residential buildings for the spring floods with a high probability (10% or once every 10 years), average probability (1% or once in 100 years) and with a low probability (0.5% or once every 200 years) with losses and costs of restoration shown in the table 1.

TABLE 1. DISASTER PROBABILITY, DAMAGE AND RESTORATION COSTS [35]

Flooding probability in 100 years, %	Flooded buildings area, m2	Restoration costs per m2
10%	103773	19.5
1%	547400	25.8
0.5%	695111	31.8

This statistical data serves as an input for stochastic-probabilistic spring flood hazard event simulation implemented in the SD model trough function RANDOM (stochastic component) applying hazard probabilities with different return times [36]. Simulation includes a stochastic-probabilistic variable in the model and considers random sampling of 1000 simulation runs. This amount of simulation runs is enough to capture variety of different possible combinations for disaster event occurrences over 50 years from given disaster input data in Table 1.

Function describing asset loss is based on damage curve for building from national flood risk assessment and management plans [35] and for insurance model is expressed in monetary units. The damage is accounted as damaged asset area (m^2). The determined risk premium that insured assets must pay to insurance company in the model simulation is estimated for 10-year period by equation 1:

$$RP = L_{average} + \sigma * P \quad (1)$$

Where

RP – Risk premium,

$L_{average}$ – loss associated with the average yearly loss per asset in the area subjected to disaster,

σ – volatility of yearly loss per asset in the area subjected to disaster,

P – premium charge in %.

Three scenarios are compared with help of the developed SD model in a simlation for a time period of 50 years and time step of one year. The scenarios are summarized in Table 2 and include:

1) Scenario 1 - Business as usual (BAU) – conventional insurance mechanism;
2) Scenario 2 - Investment in disaster risk reduction – the insurance with bond for DRR measures without fixed premium;
3) Scenario 3 - Smart contract approach – the proposed smart contract insurance scheme with investment in disaster risk reduction (DRR) and fixed premium.

TABLE 2. ANALYSED SCENARIOS WITH THE DEVELOPED SD MODEL

Scenario	Title	Risk premium	DRR measure	Flood risk reduction measure efficiency, %	Flood risk reduction measure cost, EUR
1.	Business as usual	Assessed every 10 years	No	-	-
2.	Investment in disaster risk reduction	Assesed every 10 years	Riverbeds cleaning, coastal erosion prevention and flow-through restoration	20,5	1 200 000
3.	Smart contract approach	Fixed	Riverbeds cleaning, coastal erosion prevention and flow-through restoration	20,5	1 200 000

The Scenario 1 assumption is that the risk premium payments will increase due to increasing number of insurance contracts due to higher risk perception due to climate change. The expected behaviour in risk premium payments and insurance pay-outs for Scenario 1 is illustrated in figure 1 in payment flows of a 10-year period. Attachment point is the level of loss at which the insurance company will step in to pay for the excess for the losses and detachment point is the level of loss which will no longer be covered by insurance company. The pay-outs to insured asset are being made in the amount that is between the attachment point and detachment point of insurance, meaning the risk behind the points is not covered.

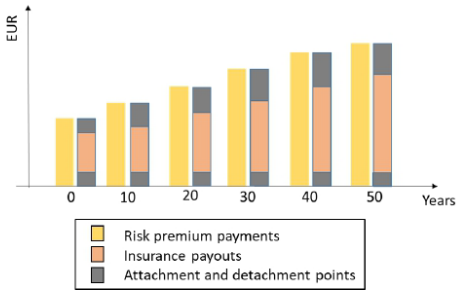

Fig. 1. Illustration of insurance companies' payment flows in business as usual (Scenario 1).

The proposed Scenario 2 and Scenario 3 approach foresees an investment made by government into DRR that will positively affect the safety of the insured assets. The idea of these scenarios is that the insurance company accepts the obligation in form of bonds to payoff the governments investment moving towards a proactive role of the insurance sector as driver for risk mitigation and prevention measure. The government is considered as the representative of the local area that is responsible for fostering the DRR and therefore is interested to be oncoming towards investment in DRR that is eventually payed-off by in insurance company trough bonds.

Such an approach considers that the risk is reduced due to effective implementation of DRR, and consequently the insurance pay-outs will reduce due to fewer events encountering damage to assets, also leading to the deacrese in the risk premium accordingly. This case is described by Scenario 2 and presented in figure 2.

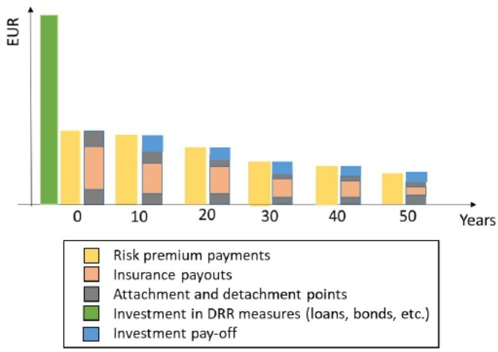

Fig. 2. Illustration of insurance companies' payment flows with Investment in disaster risk reduction (Scenario 2).

Though this is a practice towards reduction of DRR, in certain cases a negative balance in insurance companies budget may occure due to decrease in risk premium payouts due to deacrease of disaster events leading to inability to cover the initial investment into DRR, hence there must be introduced a fixed premium price. The case of a fixed premium is considered in the Scenario 3 shown in figure 3 and named as Smart contract approach. Within this approach the the share of insurance companies income, which is the difference between insurance pay-outs and the fixed risk premium is used to payoff the bonds of initial investment in DRR measure made by government.

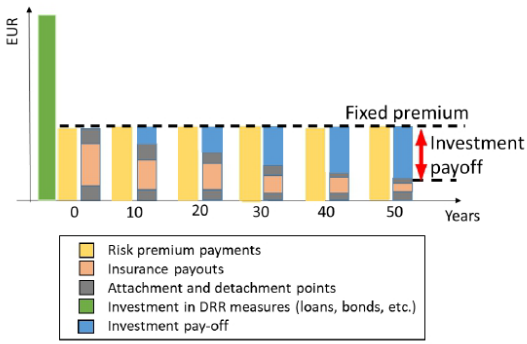

Fig. 3. Illustration of insurance companies' payment flows with Smart contract approach (Scenario 3).

The total expenditure of the compant in Scenario 1 is different from Scenario 2 and 3 approach, where the insurance companies expenditure is not only the payouts to insured assets after damage has occurred, but also the pay-off of investment. The insurance companies expenditure can be used to compare the overall costs of moving from conventional insurance scheme in BAU scenario towards Smart contract approach and in the SD model is estimated as the sum of payouts to insured assets after damage has occurred and the pay-off of investment. Also, the total disaster costs are estimated to compare the overall effectivness of studied scenarios scenarios as the sum of the damage to all the assets in the area and investment into DRR measures.

The DRR measures in Scenario 2 and 3 are selected based on the assumption for Jelgava city flood management plans and are presented in the Table 2. Study considers that under the given flood risk reduction measure falls not only the assets insured, but also other assets in the area when flood risk reduction measures are implemented. The effect of such an approach towards investment in DRR can lead to decrease of the risk and the risk premium, hence the willingness to pay for insurance can increase. The model developed SD model allows to simulate the change in the number of insured asset in the area. The assumption in case study for initial share of insured buildings in the area equal to 10%. In reality, the change in number of insured assets is influenced by such factors as perception of risk and willingness to pay for the risk. However, the perception of risk is not further studied in the model. The changes in willingness to pay for the risk parameter are tested sensitivity analysis in order to understand the influence of the variable on the models output.

Other assumtions in the model for the company's profit is that it does not consider payments for workers and other expenses related to the administrative processes. Only Risk premium payments are accounted as income and the payouts with investment pay-off as outcomes. The difference between income and outcome is considered as the insurance companies profit.

2.4. Model Testing and Validation

Multiple structure verification experiments were conducted in order to validate and verify the developed System Dynamics model. The tests to check the model's structural soundness and gauge how well it captured the system's behaviour in various scenarios included a number of methods. The model was simulated to see if it could replicate the foreseen behaviour of a system's after the initial stock and parameter values were estimated using available data and expert knowledge.

2.4.1. Content validation procedure

A thorough validation process was used to evaluate the model's content validity, and a panel of subject-matter experts in climate change, insurance, and system dynamics modelling. The experts reviewed the model's structure, assumptions, and parameters as part of the process. The validation procedure was conducted in several stages. First, the models CLDs were presented to the panel for review, and feedback was solicited on the model structure and assumptions. The panel provided input on the key variables and interrelationships in the model, and suggested changes to improve the accuracy and robustness of the model. Next, the model parameters were reviewed by the panel. The experts provided feedback on the values and ranges of the parameters values and suggested changes based on their expert knowledge and available data.

2.4.2. Extreme value test

The SD model is validated through an extreme value test, in which the model is calibrated using historical data of case study and then simulated with an extremely high and low parameter values to understand if the model behaviour is logical to the assumptions made in CLD and SD stock and flow model under extreme condition. The test involves comparing the model predictions to extreme changes in model variables Hazard occurrence. For extremely low value test Hazard occurrence is set no hazard during the simulation period and Area of assets with insurance was equal to all the assets in the area. For the extreme high value test, the Hazard occurrence is set to occurrence of the hazard with maximum damage every simulation year with all the assets insured. In addition to these changes for both extreme value tests, also the Area of assets with insurance variable is set to be equal to all asset area in selected case study and the Exhaustion point (e.c. Detachment point) of insurance payouts is set to 0, meaning all losses will be covered by insurance company.

2.4.3. Sensitivity analysis

Understanding the effects of model uncertainty and identifying the crucial variables that have the biggest impacts on the model's output is important for further use of the model in practice. I nthis case sensitivity analysis is used for analysing how a system responds to changes in the values of one or more input parameters, which data is uncertain, but the variable may be crucial for model output.

In this study, a sensitivity analysis is conducted by testing the effect one specific parameter influencing the number of insured assets, because it is important factor for the overall output of the model regarding the risk premium payments and pay-outs for damage to assets. The Willingness to pay for insurance in the model is determined by Number of new contracts based on Risk Premium cost. The number of new contracts in the model is based on the hypothetical functions presented in figure 4, where risk premium is measured in EUR per m^2 and Number of new contracts in m^2 (new insured area of assets).

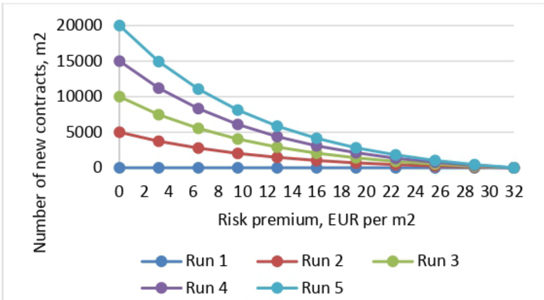

Fig. 4. Hypothetical functions for the number of new contracts variable in the sensitivity analysis.

For sensitivity analysis, the hazard event is kept static as in extreme value test with maximum hazard occurrence possibility to obtain comparable results over several sensitivity analysis simulation runs.

3. Results

3.1. Causal Loop Diagrams of the developed model

The behaviour of the studied insurance mechanism implemented in SD model explained through CLDs shown in figures 5, 6, and 7, and show only the main variables important to explain the dynamic behaviour of the SD model.

The BAU scenario CLD in figure 5 consists of two feedback loops and the out variable of Damage to assets and Extreme weather event. The links between variables show that increase in Extreme weather event variable value will lead to increase in Damage to assets value, under the assumption "all other things being equal". Applying the same assumption, the increase in Damage to assets will lead to the increase in Risk premium value. The two stripes on connector between Damage to assets and Risk premium symbolise the time delay between the accounted damage to assets over a period of time for which the risk premium is estimated.

The variables connected in the reinforcing loop R1 are Risk premium, Willingness to pay for insurance, Assets insured and Insurance companies budget. The reinforcing loop R1 is positive loop, meaning that there is an increase of values in the variables connected in the loop. This loop represents the dynamic problem of increasing Risk premium over time due to increase of Damage to assets that leads to growth of insurance companies budget and thus decrease in Risk premium as introduced in figure 1. In this case, the strength of decrease in Risk premium value is depending on supply-demand elasticity function. The growth in loop R1 depends on the amount of assets in the area, and CLD is marked with balancing loop B1 that includes variable Assets insured and Assets remaining to be insured.

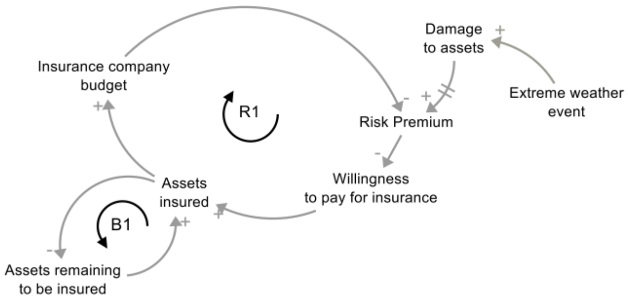

Fig. 5. CLD for with Business as usual (Scenario 1).

Two more feedback loops are added to Scenario 2 including the investment in disaster risk reduction (figure 6). The loop R2 shows how investment in DRR measures by smart contract will lead to decrease in Damage to assets, thus decrease in Risk premium and consequently increase in Willingness to pay for insurance, Assets insured and Insurance company budget. The loop B2 is the balancing loop of reinforcing loop R2, which does not allow to infinitely grow the in insurance companies budget.

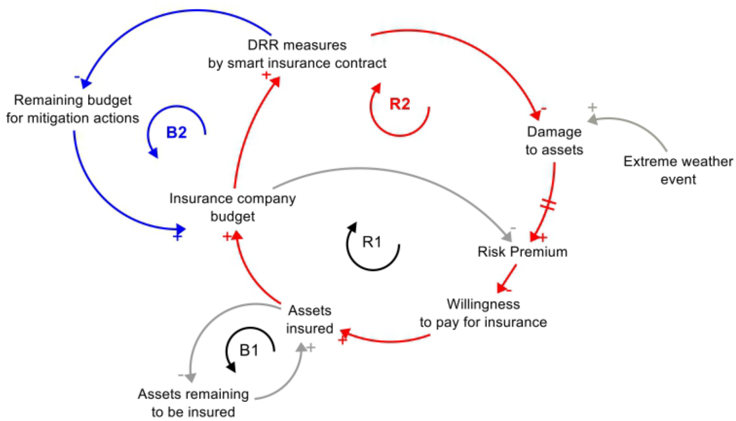

Fig. 6. CLD for Investment in disaster risk reduction (Scenario 2).

To implement smart insrunce scheme it is neccesery to cancel the effect of loop R2 in the given insurance system model by introducing fixed premium that is not depending on the damage to assets and is determined based on the historical data at the moment when it is fixed. Therefore, in figure 7, the CLD showing for Smart contract approach does not include the link between Damage to assets and Risk Premium. The panel of SD and insurance experts reviewed and approved the proposed CLD for further implementation in a SD stock and flow model.

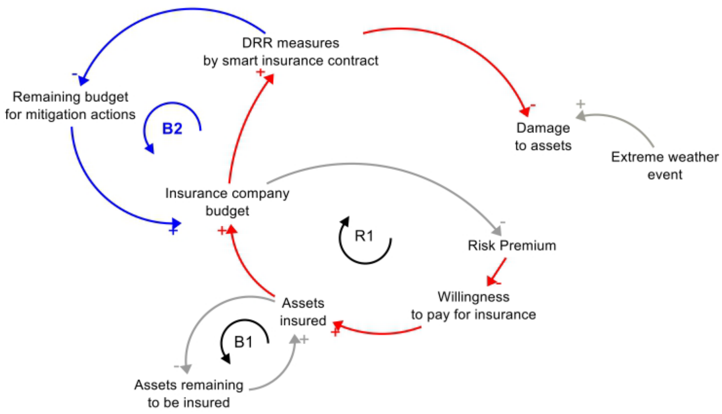

Fig. 7. CLD for Smart contract approach (Scenario 3).

3.2. Empirical model testing and validation

3.2.1. Results of extreme value test

Model testing by extreme value test is performed for Hazard occurrence variable into separated simulations with minimum and maximum values of hazard event magnitude (i.e. Flooded buildings area, m^2) set for each simulation step. This simulation result for the risk premium variable in figure 8 shows a decrease of the value to 0 over the simulation time due to no risk of hazard event.

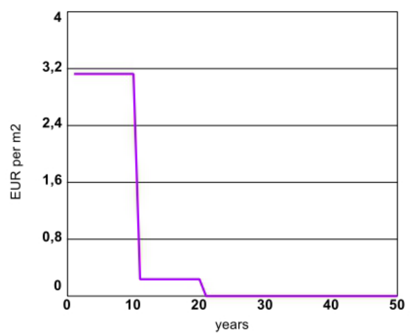

Fig. 8. Risk premium value in extreme test with minimum hazard occurrence value.

The Risk premium variable's behaviour corresponds to the variables shown in figure 9. The values of variables shown in figure 9 are cumulative values in a given simulation step. The increase in insurance companies profit occurs due to received risk premium payments in the first 10 years of simulation, considering that there are no damage costs to cover. In this case, the risk premium is still based on historical risk statistics. In the next 10 simulation years the risk premium is decreased due to decrease of risk as the hazard occurrence variable is set to zero. Consequently, the insurance companies profit is growing slower. The rest of simulation period after simulation year 20 when risk premium is equal to zero and the profit is of company has reached plateau.

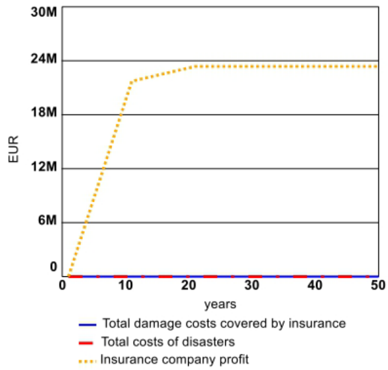

Fig. 9. Insurance company profit, Total costs of disaster and Total damage costs covered by insurance in extreme test with minimum hazard occurrence value.

The result of extreme value test for hazard occurrence variable maximum value is presented in figure 10 for Risk premium variable and figure 8 for Insurance company profit, Total costs of disaster and Total damage costs covered by insurance.

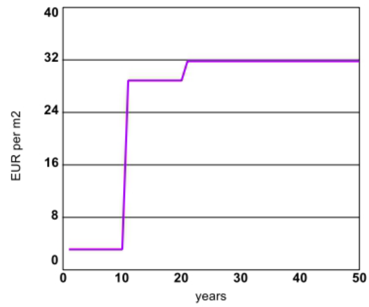

Fig. 10. Risk premium value in extreme test with maximum hazard occurrence value.

The results show an increase of Risk premium after 10 years of simulation due to increased risk of hazard and another increase after 20 years of simulation. Further growth does not occur as Risk premium value has reached is a plateau in regard to maximum risk of hazard. The Insurance company profit appears to be negative, meaning that insurance company experiences financial losses in case of extremely high-hazard event occurrence. Consequently, The Total costs of disaster and the Total damage costs covered by insurance are increasing over simulation and have the same value as all of the assets in the area are considered insured for extreme maximum value test (see figure 11). The Extreme value test results show that the model behaviour is logical to the assumptions made in CLD and SD stock and flow model.

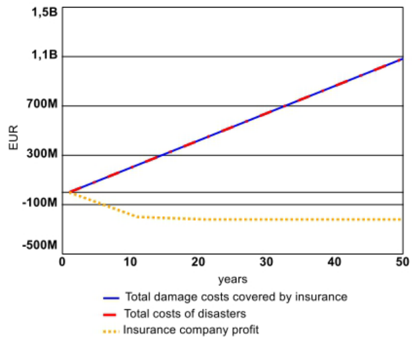

Fig. 11. Insurance company profit, Total costs of disaster and Total damage costs covered by insurance in extreme test with maximum hazard occurrence value.

3.2.2. Sensitivity analysis output

The results of the sensitivity analysis show that the model is sensitive to changes in the Number of new signed contracts variable. The figure 12 shows how the Assets with insurance variable, measured as area of assets with insurance in m^2 units, changes under assumptions of hypothetical function for Number of new signed contracts variable shown in figure 3. Simulation run 1 considers that no new contracts are made and therefore the area of insured assets remains the same. In further simulations runs, the sensitivity of willingness to pay for insurance is increased and therefore for each simulation run more new assets sign insurance contracts.

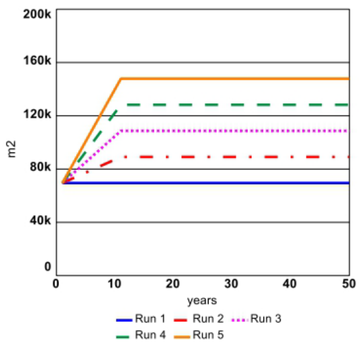

Fig. 12. Sensitivity analysis results for Area of assets with insurance.

The hazard occurrence is maintained at maximum possible and the Risk premium value remains the same as in figure 10. The Area of assets with insurance in figure 12 after the simulation year 10 reaches plateau as no new contracts are signed due to the increase in Risk premium. Moreover, the figure 13 showing Insurance company profit under sensitivity analysis corresponds to the expect logical behaviour of the model. The figure shows how higher number of contracts will lead to higher losses in insurance companies budget due to higher payouts for damage under extremely high hazard occurrence every simulation year compared to the historical hazard occurance at the start of the simulation. Again, the results of sensitivity analysis show that the model behaviour is logical to the assumptions made in CLD and SD stock and flow model.

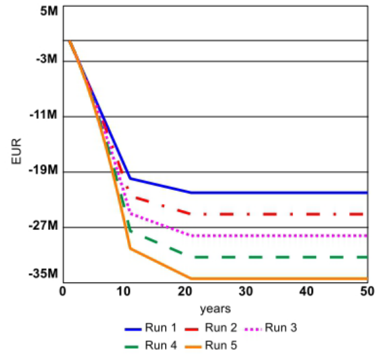

Fig.13. Sensitivity analysis results for Insurance company profit.

3.3. Results of case study and policy scenarios

3.3.1. Business as usual scenario

The results obtained for Risk premium in BAU scenario shown in figure 14 (A) indicate that average mean value in all simulation runs for the Risk premium value increases compared to historical risk premium at the start of the simulation. Nevertheless, the Risk premium value in all simulations leads to increase in Area of assets insured value by the effect of hypothetical function for Number of new signed contracts variable as shown in figure (B).

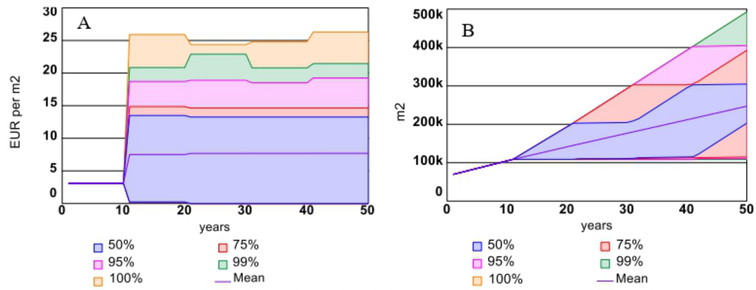

Fig.14. Confidence intervals for Risk premium (A) and Area of assets insured (B) in BAU scenario.

The mean average of simulation runs for insurance companies profit in BAU scenario shown figure 15 (A) is increasing during simulation period. However, there are simulation results appearing as negative values in Insurance company profit for simulation with the most often occurrence of hazard events. The probabilities of the final insurance companies profit at the end of simulation run is shown in figure 15 (B).

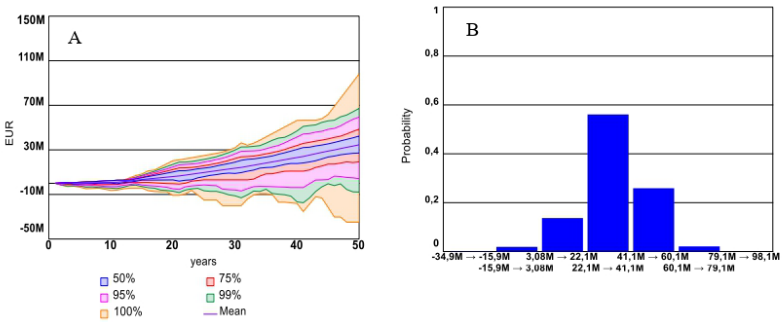

Fig.15. Confidence intervals (A) and histogram (B) for Insurance company profit in BAU scenario.

The confidence intervals and histogram for Insurance companies expenditure in BAU scenario are shown in figures 16 (A) and (B) respectively. In case of BAU scenario, the Damage costs covered by insurance company due to insurance payouts for assets insured are equal to the total insurance companies expenditure.

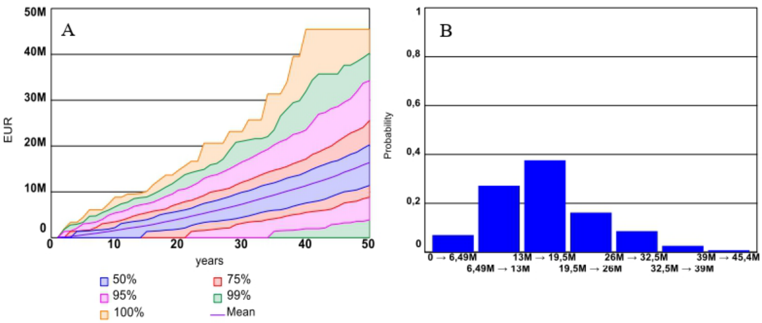

Fig.16. Confidence intervals (A) and histogram (B) for insurance companies expenditure in BAU scenario.

The Total costs of disaster for all assets in the area (see figure 17) appear to be much higher than the Damage costs covered by insurance company in figure 16. This is due to the fact that at the start of the simulation only 10% of assets in the area are considered to be insured and during the simulations a relatively small share of the total assets area is signing insurance contract based on Hypothetical functions for the Number of new contracts variable, which is dependent on risk premium value, which again is dependent on the hazard occurrence over simulation period.

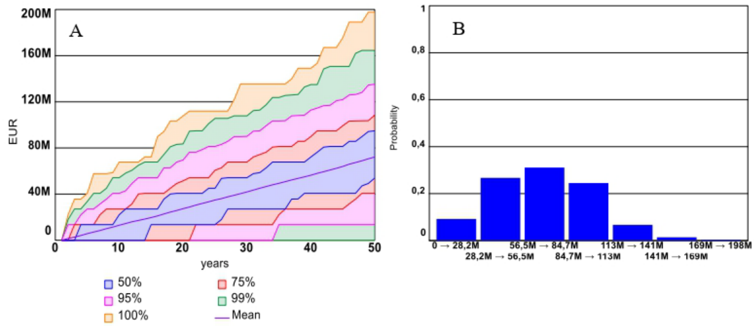

Fig. 17. Confidence intervals (A) and histogram (B) for Total costs of disaster in BAU scenario.

The results of BAU scenario can be interpreted in the follow way according to the CLDs: the occurrence of disaster event during the simulations is higher than historical and therefore the Risk premium is increasing and also Area of assets insured value by the effect of hypothetical function for Number of new signed contracts (figure 14) therefore the Insurance company profit is also increasing (figure 15). Nevertheless, Damage costs covered by insurance company (figure 16) and the Total costs of disaster (figure 17) are increasing significantly over simulation time. The results of the BAU scenario underline that the model represents the dynamic problem of existing disaster insurance mechanisms defined for the study.

3.3.2. Scenarios with investment in disaster risk reduction

The results of simulation for Scenario 2 with investment in flood risk reduction measures in figure 18 (A) show the conficence intervals for Risk premium, which is similar to BAU scenario output. In figure 18 (B) the Risk premium for Scneario 3 is given as static due to definition of the fixed Risk premium value in all 1000 simulation runs.

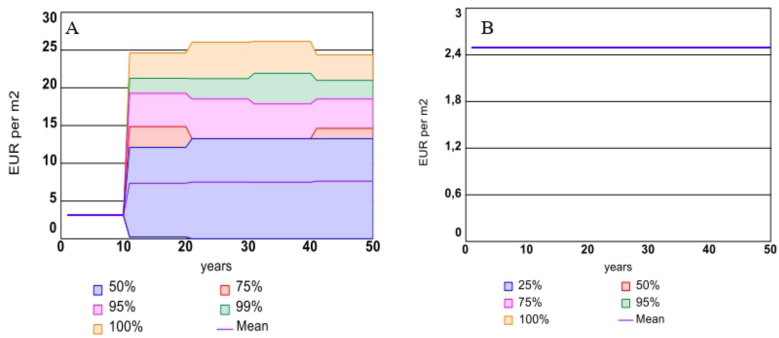

Fig.18. Confidence intervals for Risk premium in Scenarios 2 (A) & 3 (B).

In the figures 19 (A) and (B) corresponding tendency of Number of insured assets is shown for Scenario 2 and Sceanrio 3, respectively. The Scenario 2 has variation in number of insured asstets corresponding to variation in Risk premium, while Scneario 3 has a same trend in all simulation due to the fixed premium definition.

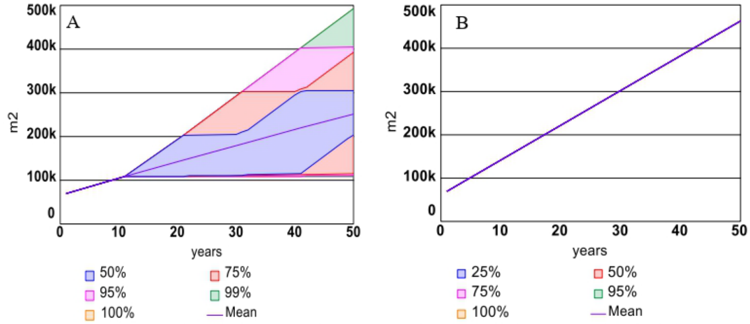

Fig.19. Confidence intervals for number of insured assets in Scenarios 2 (A) & 3 (B).

The results of Number of insured assets both scenarios with investment in DRR ar shown in figure 20. Scenario 2 (see figure 20 A) has as similar tendency in confidence intervals as Scenario 1 (See figure 20 A) showing that the investment in flood risk reduction measure will lead to slight deacrese in variability of insurance company profit. For the Scenario 3 (figure 20 B) the confidence intervals for the Insurance company profit are showing that the range of profit uncertaintly has decreased and most of simulation results are located at the higher levels of the graph with mean average of the simulation outputs is moved closer to the higher income values. There are also less probable outcomes with negative insurance companies profit values. The distribution of Insurance company profit in Scenarios 2 and 3 in form of Historgram is shown in figure 21 (A) and (B), respectively.

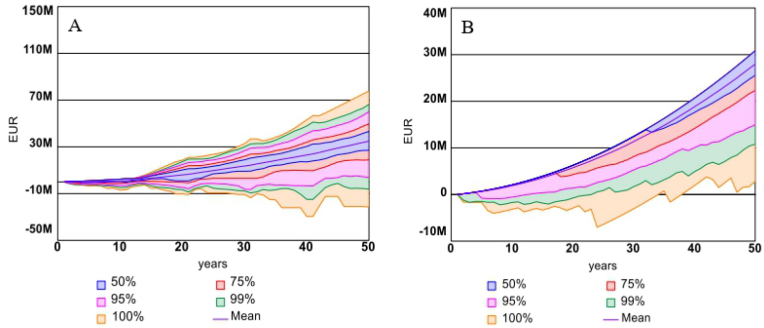

Fig.20. Confidence intervals for Insurance company profit in Scenarios 2 (A) & 3 (B).

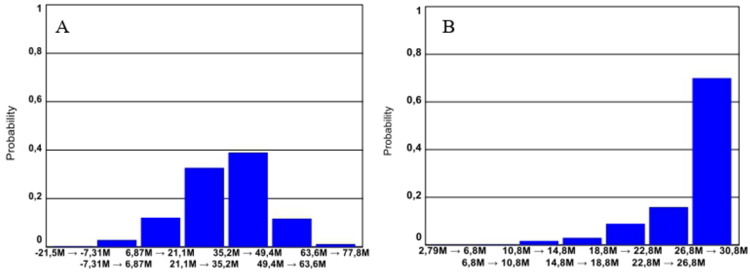

Fig.21. Histograms for Insurance company profit in Scenarios 2 (A) & 3 (B).

Thought there is a certain probability to have a higher company profit in Scenario 2 then in Scenario 3, the total Expenditure of insurance company on disaster including the damage related payouts and pay-off of investment in figures 22 and 23 show how that Scenario 3 leads to lower overall expenditure and maintains very high probability of having low the average mean of the payouts. This signifies that the Scenario 3 has overall lowest costs in all scenarios compared, while Scenario 2 is slightly better then businees as usual in Scenario 1.

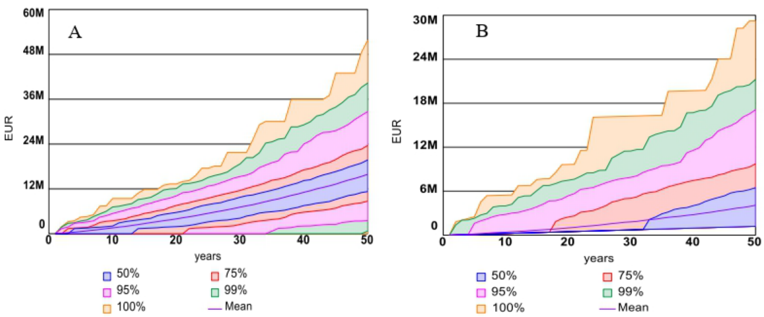

Fig.22. Confidence intervals for Total expenditure of insurance company in Scenarios 2 (A) & 3 (B).

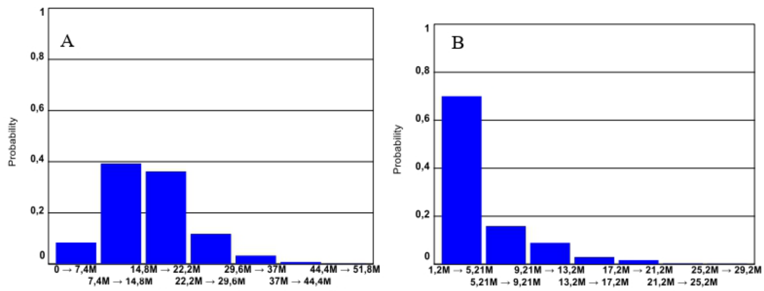

Fig.23. Histograms for Total expenditure of Insurance company in Scenarios 2 (A) & 3 (B).

Finally, the Total costs of disaster are compared in figures 24 and 25. The results show that Scenario 3 leads to much lower total costs of disaster due to fixed premium. As for Scenario 2 the total costs of disaster appear slightly lower than shown for Scenario 1.

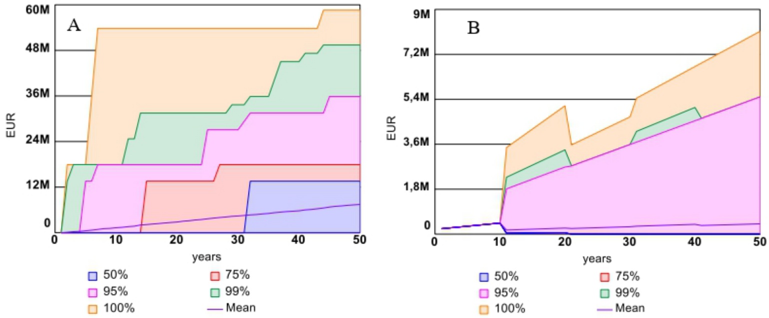

Fig.24. Confidence intervals for Total cost of disaster in Scenarios 2 (A) & 3 (B).

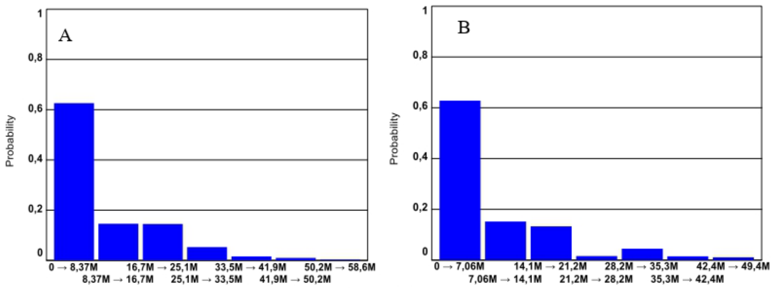

Fig.25. Histograms for Total cost of disaster in Scenarios 2 (A) & 3 (B).

4. Conclusions

Insurance mechanisms that decline and mitigate climate change-related disasters play a key role in protecting lives, livelihoods, and infrastructure. Through robust risk assessment, innovative insurance mechanisms, incentives for risk reduction, capacity building, stakeholder collaboration, and continuous monitoring and evaluation, these mechanisms enhance community resilience and foster sustainable development in the face of climate change challenges. As climate risks continue to evolve, it is imperative to foster ongoing innovation, research, and policy support to ensure the effectiveness and accessibility of insurance mechanisms in the future.

The study highlights the usefulness of the System Dynamics modelling approach for examining the feedback loops that govern the behaviour of complex system related to the insurance mechanism of disaster insurance. The study aims to solve an existing problem in conventional disaster insurance mechanism, which aims only at providing the financial safety for asset recovery after disaster event and not at decreasing the risk of disaster it-self. This problem is especially becoming topical with climate related disaster risk increase and can lead only to higher damage costs in the long term.

A new insurance mechanism in this study is suggested to overcome the current ineffectiveness of the conventional insurance model to deal with the growing threats of disasters and applied in a local case study. For the proposed insurance mechanism, a dynamic hypothesis is created that foresees a smart insurance contract supporting investment in disaster risk mitigation measures to reduce damage costs, thus protecting insured assets, and at the same time allowing to attract new assets to be insured due to to a more effective insurance scheme resulting even in higher benefits for the assets insured. Model is structure is described by the causal loop diagrams and implemented in a stock and flow model, which content is validated by experts and tested by extreme value test and sensitivity analysis to verify the reliability of the model outputs.

The results of the extreme value test indicated that the model can accurately show the system's behaviour under extremely high and low variable values. This increases confidence in models ability to predict the behaviour of the studied system. The sensitivity analysis also showed that the model is sensitive to small changes in a single variable value. It is important to notice how these small changes can significantly affect the long-term behaviour of the studied system under different inputs. Sensitivity analysis showed how change in willingness to pay for insurance would influence the expected outcomes of the model. Overall, these structure verification tests provided important validation of the system dynamics model and increased confidence in its ability to accurately represent the behaviour of the system under different conditions. By verifying the model structure, parameters, boundaries, extreme conditions, and unit consistency, the model was able to provide more accurate predictions and insights for the defined case study scenarios.

Results of case study showed that fixing risk premium for insurance company is a crucial step towards decreasing the overall costs of disaster when investing in DRR measure, while the business as usual scenario had the highest disaster costs. The investment in DRR without fixed premium is better than conventional mechanism, but does not provide such consistent revenue for insurance company as in a case of a Smart contract approach.

The results obtained from the case study with developed SD model show an agreement with the desired dynamic hypothesis of innovative insurance mechanism and show a logical coherence throughout analysis of results. The model's predictions consistently match the expected trends and patterns postulated according to existing theoretical underpinnings foreseen in the methodology. The created SD model can further boost the application of innovative insurance mechanisms in practice in different regions and give valuable insights for insurance companies, policymakers or disaster risk managers by providing information on the most beneficial scenarios for local communities and other stakeholders.

REFERENCES

[1] EM-DAT. (2022). The OFDA/CRED International Disaster Database / UCLouvain, Brussels, Belgium. UCLouvain, Brussels, Belgium. https://www.emdat.be/.

[2] Centre for Research on the Epidemiology of Disasters (CRED), & United Nations Office for Disaster Risk Reduction (UNDRR). (2020). Human Cost of Disasters, an overview of the last 20 years (2000-2019). https://doi.org/10.18356/79b92774-en.

[3] L. Bevere, M. Gloor, and A. Sobel, 'Natural catastrophes in times of economic accumulation and climate change,' Swiss Re sigma, no. 2, 2020.

[4] W. R. Berghuijs, S. T. Allen, S. Harrigan, and J. W. Kirchner, "Growing Spatial Scales of Synchronous River Flooding in Europe," *Geophys. Res. Lett.*, vol. 46, no. 3, pp. 1423–1428, 2019, doi: 10.1029/2018GL081883.

[5] G. Forzieri *et al.*, "Multi-hazard assessment in Europe under climate change," *Clim. Change*, vol. 137, no. 1–2, pp. 105–119, 2016, doi: 10.1007/s10584-016-1661-x.

[6] J. G. Carter, "Climate change adaptation in European cities," *Curr. Opin. Environ. Sustain.*, vol. 3, no. 3, pp. 193–198, 2011, doi: 10.1016/j.cosust.2010.12.015.

[7] European Environment Agency, 'Mapping the impacts of natural hazards and technological accidents in Europe', technical report no. 13. 2010.

[8] The natural disasters of 2018 in figures | Munich Re. https://www.munichre.com/topics-online/en/climate-change-and-natural-disasters/natural-disasters/the-natural-disasters-of-2018-in-figures.html (accessed Oct. 14, 2020).

[9] M. Feofilovs, "DYNAMICS OF URBAN RESILIENCE TO NATURAL HAZARDS," 2020.

[10] Cabinet of Ministers, *Latvian Adaptation Plan to Climate Change for Time Period to 2030*. https://likumi.lv/ta/en/en/id/308330.

[11] Vaijhala, S., & Rhodes, J. (2015). Leveraging Catastrophe Bonds As a Mechanism for Resilient Infrastructure

Project Finance. www.refocuspartners.com.
[12] Hofer, L., Gardoni, P., & Zanini, M. A. (2021). Risk-based CAT bond pricing considering parameter uncertainties. Sustainable and Resilient Infrastructure, 6(5), 315–329. https://doi.org/10.1080/23789689.2019.1667116.
[13] Larvis, M. H., Bohensky, E., & Yarime, M. (2015). Can resilience thinking inform resilience investments? Learning from resilience principles for disaster risk reduction. Sustainability (Switzerland), 7(7), 9048–9066. https://doi.org/10.3390/SU7079048.
[14] Vaijhala, S., & Rhodes, J. (2018). Resilience Bonds: a business-model for resilient infrastructure. 18, 58–63.
[15] UNDRR https://www.undrr.org/terminology/disaster.
[16] National Academies. (2012). Disaster Resilience: A National Imperative. https://doi.org/10.17226/13457.
[17] Gall, M., & Friedland, C. J. (2020). If Mitigation Saves $6 Per Every $1 Spent, Then Why Are We Not Investing More? A Louisiana Perspective on a National Issue. Natural Hazards Review, 21(1), 04019013. https://doi.org/10.1061/(asce)nh.1527-6996.0000342.
[18] Colker, R. M. (2019). Optimizing Community Infrastructure: Resilience in the Face of Shocks and Stresses. In Optimizing Community Infrastructure: Resilience in the Face of Shocks and Stresses. Elsevier. https://doi.org/10.1016/C2017-0-03645-5.
[19] Kai-Uwe Schanz. Future Urban Risk Landscapes: An insurance perspective. The Geneva Association. 2021.
[20] Hannah Hennighausen, Yanjun Liao, Christoph Nolte, Adam Pollack. Flood insurance reforms, housing market dynamics, and adaptation to climate risks, Journal of Housing Economics, 2023, https://doi.org/10.1016/j.jhe.2023.101953.
[21] Coffee, J. (2020). Financing Resilient Infrastructure. Optimizing Community Infrastructure: Resilience in the Face of Shocks and Stresses, 101–121. https://doi.org/10.1016/B978-0-12-816240-8.00006-9.
[22] Mukhtar Jibril Abdi, Nurfarhana Raffar, Zed Zulkafli, Khairudin Nurulhuda, Balqis Mohamed Rehan, Farrah Melissa Muharam, Nor Ain Khosim, Fredolin Tangang, Index-based insurance and hydroclimatic risk management in agriculture: A systematic review of index.
[23] Clarvis, M. H., Bohensky, E., & Yarime, M. (2015). Can resilience thinking inform resilience investments? Learning from resilience principles for disaster risk reduction. Sustainability (Switzerland), 7(7), 9048–9066.
[24] Peter John Robinson, et al. Risk communication nudges and flood insurance demand., Clim. Risk Manag., 34 (2021), p. 100366, 10.1016/j.crm.2021.100366.
[25] Giulia Roder, Paul Hudson, Paolo Tarolli, Flood risk perceptions and the willingness to pay for flood insurance in the Veneto region of Italy, International Journal of Disaster Risk Reduction, Volume 37, 2019, 101172, ISSN 2212-4209, https://doi.org/10.10.
[26] Qiang Li, Wei Liu, Impact of government risk communication on residents' decisions to adopt earthquake insurance: Evidence from a field survey in China, International Journal of Disaster Risk Reduction, Volume 91, 2023 https://doi.org/10.1016/j.ijdrr.2023.
[27] Kunreuther, H., Michel-Kerjan, E., & Tonn, G. (2016). Insurance, Economic Incentives and other Policy Tools for Strengthening Critical Infrastructure Resilience: 20 Proposals for Action.
[28] Paul Hudson, W.J. Wouter Botzen, Jeroen C.J.H. Aerts, Flood insurance arrangements in the European Union for future flood risk under climate and socioeconomic change, Global Environmental Change, Volume 58, 2019, https://doi.org/10.1016/j.gloenvcha.2019.1.
[29] Frisari, G., Mills, A., Silva, M., Ham, M., Donadi, E., Shepherd, C., & Pohl, I. (2020). Climate Resilient Public Private Partnerships: A Toolkit for Decision Makers. https://doi.org/http://dx.doi.org/10.18235/0002365.
[30] A. Blumberga *et al.*, *System Dynamics for environmental engineering students*, 1st ed. Riga: Riga Technical University, 2011.
[31] J. Forrester, "Some basic concepts in system dynamics," *Sloan Sch. Manag. …*, pp. 1–17, 2009, [Online]. Available: http://www.systemsmodelbook.org/uploadedfile/238_63f73156-02df-4d87-b0c6-c286a7beec26_SomeBasicConcepts.pdf.
[32] J. D. Sterman, "Learning in and about complex systems," *Syst. Dyn. Rev.*, vol. 10, no. 2–3, pp. 291–330, 1994, doi: 10.1002/sdr.4260100214.
[33] Diva Kurnianingtyas, Budi Santosa, Nurhadi Siswanto. A System Dynamics for Financial Strategy Model Assessment in National Health Insurance System. MSIE 2020, April 7–9, 2020, Osaka, Japan © 2020 Association for Computing Machinery. DOI: https://doi.org/1.
[34] M. Chen, C.-T. Hsiao, G. C. Lai, and P.-L. Chang, "A System Dynamics Model of Development and Business Strategy in Taiwan Life Insurance Industry," 2009.
[35] G. A. M. LATVIAN CENTER FOR ENVIRONMENT, "Preliminary flood risk assessment for 2019 -2024," 2019.
[36] Maksims Feofilovs, Francesco Romagnoli, Dynamic assessment of urban resilience to natural hazards, International Journal of Disaster Risk Reduction, Volume 62, 2021, 102328, ISSN 2212-4209, https://doi.org/10.1016/j.ijdrr.2021.102328.

Title page (with author information)

Climate change-related disaster risk mitigation through innovative insurance mechanism: a System Dynamics model application for a case study in Latvia

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Publication 2

Non-incomes risk mitigation mechanisms for cultural heritage: role of insurances facing Covid-19

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Non-Incomes Risk Mitigation Mechanisms for Cultural Heritage: Role of Insurances Facing Covid-19 in the Italian Context

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Abstract **– The economic cultural heritages are exposed to several natural and nowadays biological hazards, which, in addition to causing potential structural damage, can lead to severe loss deriving from financial non-incomes. The paper aims to highlight the role of insurance in mitigating financial damages and losses, specifically explaining the key role of insurance in mitigating biological hazards like Covid-19. The paper is part of broader research by the authors and uses the assumptions and results already obtained previously in the context of the case study relating to the asset of *Villa Adriana* and *Villa D'Este*.**

Keywords **– Biological and natural hazards; Covid-19; cultural heritages; risk mitigation; risk and resilience; insurance**

Nomenclature		
AIP	Approved Insurance Provider	–
AGR	Adjusted Gross Revenue	–
CPD	Department of Civil Protection	–
NFIP	National Flood Insurance Programme	–

1. Introduction

1.1. Background

The rise in the number and economic consequences of hazards triggered by natural disasters creates momentum for developing insurance tools schemes as a risk financing and management instrument. For many years, insurance mechanisms against natural hazards have been one of the most crucial matters of discussion at the European level. In 2013, the European Commission drafted a Green Paper entirely dedicated to 'Insurance against Natural and Anthropogenic Disasters'. Moreover, in the focal Paris Agreement of COP 21 of December 2015 [1] this relevant topic was a key aspect to enable cooperation within different disciplines, and improve understanding, and support in several fields, such as, among others, risk insurance.

In many countries around the world, including Italy, interest in a natural hazard insurance system [2] emerges from the search to find an efficient tool for compensating those insured who suffer losses, assessing the financial risk of uncertain losses, and ensuring faster and

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better rebuilding repair timeframe. In Italy, natural hazards, such as earthquakes, floods, and landslides, are responsible for annual losses equal to 0.2 % of the national gross domestic product. This issue is particularly significant due to the insurance market's problematic aspects, inherent limits, and disaster insurance's low penetration rate [3].

The current situation of the insurance market, in particular the Italian one against biological and natural disasters, sees a general context in which the assets of individuals are not almost entirely insured against the risks of disasters. Indeed, only a limited part of public entities and small-medium sized companies are insured with specific policies to cover earthquakes and floods. On the other hand, there has been a slight growth trend of medium-large companies in the last decade, which have deemed it appropriately and coherently to take advantage of specific insurance policies over the years. According to Porrini, the cause of the lack of penetration of insurance policies in the context of individuals has to be found in the so-called disaster syndrome – stunned, shocked state common in the impact phase of disasters – due to the distortions on the demand side and insufficient supply of coping disaster resources [2].

According to the study of Croce [4], the year 2020 was the first of the Covid-19 Pandemic era that profoundly marked the life of the entire world population, as the current pandemic is one of the systemic challenges that are likely to intensify in the coming years. The reason lies in the policies and economies oriented by the capitalist mechanisms triggering a more critical effect as environmental and human decline. To cope with this scenario, it is necessary to radically rethink our lifestyles and organizational forms towards a structural change towards environmental sustainability that affects everyone and requires everyone's commitment.

The health emergency caused by COVID-19 immediately reverberated its effects also on cultural heritage [5]. As of February 24, 2020, the Italian Ministry of Culture (MIBACT) had suspended free admission to museums and places of culture from Sunday 1 March 2020. A decision preceded a few days before by the closure of museums, cinemas and theatres in the areas most affected by the pandemic, which was followed, in the days immediately following, by the suspension throughout the national territory of the public opening services of institutions and places of culture [5]. In the following months, from May 2020, the opening service to the public of museums and other cultural institutes and places was allowed, under certain conditions, and, from June 2020, the holding of shows open to the public in theatrical halls, halls concert halls, cinemas and other spaces. Indeed, from 6 November 2020, the exhibitions and public opening services of museums and other cultural institutes and places have been suspended again [6].

Natural hazards, particularly those enabled by climate change, have been causing increasing numbers of catastrophic events, leading to a higher probability of damage to cultural heritage.

According to a recent report published by the Italian Association of Insurance Companies (ANIA) in 2017, 'the catastrophic events of August 2016 in the Centre of Italy have highlighted, once again, how vulnerable the Italian territory is and to what extent the historical buildings in Italy are incapable of withstanding earthquakes, even ones that are not particularly severe. Based on the estimates of the Department of Civil Protection, the earthquakes of the summer 2016 caused damage for over € 23.5 billion, of which € 12.9 billion for damages to private dwellings (the estimate includes direct damage, both public and private – namely the destruction of buildings, infrastructure, crops and damage to businesses and enterprises, cultural heritage, power networks, gas and water distribution systems – and eligible costs, borne by the state in response to the emergency' [7].

Disaster prevention is essential to save cultural heritage. Management and investigations after a disaster are also very important to define the extent of damage to movable and immovable cultural heritage [8].

Within this context, the Italian experience with the Department of Civil Protection (CPD) and the Ministry of Civil Protection considered it seems appropriate also for the European context. In fact, setting up a special Committee that has recently disseminated, released, and published behavioural models compiled by specially trained teams after an earthquake seems a consistent approach. These models allow a description of the damage, calculate the vulnerability indexes and calculate the cost of the intervention [9].

Several European countries have implemented and developed important web systems of information and advice for emergencies [10] related to natural disasters, in particular floods. But, unfortunately, they usually do not contain specific information and instructions on the conservation and protection of cultural heritage.

Preventive measures, in the general context of hazards, regardless of their nature, are typically sorted into two categories: structural and non-structural. Structural measures are challenging to materialize in the case of cultural heritage protection because they are mostly visible, disturbing, and often not cost-effective [11]. This subject would require further research and comparison to best practice non-structural measures. As far as structural measures are concerned, the application of standards to protect cultural heritage from natural hazards leads to the problem that historic monuments' originality, authenticity, aesthetic qualities, and values should not be compromised. However, only one European Standard is in practice available for effective protection of cultural heritage against earthquakes [12].

In the light of the case study presented *infra*, it appears extremely relevant to verify the legal and operational conditions in the Italian regulatory framework. In the context of Italian legislative prescriptions, a Seismic Code (EuroCode-8) was published in March 2003 [13], containing standards for buildings (minor historical architectures). The Ministry of Cultural Heritage has extracted and outlined the guidelines for cultural heritages from this standard. Recent experience with catastrophic damage, linked to real opportunities to adapt the architectural heritage to reduce such damage, indicated that some changes to the relevant standards could be adapted and implemented.

Insurance companies have a triple role as risk managers (physical risk management), insurers (financial risk management) and investors (investment management). They may be linked to sensitive clients and investees through their insurance, reinsurance and investment activities [3].

Insurance transactions related to sensitive customers expose insurance companies to several risks. In particular, in underwriting, these risks apply and are evident to many sectors of the non-life insurance business, particularly in the industrial and commercial insurance business [2].

European countries have decided to assess various approaches to insuring cultural heritages against natural disasters. In particular, flood insurance is not popular in the European context, and in some countries, it is not possible at all to insure property positioned in an area of potential floods and inundations, such in the Czech Republic. A specific study of flood insurance assessments in the European Union and a comparison with the US NFIP (National Flood Insurance Programme) defines that the American system offers several substantial benefits and has determined and decreased federal disaster assistance. Łasut assess the situation in Europe as it follows: '*France has a functional system of insurance protection against natural disasters* [...] *In Germany, three classes of flood zones are declared, which correspond to the risk of flood occurrence, and insurance premiums depend on the location of the property in the zones. As in the USA, there are some conditions that a property owner has to fulfil before the insurance can proceed. This situation means that the state and local governments are the main providers of flood reparations in major catastrophes. In Britain, insurance policy changed in 2002 and flood insurance is becoming harder to obtain as* *agreements on providing household flood insurance at reasonable cost expire.*' [14]. Nevertheless, the insurance companies, among the European area, are increasing their involvement in advisory tools, namely in relation to floods.

Otherwise, the American National Flood Insurance Program (US NFIP) was conceived and designed as an alternative to disaster relief, and distributes the responsibility and social and economic burden for floodplain management to each government level and the private sector, setting a federal standard for assessing new developments in floodplains and materializing a comprehensive floodplain mapping program. The prescriptions of NFIP can be understood with the most relevant literature [15], [16] or through analytic description [17].

In a nutshell, concluding this section relating to the introduction, the authors' objectives aim at highlighting an innovative strategy of *ex ante* (prevention) and *ex post* (losses) risk mitigation for all those economic heritages which, as occurred with the SARS Cov2 pandemic, may suffer damage and losses, *latu sensu*, such as to affect their profitability.

1.2. The Definition of the (Economic) Cultural Heritage

To verify the extrinsic and intrinsic importance of cultural heritages, the criticality of a threat such as that relating to any hazard, it appears extremely decisive to assess the characteristics of an economic heritage, in the sense in which, broadly speaking, the latter has a financial connotation in the country's economic macro-system.

Like any other public asset, cultural heritages are exposed to the risk referred to in natural and biological hazards. Many authors have offered valuable disseminations on catastrophic risks from natural disasters [18] and their consequences in terms of human and economic damage from reconstruction. Recently, this interest has also turned towards the biological hazards due to the Covid-19 pandemic. However, natural hazards similar to biological hazards involve other problems, perhaps less immediately perceptible but equally serious, such as the purely financial ones from non-incomes. In recent years, attention on the mitigation of cultural heritage risk has considerably increased. More specifically, a momentum started towards a better understanding of the economic aspects that could have an essential part of municipalities' budget and thus on the municipality planning and risk management.

In fact, the so-called economy of cultural heritages, understood as managed assets, plays a key role in the public economy [19], especially in some areas of the world, such as Europe. Moreover, like a private company, economic management in cultural heritage dynamics, has made it possible to implement tourism, welfare, and heritage management [20]. Nevertheless, it seems opportune, before delineating, in the continuation of the paper, the nodal fulcrum of the text, to settle the main objective and subjective characteristics of cultural heritage with an emphasis on the economic one.

Starting from the general concept of heritage, Europe, in the past, developed a typically monumental conception of cultural heritage: it included sites and monuments on the basis of their historical and aesthetic value, a method which was gradually abandoned in favour of a more anthropological and global approach in order to safeguard not only the materiality of goods, but also the symbolic, social, cultural (and subsequently economic) values of which they are an expression [21]. Therefore, the notion of cultural heritage has considerably expanded over time and has become progressively more complex. This is no longer limited to historical monuments, but includes the urban sector, natural landscapes and any construction considered worthy of being preserved.

The renewed meaning of the notion of 'cultural heritage' has stimulated a new relationship of collaboration between scientific and humanistic disciplines. This new approach opened up the possibility of broader and deeper involvement in the vast range of potential actors of conservation, protection, safeguarding, and enhancement of cultural heritage [22], paying particular attention to the recipients of use: the communities of citizens.

Moreover, precisely starting from the broader concept of cultural heritage, economic management is understood as the enhancement of the intrinsic and extrinsic value of tangible and intangible assets [23] from an economic/financial point of view in accordance with the 'esprit' of obtaining resources and income for self-financing and in- house livelihood of the cultural site *ex se* [24].

The enhancement of the heritage is structured in different degrees of intervention, the first of which is represented by the finding of resources: to meet the needs of the cultural heritage it is necessary, first of all, to build suitable financing systems [25] that involve not only the governing bodies, such as the proverbial lack of resources, but also the private actors (profit and non-profit) in a subsidiary perspective, of involvement and participation and taking responsibility.

1.3. The Importance of the Cultural Sector in the Italian National Macroeconomic Perspective

Leaving aside the 2020 data, affected by the Covid-19 pandemic outbreak, it is necessary to highlight the role of cultural heritage as a macroeconomic industry, with a specific emphasis on Italy. As of 2019, Italy claims for 4,908 museums, archaeological sites, monuments and eco-museums open to the public. It is a widespread and vital heritage resource throughout the whole territory. According to the detection, at least one recognized museum structure is in one out of three Italian municipalities [26]. Most are museums, galleries or collections, in addition to 327 archaeological areas, 630 monuments and 69 eco-museum structures.

The market value of the cultural heritage industry, according to the latest survey carried out by the National Institute of Statistics (hereinafter ISTAT), outlines incomes for a total of € 168 billion [27].

Taking as reference only the museum compartments, of which ISTAT has drafted a specific section, since the last annual survey, the 358 Italian state museums have produced € 27 billion, a value equal to 1.6 % of GDP, it is equivalent around to 10 % of the total museums in Italy, which has about 5 thousand archaeological sites and parks throughout the national territory. With 117 000 jobs, € 278.000.000 of revenues and 53 million visitors during the year, Italian state museums are a fundamental and strategic force for the country's growth [28].

2. The Effects of Natural Hazards on the Economic and Financial Components of Cultural Heritage

2.1. Financial and Economic Data on Damage from Natural Disasters

Natural disasters represent a severe threat to cultural heritage. Many heritage objects are further negatively affected and damaged by inadequate emergency interventions because urgent responses to basic and fundamental needs may bring to emergency measures and to planning and rehabilitation measures for recovery that are not sensitive to cultural heritage. According to the World Bank's Independent Evaluation Group [29], the cost of disaster damage is rising, and in the 1990s it reached US $ 652 billion, which is 15 times higher than in the 1950s. The number of events grew by 400 % between 1975 and 2005, with 2,6 billion people affected by natural disasters over the past ten years [30], [31].

As reported by the European Parliament, 'long-term climate effects and other disasters sometimes cause irreversible damage to Cultural Heritage, or completely destroy entire areas of Cultural Heritage, both movable and immovable' [32].

On one side, Italy, is extremely known for its cultural heritage, one of the most important and largest in the world (50 UNESCO World Heritage cultural sites). However, on the other side, the Italian territory is extremely exposed to natural disasters [31]. Moreover, in addition to the above data, it is worth mentioning two important hazards occurred recently that seriously affected Italian Cultural Heritage, such as '*the 1997 earthquake that destroyed the San Francis Basilica in Assisi and the 2009 earthquake that damaged the L'Aquila Cathedral. Therefore* […]*, concerning the protection of Cultural Heritage, a relevant role could be played by insurance instruments*' [33].

Within this background, a multi-hazard perspective nowadays due to the occurrence of biological hazards, like pandemic from Covid-19, created the ground for a more important role of insurance mechanisms specifically addressed to cultural heritages.

2.2. Traditional Forms of Insurance on Cultural Heritage Sites Affected by Natural Hazards

According to several authors [34], [35], insurance companies are extremely relevant according three economic points of view. The first is represented by the risk transfer, which is transferred from a risk-averse and weak counterpart individual to the risk-neutral insurer, namely the insurance company. The second is represented by risk pooling, whereby, by operating a multi-insurance in favour of several insured individuals, the inherent uncertainty of the individual instead becomes the 'certainty' for the insurance company that this risk will materialize, at least, in the premiums paid by the same insured. The last economic role play is taking the form of risk allocation by which the payment of the premium by each insured party should be directly proportional to its own level of risk.

In the light of the economic key roles of above, it seems appears pretty obvious that insurance increases general social welfare and nevertheless, convincing the holders to act preventively, as well as encourages the risk-averse individuals to enter the market, since the determination of the risk price obviously involves a general economic benefit from the precautionary expense. Consequently, risk transfer, risk pooling, and precautionary risk mitigation from the abovementioned assumptions create the substrate for the optimal economic risk management portfolio [36].

In view of the preservation and maintenance of cultural heritage, it seems appropriate to recall an important contribution according to which '*Thus, the preservation of Cultural Heritage assets must guarantee not only their capacity of lasting over time against natural decay without losing their authenticity and usability but also their capacity to withstand natural hazards and extreme events with limited and expected structural performance*' [37].

In this case, the role of insurance arises as a suitable mechanism both from an ex-ante and an ex-post point of view. First of all, it might be seen as an ex ante tool because it allows to make an in-depth analysis about vulnerability aspects and the exposure to hazard risks of the heritages, which would be necessary for the calculation of the premium. Consequently, it might be understood as an ex post tool because it covers heritages for the damages and the consequent reconstruction [38].

Insurance, so far, is an active tool for unexpected losses [39] caused by natural hazards. It might aid in well in depth understanding all the aspects of the risks connected to catastrophic events [40] and in decreasing the related immediate long-term financial losses [41].

3. METHODOLOGY

This study has been organized in the following methodological steps.

An in-depth literature analysis is performed to identify the general background and the state of the art of the insurance tools in biological and natural hazards at the Italian and international levels. In specific, this first step is addressed to identify the general framework that regulates the insurance schemes for cultural heritage within the scope of the regulatory and binding laws.

The second stage, better outlined infra, is addressed to identify the key features and critical aspects of risk mitigation of cultural heritage against biological and natural disasters with a specific focus on the Italian national point of view.

The final stage is about presenting an innovative concept for elaborating insurance tools addressed to non-incomes risk mitigation mechanisms for cultural heritage facing Covid-19.

Cultural heritages are an essential industry for countries [5]. They can be considered critical assets exposed to natural hazard potential, enabling physical damage and cash flow disruptions.

As mentioned in the introduction, the paper fits into the context of a broader scientific research [15] on the relationship between biological hazards [16] and cultural heritage. In particular, this section refers to the sum of the losses from non-incomes suffered by the cultural heritage referred to in the case study, in particular, *Villa Adriana and Villa D'Este*, during the pandemic outbreak from Covid-19.

From the forecast of losses non-incomes from ticket sales [5], it might be possible to assess a possible use of insurance coverage to deal with the risks described above, considering a flexibility component of the periodic cost according to the claims experience ongoing registered.

Consider a random variable X that describes the theoretical amount of compensation in the time unit (for example, one year), from which an insurance premium P can be calculated and for which in a traditional insurance has to be considered constant, for each period of coverage and function of the distribution of X.

As an element of the insurance coverage, in addition to the cost of restoring the damage deriving from the occurrence of accidents, the revenue from ticketing could also be considered in terms of damage of closures of the structures due to accidents that prevent the use of the same for the potential clients. The variable X is to be considered all-inclusive of all damages.

The flexible approach is based on recording the amount of the adequate compensation in the period prior to a recalculation date t, from the start of the insurance coverage, which can be fixed as time 0, i.e. the compensation for t years, $Y(0,t)$. The periodicity of recalculation must be contractually fixed every year or with a different frequency.

Let $Y(0,t)$ be the total amount compensated by the insurance and P the number of premiums paid by the insured in the same period, the flexibility consists in setting a *bonus-malus* scheme according to the different levels that the difference as described in the equation below:

$$Y(0,t) - P = D(t). \quad (1)$$

If $D(t)$ exceeds a certain threshold, i.e. more compensation than premiums paid, then the flexibility scheme could increase the premium until the next recalculation.

While in case $D(t)$ is negative, there could be a decrease in the premium until the next recalculation and/or retrocession of part of $D(t)$ to the insured, perhaps to be tied to risk mitigation works.

Precisely the possible progression of risk mitigation works, to be financed independently and/or by resorting to these possible insurance retrocessions, could gradually decrease the cost of insurance coverage, provided that the amount of the actual damage is affected in the right way (i.e. reducing) of the mitigation effect, otherwise, this flexibility scheme would return to generate positive $D(t)$ levels which would consequently increase the premium.

The systematic-quantitative approach outlined above refers to an evaluation that poses as focal and prodromal to the case study referred to in the next section.

4. A New Insurance Approach for Cultural Heritage Based on the Adjusted Gross Revenue: A Case Study

This paragraph proposes a real case study based on the methodology and calculation methods.

Cultural heritage, as highlighted above, has always been considered a static element whose value is represented by the intrinsic value of the assets that compose it and by the cost of reconstruction.

And therefore, companies have, over time, adopted traditional forms of risk mitigation and reconstruction insurance without even the diffusion that would have been desirable for such a decisive and important issue for public welfare.

In fact, the insurance coverage, ab initio, has focused on ex-post protection, i.e. on the disbursement of equal sums, theoretically to the reconstruction of damaged assets, or, more recently, attempts have been made in order to provide ex-ante protection, i.e. the possibility, through constant disbursement of the insurance premium, to allocate part of these to the construction of risk mitigation structures.

The author's idea in the possible development of a different approach underlies the idea that the economic cultural heritages, whose definition has been outlined, among others by Pagano [5] by now, can no longer be understood as any public asset, whose value is outlined by the cost of the immovable asset ex self. In fact, the cultural heritage, and *Villa Adriana and Villa D'Este* are an example of this, they must be, for the aforementioned reasons, as well as economic activities, industries, exposed not only to the risk of natural hazards, but also to the so-called business risk in the sense in which, although 'public entities' are not subject, at least in accordance with Italian law, to the rules of insolvency, they are subject to market rules and to these fluctuations in the context of cash flow. In practice, having unravelled the doubts on the systematic classification of economic cultural heritage as public industries, it seems appropriate to verify whether some form of insurance, ab initio used for other areas, could be used and useful for the purposes of heritage when incomes are affected due to hazards to losses and negative fluctuations.

Therefore, to mitigate the catastrophe risk from natural hazards regarding financial losses, the author suggests evaluating the option of adopting a particular form of insurance, widespread above all in the USA in the agricultural field, i.e. the protection deriving from the Adjusted Gross Revenue (AGR).

AGR insurance is a non-traditional insurance plan that allows the risk management of the entire company. It is a very interesting product because it could be a study model for a possible application in Italy and other European Union countries.

AGR is a policy that insures company revenues; the historical gross revenues of an agricultural company are used as a reference parameter, obtainable from the tax data (average of the last 5 years) reported by the parties.

It is an insurance product applicable to any production sector.

Although strictly related to the paper, the AGR Policy offers, among others, insurance coverage for losses of gross revenues due to natural disasters or calamities.

Using the data obtained from the paper on the calculation of Covid-19 losses for the heritage of *Villa D'Este and Villa Adriana*, proceeding to the calculation table for the elaboration of the insurance premium and respective disbursement, the following calculations are reported.

TABLE 1. RELEVANT INDICATORS (2017–2019) [5]

	2017	2018	2019
Tax charges, €	316 491.81	31 500.00	55 905.12
Charges for active workers of service, €	229 136.30	215 000.00	161 517.36
Purchase of goods of consumption and services, €	710 067.95	801 500.00	1 209 335.69
Recovery, restoration, adjustment and maintenance of the immaterial assets (software/hardware) and material movable and immovable assets, Purchase of goods of consumption and services, €	1 237 997.60	975 000.00	1 343 449.73
Ministerial and state grants: concession assets, €	200 000.00	400 000.00	199 744.81
Ticket sales, €	3 350 822.12	4 000 000.00	4 869 535.94

Eligible Revenues (2017): (€)

$$3\ 350\ 822.12 + 1\ 237\ 997.60 - 710\ 067.95 - 229\ 136.30 - 316\ 491.81 = 3\ 333\ 123.60$$

The eligible income for 2017 was therefore equal to € 3 333 123.66.

Once the eligible income has been calculated for each year, the adjusted gross revenue by means of increases or decreases is calculated:

TABLE 2. CALCULATION OF AGR

Year	Eligible Incomes, €	Increase/Decrease, %
2017	3 333 123.66	
2018	4 327 000.00	4 327 000.00/3 333 123.66 = 1.2981
2019	4 985 972.31	4 985 972.31/4 327 000.00 = 1.1522

The average eligible income is calculated in Eq. 2 (€).

$$\frac{(3\,333\,123.66 + 4\,327\,000.00 + 4\,985\,972.3)}{3} = 4\,215\,365.12 \tag{2}$$

The average % increase/decrease is calculated in Eq. 3 (%).

$$\frac{(1.2981 + 1.1522)}{4} = 1.22 \tag{3}$$

The value obtained is squared: $1.22^2 = 1.488$.

The adjusted gross revenue is calculated in Eq. 4.

$$4\ 215\ 365.32 \cdot 1.488 = 6\ 274\ 149.74\ AGR \quad (4)$$

The value is verified by AIP (Approved insurance provider) which then uses it to calculate the insurance coverage.

The insurance program offers different levels of income coverage. The insured per- son may choose the package that best suits to the needs. The packages offered are:

- 80/75 or 80/90 = coverage level of 80 % with the payment of a rate of 75 % or 90 %;
- 75/75 or 75/90 = coverage level of 75 % with payment of a rate of 75 % or 90 %;
- 65/75 or 65/90 = coverage level of 65 % with payment of a rate of 75 % or 90 %.

5. Conclusions

In the first place, the paper highlights a long-lasting exposure and vulnerability of cultural heritages to natural hazards, the effects of which have not yet been fully mitigated with ex-ante tools. In particular, the paper clarifies that cultural heritages are highly exposed to catastrophic effects due to their geographical and systematic connotation and the rules of public law that govern them. Moreover, this ruling underlies a long-standing problem that involves most of the Italian and world cultural heritage so that the latter, inherently exposed to any hazards – even pandemics – are not adequately protected from an insurance point of view.

Secondly, the paper underlines the evolution of the concept of heritage, from a mere immovable static asset to a real economic industry comparable to a financial institution capable of producing income from cash flow. In relation to this, the more serious the natural hazards result in these cases, the more the heritages take the form of economic companies. As more they are subject to losses, they are unproductive and unable to remedy as non-incomes. Therefore, the second conclusion underlies the delicate managerial and financial situation inherent in an economic, cultural heritage and the pathological consequences that derive from any occurrence of hazards, such as, for example, the COVID-19 pandemic analysed in the case study.

Ultimately, the paper envisages the introduction of an insurance policy, the so called AGR. This approach's benefits rely on limiting the macroeconomic and financial effects, mitigating losses, and declining the risk from natural hazards from a resilience and risk management strategy perspective. Not only could such an elaboration as per the proposed insurance implementation could naturally feed new operational variations of the insurance market, but it would be aimed at mitigating the pathological consequences of a hazard, if only from the point of view of limiting costs and financial damage

References

[1] Morandi Da Silva A. G., Feres J. G. Environment and insurance. November, 2017.

[2] Gizzi F., Porrini D., De Masi F. Building a Natural Hazard Insurance System (NHIS): The Long-Lasting Italian Case. *Sustainability* 2021:13(21):12269. https://doi.org/10.3390/su132112269

[3] Pagano A. J., Feofilovs M., Romagnoli F. The relationship between insurance companies and natural disaster risk reduction: overview of the key characteristics and mechanisms dealing with climate change. *Energy Procedia* 2018:147:566–572. https://doi.org/10.1016/j.egypro.2018.07.072

[4] Croce G. Le politiche attive del lavoro nella crisi da Covid-19 (Active labor policies in the Covid-19 crisis.). *Econ. Lav.* 2020:54(2):91–116. https://doi.org/10.7384/98577 (in Italian)

[5] Pagano A. J., Romagnoli F., Vannucci E. COVID-19 Effects on Cultural Heritage: The Case of Villa Adriana and Villa D'Este. *Environmental and Climate Technologies* 2021:25(1):1241–1252. https://doi.org/10.2478/rtuect-2021-0094

[6] Agostino D., Arnaboldi M., Lampis A. Italian state museums during the COVID-19 crisis: from onsite closure to online openness. *Museum Manag. Curatorsh.* 2020:35(4):362–372. https://doi.org/10.1080/09647775.2020.1790029

[7] ANIA. Associazione Nazionale tra le Imprese Assicuratrici. Italian insurance 2016–2017. Rome: ANIA, 2017.

[8] Munasinghe M., Clarke C. Disaster Prevention for Sustainable Development-Economic and Policy Issues. Washington: WBG., 1994.

[9] Civil Protection Department. Emergency planning and damage scenarios [Online]. [Accessed 12.11.2021]. Available: https://rischi.protezionecivile.gov.it/en/seismic/activities/emergency-planning-and-damage-scenarios

[10] Ministry of the Interior. Plan ORSEC et Plans Particuliers d'Intervention (ORSEC Plan and Specific Intervention Plans) [Online]. [Accessed 12.11.2021]. Available: https://www.gouvernement.fr/risques/dispositif-orsec (in French)

[11] Bedate A., Herrero L. C., Sanz J. Á. Economic valuation of the cultural heritage: Application to four case studies in Spain. *J. Cult. Herit.* 2004:5(1):101–111. https://doi.org/10.1016/j.culher.2003.04.002

[12] NIBS. HAZUS: Hazards U.S.: Earthquake Loss Estimation Methodology. NIBS Doc. N. 5200. Washington: HAZUS, 1997.

[13] Gazzetta Ufficiale. OPCM 3431/2003 – Ulteriori modifiche ed integrazioni all'O.P.C.M. 20 marzo 2003 n. 3274, recante «Primi elementi in materia di criteri generali per la classificazione sismica del territorio nazionale e di normative tecniche per le costruzioni in zona sismica (Further changes and additions to the O.P.C.M. March 20, 2003 n. 3274, containing 'First elements regarding general criteria for the seismic classification of the national territory and technical regulations for constructions in seismic areas.). Rome: Ministry of Economy and Finances, 2003. (in Italian)

[14] Łasut A. Insurance as a means of reducing economic losses due to floods. *Proceedings of the Int. Conference Towards natural flood reduction strategies* 2003.

[15] Thomas A., Leichenko R. Adaptation through insurance: Lessons from the NFIP. *Int. J. Clim. Chang. Strateg. Manag.* 2011:3(3):250–263. https://doi.org/10.1108/17568691111153401

[16] Miller B., Dixon L., Clancy N. Reasonable and Risk-Based? Replacing NFIP Generally Subsidized Rates with a Means-Tested Subsidy: Replacing NFIP Generally Subsidized Rates. *South. Econ. J.* 2019:85(4):1180–1195. https://doi.org/10.1002/soej.12329

[17] Federal Emergency Management Agency. National Flood Insurance Program Regulations. Hyattsville: FEMA, 2002.

[18] Appiotti F., *et al.* Definition of a Risk Assessment Model within a European Interoperable Database Platform (EID) for Cultural Heritage. *J. Cult. Herit.* 2020:46:268–277. https://doi.org/10.1016/j.culher.2020.08.001

[19] Severini G. L'immateriale economico nei beni culturali (The economic immaterial in cultural heritage.). *Aedon* 2015:3. (in Italian)

[20] Bottero M., Datola G., de Angelis E. A system dynamics model and analytic network process: An integrated approach to investigate urban resilience. *Land* 2020:9(8):24–26. https://doi.org/10.3390/LAND9080242

[21] Guccio C., *et al.* Technology and Public Access to Cultural Heritage: The Italian Experience on ICT for Public Historical Archives. 2016.

[22] Bellè B. M. Promesse e fallimenti nella valorizzazione degli immobili pubblici. *Sci. Reg.* 2017:16(3):463–472. https://doi.org/10.14650/87465

[23] Istituto Guglielmo Tagliacarne. Il sistema economico integrato dei beni culturali (The integrated economic system of cultural heritage.). Rome: Istituto Guglielmo Tagliacarne, 2009. (in Italian)

[24] Antonelli A. La valorizzazione del patrimonio mobiliare dello stato e degli enti locali (The enhancement of the movable assets of the state and local authorities.). Pisa: Universita di Pisa, 2017. (in Italian)

[25] Emiliani A. Per un nuovo concetto di bene culturale. *Capitale Cult.* 2020:21:463–467. https://doi.org/10.13138/2039-2362/2338

[26] Bottero M., Datola G., Monaco R. Fuzzy cognitive maps: A dynamic approach for urban regeneration processes evaluation. *Valori e Valutazioni* 2019:2019(23):77–90.

[27] Instituto Nazionale di Statistica. L'Italia dei musei (The Italy of museums.). Rome: ISTAT, 2019. (in Italian)

[28] Cherchi A. I musei statali valgono 27 miliardi di euro (l'1,6% del Pil italiano) (State museums are worth 27 billion euros (1.6% of the Italian GDP).). IL Sole 24 Ore [Online]. [Accessed 19.12.2021]. Available: https://www.ilsole24ore.com/art/i-musei-statali-valgono-27-miliardi-euro-l-16percento-pil-italiano-ACMvVjp (in Italian)

[29] Parker R. S. Hazards of Nature, Risks to Development. Washington: World Bank Publications, 2006.

[30] Hallegatte S., Przyluski V. The economics of natural disasters. *CESifo Forum* 2010:11(2):14–24. https://doi.org/10.4337/9781785365980

[31] Instituto Nazionale di Statistica. Mappa dei rischi dei comuni italiani. (National Institute of Statistics. Risk map of Italian municipalities). [Online]. [Accessed 12.02.2022]. Available: https://www.istat.it/it/mappa-rischi

[32] Drdácký M., *et al.* Protecting the cultural heritage from natural disasters. Brussels: The European Parliament, 2007.

[33] De Masi F., Porrini D. Cultural Heritage and natural disasters: the insurance choice of the Italian Cathedrals. *J. Cult. Econ.* 2021:45:409–433. https://doi.org/10.1007/s10824-020-09397-x

[34] Abraham K. S. Efficiency and Fairness in Insurance Risk Classification. *J. Storage* 1985:71(3):403–451. https://doi.org/10.2307/1072963

[35] Blanco E., Dutcher E. G., Haller T. Social dilemmas with public and private insurance against losses. *J. Econ. Behav. Organ*. 2019:180:924–937. https://doi.org/10.1016/j.jebo.2019.02.008

[36] Polzin F., *et al*. How do policies mobilize private finance for renewable energy? A systematic review with an investor perspective. *Appl. Energy* 2018:236:1249–1268. https://doi.org/10.1016/j.apenergy.2018.11.098

[37] Maio R., Ferreira T. M., Vicente R. A critical discussion on the earthquake risk mitigation of urban cultural heritage assets. *Int. J. Disaster Risk Reduct*. 2018:27:239–247. https://doi.org/10.1016/j.ijdrr.2017.10.010

[38] Xing J., *et al.* Detection and reconstruction of catastrophic breaks of high-frequency financial data with local linear scaling approximation. *Phys. A Stat. Mech. Appl*. 2020:561:124121. https://doi.org/10.1016/j.physa.2019.124121

[39] Feofilovs M., Romagnoli F. Assessment of Urban Resilience to Natural Disasters with a System Dynamics Tool: Case Study of Latvian Municipality. *Environmental & Climate Technologies* 2020:24(3):249–264. https://doi.org/10.2478/rtuect-2020-0101

[40] Fagioli F. F., Paolotti L., Boggia A. Trends in Environmental Management Systems Research. A Content Analysis. *Environmental and Climate Technologies* 2022:26(1):46–63. https://doi.org/10.2478/rtuect-2022-0005

[41] Bellieri dei Belliera A., *et al.* Flood risk insurance: the Blockchain approach to a Bayesian adaptive design of the contract. *Colloquium 2019 'Innovating Actuarial Research on Financial Risk and ERM'* 2019:1–15.

Publication 3

COVID-19 Effects on Cultural Heritage: The Case of Villa Adriana and Villa D'Este

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COVID-19 Effects on Cultural Heritage: The Case of Villa Adriana and Villa D'Este

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Abstract **– The paper aims to provide a clarification of assessing insurance risk related to an asset owned by a subject under public law and, more specifically, to an economic cultural asset. This study is aligned with key aspects proposed by the EU for the protection of the cultural heritage from natural disasters. In the first place, given the peculiarity of the material inherent to cultural heritage, a motivation underlies the search for the correlation between the latter and the commonality. Secondly, it appeared necessary to verify the differences, similarities and importance of the economic management of cultural heritage in order to understand the social, economic, material and intangible importance of an asset managed in an economic way within a social axis (municipality). The third reason relates to the general severity and the risk and subsequent damage that a hazard, such as a pandemic outbreak (COVID-19), can cause on one or more cultural heritage. In the final analysis, perhaps the most meaningful aspect underlies the verification of the possible consequences in the analysis of summations of losses generated by a hazard in order to allow a prospect of what could be the consequences of such a catastrophic scenario.**

Keywords **– Covid-19; cultural heritage; losses; natural hazard; risk assessment**

1. INTRODUCTION

1.1. The Organization and Protection of the Cultural Heritage in Italy

It appears prodromal and necessary to carry out a brief analytical and temporal excursus on the political measures that have affected this broader concept in the context of the Italian Republic. Then, the authors would proceed to an examination of the ontological concept relating to nature referred to in the sub appropriation of the material and intangible asset [1] belonging to and derivation of publications corresponding to cultural heritage [2].

A department responsible for the protection of cultural and environmental heritage will only find its formal entry into the country's institutional landscape in 1974/1975.

The most significant publication of the Department is attributable to the acts of the Investigation Commission for the protection and enhancement of the historical, archaeological, artistic and landscape heritage, established by law No. 310, known as the Franceschini Commission, named after its President [3]. The authors describe the legislative and legislative implementation that has taken place and has affected the sector of cultural heritage. In the following, in the drafting of the text, the authors explain the qualitative

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connotation of the term 'cultural heritage', highlighting universally recognized, objective and subjective distinctive features.

Starting from the chronological excursus of the Italian Law in the Cultural Heritage field, the Ministry, which will take the name of Ministry for Cultural and Environmental Heritage, was born by decree law 14 December 1974, No. 657, converted into Law 29 January 1975, No. 5, will then find complete organizational articulation with the Decree of the President of the Republic (D.P.R.) December 1975, No. 805. The responsibilities relating to Antiquities and Fine Arts, made the competent public body to decide to postpone the transfer of competences in the field of entertainment (3rd paragraph of article 1 of decree law 657/1974).

The following events see in 1998, by the legislative decree of 20 October 1998, No. 368 and subsequent amendments and additions, the Ministry assumes the name of Ministry for cultural heritage and activities, following the transfer of competences in the field of sports and sports facilities and in the field of entertainment, (i.e. cinema, theatre, music, travelling shows and dance); with the decree law 18 May 2006, No. 181, the competences in matters of sport are attributed to the Ministry for youth policies and sporting activities. In 2006, the organizational system by Departments was replaced by a system that still includes a general secretariat and general management, and Italy moved from a horizontal organizational model to a pyramid system. Given the D.P.R. 26 November 2007 No. 233, a new organizational model is issued which sees the birth of seventeen general managers with the function of regional directors, while in 2009 with D.P.R. 2 July 2009 No. 91, a new regulation for the reorganization of the Ministry is issued. In addition to statements of rationalization, efficiency and economy, sees the birth of a general direction for the enhancement of cultural heritage. In 2013 with law no. 71 the Ministry assumes a new name of Ministry of Cultural Heritage and Activities and Tourism [4], MIBACT, on 21 October 2013 the Office for Tourism Policies passes from the Presidency of the Council of Ministers to MIBACT. During 2014, a further reorganization of the Ministry took place following the provisions made by the so-called 'Spending review', by reason of which each Ministry was required to reduce its workforce, will thus lead to the issuance of the Decree of the President of the Council of Ministers 29 August 2014, No. 171 containing: 'Organization Regulations of the Ministry of Cultural Heritage and Activities and Tourism in accordance with Article 16, paragraph 4, of Decree Law April 24, 2014, No. 66, converted into law No. 89 [5]. It is evident that the cultural heritage system has undergone significant organizational and institutional changes over a few decades, highlighting critical issues and operational difficulties. The new Regulation intends to pursue broader objectives whose effects are difficult to predict over time, with the awareness of the possibility of having to make further changes and additions. During last years the fragile ministerial structure has encountered difficulties that cannot always be overcome, with serious damage to the entire protection system.

The new Regulation is developed in seven Heads and 41 articles plus two tables A and B relating respectively to Organic Endowment of Management and Organic Endowment of the Areas. The design sets itself a number of goals that aim to integrate culture and tourism, the overcoming the multiplication of command lines, the lack of autonomy of the Museums, and a new attention towards contemporary art and creativity [5].

Cultural heritage is a wealth that has its own resources inherent in the innate objective meaning, to be exploited even if sometimes new ones have to be added, in terms of people, skills and money or in the form of capital contributions for maintenance or, again, for substantial changes in content and form.

Cultural heritage contributes to identity, image, education, landscape, land management, housing heritage, the satisfaction of religious and cultural needs, tourist attraction, etc.

First, it is necessary to define the subject of the discussion or clarify what is meant by 'cultural property', *pars pro toto* of the wider concept of cultural heritage [7].

The expression made its debut in the Convention for the Protection of Cultural Property in the Event of Armed Conflict, signed in The Hague in 1954 [8] From there the notion 'cultural property' entered the internal legal language, with initially sporadic references, in the Statutes of the ordinary Regions and in the very first regional laws, and then was used 'officially' with the aforementioned law establishing the Ministry of the sector, which was called, as already highlighted, precisely 'Ministry of Cultural and Environmental Heritage'.

The aforementioned Commission's work ended with a Concluding Report, accompanied by a series of Declarations, which could already very well be considered an organic proposal for legislative modification.

What emerged was not only the result of a superficial analysis of the state of the cultural heritage, but a careful research, without rhetoric and poor in summary judgments. The Commission brought out a general state of precariousness and decay of the Italian archaeological, artistic, historical, environmental, book and archival heritage that could not (and cannot) be attributed only to 'funding deficiencies, but to the very idea that one has of cultural heritage 'and the tools that the legislator makes available to protect it. It is appreciated only in parts or only as an artistic value, often ignoring the importance that this has as a testimony of history.

The Commission in Declaration I used the expression 'cultural property' and made explicit two meanings. In the first place, a very broad notion of 'cultural heritage of the nation', since it included 'all assets referring to the history of civilization'; secondly, and this will be the definition that will acquire greater notoriety, a defining criterion was introduced residual and general, for which 'any other good that constitutes material testimony having the value of civilization' is a cultural asset. This expression broke into social consciousness and represented a fact of modernity, since the idea of recognizing cultural value only to things with a certain artistic and aesthetic value was still pregnant. The way was also paved for what are defined as 'minor goods', meaning by such goods that do not have the required requirement of 'unrepeatability' [9].

Since then, the proposed formulation has been at the center of many debates or doctrinal interventions on this point, for which Giannini himself has discussed and deepened the notion of cultural heritage as a 'material testimony having the value of civilization'.

Although contained in an official document, this notion does not rise to a definition having a normative character and at the time it remained without recognition at the theoretical and hermeneutical level.

The notion was first introduced in national legislation with art. 148, co. 1, Legislative Decree No. 112/1998, which defined 'cultural assets': 'those that make up the historical, artistic, monumental, demo-ethno-anthropological, archaeological, archival and book heritage and the others that constitute evidence of civilization value'. This standard reflects the echo of the notion developed at the time by the Franceschini commission, which contained the following definition of cultural property: '*good that constitutes material testimony having the value of civilization*'

The art. 148, lett. a), Legislative Decree No. 112/98 has accepted a mixed notion of cultural property, which appears to be a middle way between the non-mandatory listing of the things subject to protection and a reference to new assets that the law it can identify as a 'testimony having the value of civilization'.

From here the essential characteristics of the cultural asset are derived: the 'materiality' and the 'value of civilization', which seem to echo in the same art. 10 of Legislative Decree 22 January 2004, No. 42 (Code of cultural heritage and landscape), when cultural goods are defined as 'immovable or movable things' of an author who is no longer living, produced for at least fifty years, which must have a particular legal qualification. The first character, the material consistency, is also for the 2004 legislator a trait that must distinguish the assets capable of being declared cultural.

It does not seem easy to hide the perplexities aroused by the choice of identifying a distinctive feature of cultural property in materiality, which seems to have emerged 'strengthened' by the Code, which seems to be very clear in stating that non-material goods cannot be attracted to the category cultural heritage. On closer inspection, the T.U. of 1999, had provided a definition that revealed the idea that even non-material goods could be included in the sphere of cultural heritage. The majority doctrine [10] in this regard has expressed itself in a very unanimous in believing that the legislator had also intended to refer to 'intangible' or 'volatile' goods [11], in the sense of goods that are not 'things' but an expression of popular culture. According to the Council of State, a '*reality character in the broader sense of the term must be found in the regulatory data: in other words, the good in its materiality must constitute the central element of the case regulated by the standard and its cultural and environmental value must inform the ratio of the content*' [12].

Another character that emerges from the analysis of the legislation is the dimension, so the 'cultural' character can consist of both 'individual' goods and 'universality of things' (collections, collections, series).

The third character, on the other hand, concerns the registry of the property, since it must be the work of an author who is no longer living and that the realization has taken place for at least fifty years, for it to be considered cultural. This is established by art. 10, co. 5 of the Code. The Code of cultural heritage and landscape, approved with Legislative Decree 22 January 2001, No. 42 has brought news in relation to the identification of cultural assets, specifically those belonging to the public. The expression 'ascertainment of the qualification of cultural property' is intended to refer to the activity that the Public Administration undertakes in order to identify the assets subject to protection and enhancement, that is to ascertain that a certain 'thing' possesses the characteristics 'intrinsic 'required by law, so that an asset can be considered worthy of protection and safeguarding and therefore be defined as a' cultural asset '. Art. 12 of the Code entitled 'Verification of cultural interest' dictates the procedures for identifying cultural assets in public ownership.

Therefore, once the qualitative and connotative value of the cultural asset as a whole has been etymologically outlined, the cultural heritage, as a whole, can be understood as, '*a broad concept and includes the natural as well as the cultural environment. It encompasses landscapes, historic places, sites and built environments, as well as bio-diversity, collections, past and continuing cultural practices, knowledge and living experiences. It records and expresses the long processes of historic development, forming the essence of diverse national, regional, indigenous and local identities and is an integral part of modern life. It is a dynamic reference point and a positive instrument for growth and change. The particular heritage and collective memory of each locality or community is irreplaceable and an important foundation for development, both now and into the future*' [13].

This definition of heritage enunciated in 1999 at the XII International General Assembly on the management of tourism in Mexico turned out to be the main object for the International Council on Monuments and Sites to focus on to develop strategies relating to the presentation and interpretation of historical places and cultural diversities. In this assembly the concept of heritage was discussed as a set of cultural materials that an individual or one community shapes in a determined phase of its historical becoming.

To integrate the above in a strictly national context, it seems appropriate to take a look also at the supranational level and, in particular, ,another definition of heritage, not different from that enunciated by ICOMOS in 1999 but recognized worldwide, is that given by UNESCO (United Nations Educational, Scientific and Cultural Organization) to the Convention '*concerning the protection of the world cultural and natural heritage*' adopted by the XVII General Conference held in Paris in November 1972, which distinguished cultural heritage from natural heritage. The first, the only one of interest in this scientific paper, was proposed in these terms: '*the following shall be considered as' cultural heritage': monuments: architectural works, works of monumental sculpture and painting, elements or structures of an archaeological nature, inscriptions, cave dwellings and combinations of features, which are of outstanding universal value from the point of view of history, art or science; groups of buildings: groups of separate or connected buildings which, because of their architecture, their homogeneity or their place in the landscape, are of outstanding universal value from the point of view of history, art or science; sites: works of man or the combined works of nature and man, and areas including archaeological sites which are of outstanding universal value from the historical, aesthetic, ethnological or anthropological point of view*' [14].

It is understood how the reflections addressed to this theme are heterogeneous in the specifications of heritage but univocal with respect to the concept that it can be understood as a historical, cultural, artistic, natural, intangible heritage inherent in every civilization. What these definitions have in common is the consideration of heritage as a social process that draws life and motivation from the present and that involves power, tradition, memory and identity: it implies a precise selection of reference values through which to identify what is important to preserve. of the past. Most scholars agree that heritage is linked to the past, that it represents a sort of legacy to be preserved and passed on to the present and future generations, both in terms of traditions and material objects [15].

The diversity of views on the meaning and breadth with which the term 'heritage' [16] has been used depends on whether it could have acquired various dimensions: it is considered synonymous with vestiges of the past of any kind, or the product of modern conditions attributed to the past and influenced by it, or the entire cultural and artistic production of the past or present, and also a significant commercial activity, generically identified as a heritage industry, based on the sale of goods and services related to it [17].

1.2. The Effects of a Hazard on Economic Cultural Heritages. The COVID-19 Case in 2020 as a Negative Projection of Losses from Missed Incomes

The cultural and creative sectors, worldwide, are very important since their impact on the economy and employment [7]. Furthermore, they develop innovation in a multitude of economic forms and help to implement a general positive social impact. These sectors are among the sectors most affected by the pandemic, with most of the employment system at risk concentrated in large urban centers. The relevant dynamics. in the consequences, many sub-sectors range and involve, with the activities linked to physical events and places (venue-based) and the related supply chains that are among the most affected by social distancing measures. National and supranational policies to support public and private enterprises during the covid-19 pandemic may not be adequate for non-traditional business and employment models that characterize the cultural heritage sector. In addition to short-term support for artists and businesses, which comes from both the public and private sectors, the policies put in place for recovery and revitalizing local economies can also leverage an economic and social impact generated by culture [17]. Health concerns related to the pandemic have led to unprecedented closures of museums and heritage sites. Around 90 % of the world's museums (more than 85 000 institutions) were temporarily closed during the crisis and the remaining 10 % may not reopen until 2021 due to significant economic difficulties. The sharp reduction in revenues (3 out of 5 museums in the survey by the Network of European Museum

Organizations – NEMO reported losses [18] of an average of € 20 300 per week due to the inability to travel and the obligation to close) of charitable contributions and sponsorships for cultural sites, including public and private museums jeopardize the financial sustainability of cultural heritages, especially of the smallest ones. This has led to falling wages and layoffs for a number of workers (temporary staff, external contracts including brokers, seasonal workers, exhibition-related jobs, publication of catalogs, exhibition and educational materials, events and other commercial activities). According to a survey conducted by the International Council of Museums (ICOM) the contract of 6 % of temporary staff referred to in museums and cultural heritages has not been renewed or has been terminated, while 16.1 % of museum freelance professionals he was fired. In the medium term, and if social distancing measures continue, the ticket sales and planning will be slow and difficult to return to pre-crisis levels. Any further decline in income will lead to a reduction in cultural activities. This represents a structural threat to the survival of businesses operating in the cultural economic system, which will affect other subsectors that rely on these professionals for creative content as well. In a short-medium term perspective, cultural sites, especially Italian ones, where the outbreak has been extremely severe, will have fewer resources and capacities to contribute to the social and economic development of their local communities [18]. Over the last few decades, the proceeds from cultural heritage have become an engine of local development and a point of reference for many communities. The cultural sector has always increased the attractiveness of cities, towns and communities as places to visit, to live in and to invest in, and are increasingly seen as vital centres for the community, at the centre of urban regeneration efforts [14]. The lockdown measures have led to an abrupt shutdown of cultural sites and museums from local development projects and the cancellation of cultural, social inclusion, wellness and educational programs, only partially replaced by new digital offerings. In the aforementioned time frame, it appears that the cultural sector will have less capacity to contribute to local development projects if there is no need for new regulations regarding the reduction of individual freedoms.

2. Research Methodology

The methodology of the paper is divided into four sections.

Prior the in-depth analaysis of the two main aspects described before the reseach methodolgy was considering two main implementing stages.

The first relates to the legal/regulatory dissemination of the implementation of provisions that have affected the matter of cultural heritage at national level in order to highlight the peculiarities and salient features inherent in the framework above. in particular, the first methodological section involved the analytical study of the rules that concerned the theme of cultural heritage up to a national application scope of the binding law.

The second methodological section concerned the cross-search on the Unesco database and on the Italian national database of cultural sites managed economically, directly or through tenders, with economic and social significance. the second methodological section was conducted by the authors on the UNESCO web portal in order to research the Italian cultural heritage, which, as has been highlighted, is located in one of the geographical areas most affected by the pandemic outbreak, capable of supporting a financial analytical study . the study was carried out by cross-referencing the data available on cultural heritage sites with the UNESCO list.

The third section, after the identification of the Cultural Site, was directed to the analytical and economic study of the balance sheets, which can be found on the relevant website, at least in the last three years, so as to have a scalar projection of the most relevant indicators between costs and incomes. The financial study methodology was carried out through the qualitative and quantitative analysis of the last three-year period available, highlighting the most significant balance sheet items and comparing the annuities to obtain a progressive historical analysis.

The fourth section concerns the analysis, through research for statistical data and reports, of the effects of the pandemic outbreak referred to Covid-19, on cultural activities in general and particularly on the national territory sites.

The last methodological declination concerns the quantitative analytical processing on the mathematical projection of possible catastrophic scenarios and related economic consequences (losses).

2.1. Case Study An Italian Example of Economic Cultural Heritage. The Case of Villa Adriana and Villa D'Este in Tivoli

The cultural compendium of Villa Adriana and Villa D'Este in Tivoli [16] is one of the most important cultural sites in Italy, recognized by Unesco.

Indeed, although the Cultural site is nowadays understood as a whole, *ab initio* the assets were divided and Villa D'Este was '*declared a World Heritage Site by UNESCO in 2001, the villa grounds include a masterpiece of Italian garden design with an amazing concentration of fountains, nymphaea, grottoes, water themes and a organ which produces audible effects created by water*', while Villa Adriana was '*declared a World Heritage Site by UNESCO in 1999, the Villa was built between 118 and 138 A.D. by the Emperor Hadrian in a lush and verdant oasis near Tivoli, the ancient Tibur'*. The choice of the site of the two Villae underlies a multiplicity of factors and motivations, the first of which is inherent in the inclusion of the Cultural Heritage within the recognized UNESCO list, and therefore, qualitatively, this ruling asserts the importance of the site to the within the national and international framework. The second motivation underlies the management methods of the assets that are conducted in an entrepreneurial and economic way like any private company, through its own management or public contracts in favor of third parties, and this ruling perfectly responds to the qualitative and quantitative criteria set out in the premises. The third reason concerns the ease of retrieving the fiscal, economic / accounting balance sheets for the years of exercise under consideration (2017–2020) of the company of the cultural site as well as the accuracy of the same data. The fourth and final reasoning relates to the geographical location of the site and the unfavorable economic situation conditioned by the very severe pandemic outbreak (Covid-19) which highlighted in the 2020 budget the possible losses from current revenues as well as the increase in costs for extraordinary maintenance of the site.

As better outlined in the rest of the paper, the analysis focuses on the dissertation and verification of the possible catastrophic effects (losses) of any hazard on the cultural heritage in question. In particular, as per Table 1, on the basis of the 2017–2020 extracted financial statements (the latter only provisional), the macro-data examined concern some budget items that underlie four areas: fixed, in the sense of mandatory payment and not in the recursive quantum, and variable costs on the one hand and fixed and variable revenue on the other.

In Table 2, the authors examine the most relevant values of the indicators referred to in Table 1 over the last three years in order to allow an assessment of any negative impact of a hazard.

TABLE 1. MOST SIGNIFICANT BALANCE SHEET ITEMS

	Costs	Revenue/Incomes
Fixed	Tax charges; Charges for active workers of service;	ministerial and state grants; concessions on assets
Variable	Purchase of goods of consumption and services; Recovery, restoration, adjustment and maintenance; extraordinary of real estate	ticket sales

TABLE 2. RELEVANT INDICATORS 2017–2019 [16]

	2017	2018	2019
Tax charges, €	316 491.81	31.500.00	55.905.12
Charges for active workers of service, €	229 136.30	215.000.00	161.517.36
Purchase of goods of consumption and services, €	710 067.95	801.500.00	1.209.335.69
Recovery, restoration, adjustment and maintenance of the immaterial assets (software/hardware) and material movable and immovable assets, €	1 237 997.60	975 000.00	1 343 449.73
Ministerial and state grants; concessions on assets, €	200 000.00	400 000.00	199 744.81
Ticket sales, €	3 350 822.12	4 000 000.00	4 869 535.94

At the bottom of this section, in Table 3, it seems appropriate to report the several government provisions that have limited or prevented the opening of the Cultural heritage, exacerbating its economic condition.

TABLE 3. NATIONAL PROVISIONS THAT AFFECTED VILLA ADRIANA AND VILLA D'ESTE

	Closed	Open with restrictions	Open without restrictions
DPCM (decree of the Prime Minister) 09.03.2020	Binding from 10.03.2020 to 03.04.2020		
DPCM 01.04.2020	Binding from 01.04.2020 to 10.04.2020		
DPCM 10.04.2020	Binding from 10.04.2020 to 03.05.2020		
DPCM 26.04.2020	Binding from 04.05.2020 to 17.05.2020		
DPCM 17.05.2020		Binding from 18.05.2020 to 14.06.2020	
Repeal of the DPCM 17.05.2020			Binding from 15.06.2020 to 06.11.2020
DPCM 03.11.2020	Binding from 06.11.2020 to 03.12.2020		
DPCM 03.12.2020	Binding from 04.12.2020 to 15.01.2020		

2.2. Quantitative Model for Estimating Losses Deriving from Catastrophic Scenarios

The occurrence of a catastrophe that can have a different nature, such as environmental (in the sense of climatic events and their consequences, such as a flood), or seismic, or due to fire, or health (such as the pandemic outbreak that actually registered last year, 2020, and which will also have repercussions in the current one, 2021), could or should be subject to an economic risk assessment for the cultural asset, such as Villa Adriana and Villa d'Este in this case. The various types of catastrophe have a different impact on some budget items, on the revenue side and on the expenditure side. Just to give an example, the pandemic impacts the proceeds from ticketing (reducing it) but not it has consequences in terms of the costs of restoring the structure, net of some health care costs (thermoscanner for example) that could be considered necessary. On the contrary, a fire or a flood of some spaces of the structure would probably result in the temporary closure of the site and therefore negatively impact the ticketing as in the case of the pandemic, but, unlike this, it would presumably also require considerable costs to restore the full efficiency of the structure. Obviously, as a small positive compensation of the days of closure of the site, there could be reductions in costs such as those of utilities and also related to the salary of employees, perhaps taking advantage of some flexibility in existing employment contracts. To evaluate the impact of these costs and / or lost earnings and also of the cost reductions as just mentioned, both engineering-structural prospective analyzes are needed, for all costs related to the restoration linked to events never recorded previously, and serve historical data series from which to extrapolate the estimate of the economic risk relating to the various balance sheet items that would be impacted by a catastrophic scenario. Just by way of example, given that the reduction of the ticket revenue occurs in each of the catastrophic events, from the daily average of daily incomes (b) (assuming a constant flow and without seasonality) recorded in previous years, obtainable by exploiting the data of the annual total of receipts $B(t)$, with t = 2019, 2018, ... until the availability of the data. Assuming having (m) annual revenue figures, it is possible to obtain the following

$$b = (B(2019) + B(2018) + \ldots + B(2019 - m + 1)) \cdot \left(\frac{1}{m}\right) \cdot \left(\frac{1}{365}\right), \tag{1}$$

and therefore, by estimating the days of forced lockdown which can lead to a predetermined catastrophe, whether they are n, the expected loss of collection would be (bn). A verification of this estimate can be obtained with the data of the 2020 budget, counting the number of days of forced lockdown of the sites in 2020 that can be deduced from the calendar of closures illustrated in Table 3, and comparing the estimate of the reduction of the collection from the ticketing sales illustrated above, with the actual reduction of 2020, compared to the 2017–2019 average.

Just to concretize with a numerical example what has just been said, with the data available in Table 2 relating to collections for the years 2017–2019 it is possible to have that

$$b = (3350822 + 4000000 + 4869535) \cdot \left(\frac{1}{3}\right) \cdot \left(\frac{1}{365}\right) = 11.160 \tag{2}$$

and that the number of forced lockdown days in 2020 (optimistically considering the days of partial closure with a regular ticketing flow) was n = 130, there would be an estimated loss of

$$11160 \cdot 130 = 1450818$$

which will be compared with the difference between the average 2017–2019 takings, or 4 073 452 and the total 2020 ticketing incomes.

2020 data on losses of daily incomes from ticketing is available also on opening days, compared to the average of previous years, which could be a further element of evaluation to implement a model for estimating losses from catastrophes, more in-depth than that proposed by the applied methodology.

3. Results and Analysis

The results of the paper can be summarized as follows.

First of all, the paper highlights the precariousness and the economic/financial instability of the cultural site in relation to a possible fluctuation of the cash flow due to a natural hazard, as it happened in 2020 due to the Covid-19.

In particular, by setting the average of the three-year period 2017–2019 as the average value of the receipts and using as a hypothesis a constant flow of visitors throughout the year, by reducing and dividing this value by the sum of the days in which the cultural site was closed to the public, the authors have obtained the abovementioned mathematical equation that delineates the average losses from incomes.

The second result relates to the evidence of the extremely expensive management of the cultural site, even though it is forbidden to be visited by tourists, regarding current expenses.

The third result concerns the ease of exposure of the cultural site to any hazard which highlights the absolute lack, as per balance sheets, of any risk mitigation program, even merely insurance capable of calming the effects of losses deriving from missed incomes.

The fourth result pertains to an in-depth analysis concerning the case in which the topic treated and the research that derives from it is not studied in depth in scientific publications.

The fifth and last result, from a quantitative point of view, derives directly from the mathematical analysis referred to in the previous section and concerns the case study for which, the forecasts of annual decrease in incomes, for the analyzed cultural site, are realistically in a average line from 29.79 % to 43.3 %.

4. CONCLUSIONS

The conclusions can be divided into three parts.

The first conclusion underlies the observation that the public administration, including the cultural heritage examined, is the total reward of the hazards, latu sensu intended. The hazard called Covid-19 highlighted the total lack of preventive and remedial countermeasures to stem the effects and risk exposure of the assets to the hazard which, in the intrinsic negativity of hazards, in any case, did not cause direct damage to the assets and to people.

The second conclusion concerns the total inconsistency of the provisional balance sheet drawn up prior to the pandemic outbreak and the impossibility highlighted, both in general and in particular, to remedy at an entrepreneurial level. In fact, hypothetically, when the final 2020 balance sheet is deposited, the latter will show a significant loss, in line with the above function that is difficult to stem in the next financial years.

The third conclusion, in line with the results highlighted above, concerns the total or almost total absence, as per balance sheets, of any insurance coverage related to natural events, not merely limited to the reconstruction of the real estate, but, as experienced in other business areas and highlighted in some papers, an insurance able to keep the flow of money unchanged, in the form of liquidation, in order to avoid the aggravation of direct and indirect consequences that, mostly at a private level, occurred last year (2021), including, it seems appropriate to remember, the level of employment, the loss of purchasing power and the contraction of the market.

The aforementioned conclusions highlight the peculiarity of the paper which involves, not as a primary aspect the ex se risk or, at most the cost of reconstruction of the damaged asset, but, and this is the key aspect, inherent in the systematic classification of a economic asset, outlined as a cultural heritage, and the economic, social, labor (employment), political and financial consequences tout court deriving from the hazard. In fact, too often, it is customary to think of catastrophic damage as purely direct effects on the material structure of the asset without investigating the plethora and the social-economic spectrum that surrounds it.

References

[1] De Masi F., Porrini D. Cultural Heritage and natural disasters: the insurance choice of the Italian Cathedrals. *J. Cult. Econ.* 2021:45:409–433. https://doi.org/10.1007/s10824-020-09397-x

[2] Drdácký M., *et al.* Protecting the cultural heritage from natural disasters. Brussels: European Parliament, 2007.

[3] Gordini G. Cultura e patrimonio culturale nel costituzionalismo comparato. (Culture and cultural heritage in comparative constitutionalism). *Politico: rivista italiana di scienze politiche* 2017:82(2). (in Italian)

[4] MIBACT, [Online]. [Accessed 12.03.2021]. Available: https://www.beniculturali.it/

[5] Official Gazette of the Italian Republic – general series no.274 of 25 November 2014, [Online]. [Accessed 25.11.2014]. Available: https://www.gazzettaufficiale.it/eli/gu/2014/11/25/274/sg/pdf

[6] Pellizzari S. Il ruolo dei privati e la tutela del patrimonio cultur- ale nell' ordinamento giuridico inglese : un modello esportabile? (The role of individuals and the protection of cultural heritage in the English legal system: an exportable model?) *Societ* 2010. https://doi.org/10.7390/31726 (in Italian)

[7] UNESCO Biblioteca Digital. Protection of cultural property in the event of armed conflict [Online]. [Accessed 12.02.2021]. Available: https://www.unesco.beniculturali.it/en/hague-convention/

[8] UNESCO. Final Act of the intergovernmental conference on the protection of cultural property in the event of armed conflict. *Conf. Intergub. sobre la Protección los Bienes Cult. en Caso Confl. Armado*1954:79.

[9] Tosco C. I beni culturali. Storia, tutela e valorizzazione (Cultural heritage. History, protection and enhancement.). *Itinerari* 2014:192. https://doi.org/10.7390/92253

[10] Sinisi M. 'Utilità culturale' e 'utilità economica' dei beni appartenenti al patrimonio culturale : Intangible Cultural Heritage, sponsorizzazioni e riproduzioni ('Cultural utility' and 'economic utility' of assets belonging to cultural heritage: Intangible Cultural Heritage, sponsorships and reproductions.) 2018:209–236. https://doi.org/10.1515/aida (in Italian)

[11] Adie B. A., Falk M. Residents' perception of cultural heritage in terms of job creation and overtourism in Europe. *Tour. Econ.* 2020:27(6):1185–1201. https://doi.org/10.1177/1354816620943688

[12] Giustizia Amministrativa. Consiglio di Stato. Ad. gen., n. 33/1999 (State Council. General Meeting Nr. 33/1999) [Online]. [Accessed 10.04.2021]. Available https://www.giustizia-amministrativa.it/ (in Italian)

[13] Cagiano E., Nucci G. R. Riflessioni sulla tutela: temi, problemi, esperienze. Polistampa, 2010. (in Italian)

[14] Gruber S. Convention concerning the Protection of the World Cultural and Natural Heritage 1972. *Elgar Encyclopedia of Environmental Law: Multilateral Environmental Treaties*. Cheltenham: Edward Elgar, 1972:60–66. https://doi.org/10.4337/9781783477210.v.5

[15] Bedate A., Herrero L. C., Sanz J. Á. Economic valuation of the cultural heritage: Application to four case studies in Spain. *J. Cult. Herit.* 2004:5(1):101–111. https://doi.org/10.1016/j.culher.2003.04.002

[16] Guccio C., *et al.* Technology and Public Access to Cultural Heritage: The Italian Experience on ICT for Public Historical Archives. In Borowiecki K., Forbes N., Fresa A. (eds) *Cultural Heritage in a Changing World*. Cham: Springer, 2016:55–75. https://doi.org/10.1007/978-3-319-29544-2_4

[17] P. Asproni. Il valore strategico ed economico del patrimonio culturale 1 (The strategic and economic value of cultural heritage 1.). 2018 (in Italian) [Online]. [Accessed 15.01.2018]. Available: http://www.ilgiornaledellefondazioni.com/autori/patrizia-asproni

[18] Villa Adriana e Villa d'Este - Villae [Online]. [Accessed 12.04.2021]. Available: https://www.levillae.com

Publication 4

Climate change management: a resilience strategy for flood risk using Blockchain tools

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Climate change management: a resilience strategy for flood risk using Blockchain tools

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Abstract

This work aims to offer a contribution in the analysis and management, from an economic and financial point of view, of the flood risk, and extended to the hydrogeological risk, from the perspective of a public administration. As main responsible actor for containing the phenomenon through the maintenance of the territory, public administration is responsible for the cost of restoring of the services that have been damaged by this type of phenomenon. The assets of which the public administration must ensure the restoration are all public infrastructures (i.e. transportation, energy and water supply system, communication) together with the damage suffered by private property, if these affect services to be guaranteed to the population. In this work, the authors propose possible strategies that a public administration can put in place to deal with flood risk. Three main strategies are analysed: an absolute passivity that provides for the payment of damages as they occur (i.e. business-as-usual scenario), a classic insurance scheme, a resilient and innovative insurance scheme. The economic–financial profiles of these strategies proposed in this work put an emphasis on how the assumption of a time horizon can change the convenience of one strategy compared to the others. This study highlights the key role of the quantification of flood risk mitigation measure from an engineering perspective, and their potential issues to pursue these objectives in connection to the regulatory framework of the public administrations. This synergy is supported by the potential use of Blockchain-based tools. Within the paper is highlighted the key role that such platform IT data management platform could have within risk analysis and management schemes, both as a data collection tool and as certification of the various steps necessary to complete the process.

Keywords Climate change · Flood risk · Insurance · Resilience · Blockchain

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1 Introduction

The phenomenon of climate change is intensifying the manifestations of extraordinary climatic events, and in recent decades, worldwide, the damage has raised to tens of billions of dollars. The climatic phenomena that cause damage are different depending on the geographical areas. These have already been largely addressed within the insurance market (Munich 2013), both as traditional products and with mechanism involving the financial markets, i.e. cat-bonds. Such mechanism encountered an important increase in the market since their appearance a few decades ago.

In addition to the insurance market, focused on the transfers the risk and part of the payments to other subjects, in several risk reduction strategies it is mostly the public administration that ultimately has to face the management of these risks and the consequent damages unlocking a significant and growing economic challenge on how to face with up-front investment for adaptation or mitigation risk reduction solutions (UNISDR 2015).

A particular type of risk related to extreme climatic phenomena is flooding both as riverine or coastal, which is aggravated with the increase in the number of extreme climate event such heavy rains or storm surges. The impact on the local assets depends on the local conditions including morphology of the territory and its underlying hydrogeological risk, the overall vulnerability of the population and the infrastructures exposed to the hazard. Specifically, hydrogeological risk is a type of risk that, in addition to private assets, creates damage to many public infrastructures (e.g. transportation network, energy and water distribution systems, communication network) that the public administration it is forced to restore, often at very high costs.

The theme we want to present in this paper proposes a financial scheme of a flood risk management process from the point of view of a public administration, which can choose between different risk reduction strategies.

The first is the completely passive payment of the damages as they occur (i.e. business-as-usual scenario). The second is a traditional insurance scheme. The third entails an attitude of urban resilience, which consists in evaluating the possible convenience of up-front investments for risk mitigation through an appropriate hazard mitigation or adaptation project specifically addressed to have a more resilient urban infrastructures and assets at risk.

This third strategy follows the idea of the financial structure as proposed by the so-called resilience bonds, which are having a first development in recent years starting from the first issue in 2019 of a five-year climate resilience bond by the European Bank for Reconstruction and Development (EBRD).

In this paper, a comparative quantitative assessment model of the three proposed strategies will be presented, based on a stochastic process that can describe the expectations of the level of damage that will be achieved over future time horizons. A similar quantitative-based approach has been presented in recent previous papers by the same authors, Pagano et al. (2019a, b), and by Reguero et al. (2020) for financing coastal resilience.

The problem analysis will be completed by describing the other disciplines involved in this risk management scheme, i.e. the role of engineering competence will be explained, in terms of risk assessment and costs–benefits (in terms of mitigation respect to the original level of risk) of the infrastructures that could be used for this purpose (embankments, dams, expansion tanks, …) and also what is the regulatory framework (particularly for the European context) within the public administrations can act to pursue these objectives.

Finally, this paper wants to create the ground on the use of an innovative IT technology platform for the insurance sector (i.e. Blockchain). Blockchain-based tools provide the interface for real-time climate data collection and registered damages. The platform provides the automatic certification of the acquired information within each steps of the process, both in terms of the regulatory and financial framework, and in terms of the implementation of risk mitigation infrastructures.

This paper has the following structure.

The first paragraph describes the regulatory context in which the public administration can act to deal with flood risk and catastrophic risks in general. The second paragraph is dedicated to comparing the convenience of the various strategies that the public administration can implement according to a quantitative actuarial scheme, even with a numerical example in order to offer a sensitivity analysis for some key parameters, with the crucial role of engineering expertise for their assessment. The third paragraph will highlight the possible role of Blockchain in the various steps of the flood risk management scheme presented in this work. Finally, some conclusions and ideas for further research developments will be pointed out.

2 Public administrations and the regulatory framework for flood risk assessment and management

Since the early 1970s, extreme events associated with natural disaster have been growing both in frequency and intensity. Specifically, during the last 15 has been recorded an increase of 2% per year as reported in Serre and Heinzlef (2018).

The same increased trend was also reflected on flood disasters registered from 2007. What happens in the year 2013 in the Central Europe was particularly impactful: 16.5 billion in economic losses (large-scale damage across Germany, the Czech Republic, Hungary and Poland) for 4.1 billion in insurance paid claims. The year 2013 has the negative record of the increase in flood damages of approximately 50% respect to the period 2003–2012 and to show for the first time three consecutive losses exceeding 100 billion in a 10 years period time (Swiss 2014).

These figures represent an evidence how the increase in the population in urban areas and the consequential increase in their complexities of both social and technological dimensions define a bottleneck within flood risk management in public administration.

In fact, the rapid growth of human concentration and urbanized areas has increased the exposure to the existing flood recurrence time making more difficult the realization of proper mitigation measures such as the availability of the land to be settled as potential flood risk zone, or protection and improve safety of river banks.

Among different assets that increased their risk to flood due to an increased exposure, Critical Infrastructures (CI) need a specific emphasis. Critical infrastructures represent body of systems, networks and assets that are essential for the functioning of a society, public's health and/or safety and economy of a nation. CI are thus engineering and technological networks, such as energy and water supply systems, transport services, banking and finance, and ICT (information and communication technology) systems. All these systems are important (and thus critical) to maintain essential functions of society, and their failures can heavily seriously affect the population, economy and national security [as stated in Galland (2010) and in Serre (2018)].

This is the reason that addressed the attention of policy-makers, economist, urban planners, engineers, insurance companies and scientist to find innovative risk management frameworks to more sustainable and more resilient cope with climate changes effect and natural hazards (Quenault 2014).

There are initiatives at various levels worldwide with the aim of creating coordination and guidelines for public administrations, to design resilient schemes in the face of the risks of climate change, also with regard to the economic–financial aspects of risk assessment and financing of resilient actions.

Keenan (2019) describes the reference legislation and the opportunities granted by it, to adopt resilient strategies against the risks associated with climate phenomena in that area as exposed as California is.

Also in the European context, significant steps towards a coordination of local administrations have been observed, mostly in the assessment of risks deriving from the climate change phenomenon.

In particular, in 2008, the European Commission launches the first, and to date the most ambitious, initiative targeting local and subnational authorities to lead climate and energy action. As part of the Covenant of Mayors, cities and towns take action towards sustainable energy, including alleviation of energy poverty, climate change mitigation and adaptation to secure a better future for their citizens.

Covenant of Mayors for Climate and Energy (2008) is a voluntary-based initiative focused on the proactive role of local authorities for making territories (more) resilient to the impacts of climate change. That work produced Sustainable Energy and Climate Action Plan (SECAP) in 2015 (Bertoldi 2018).

One key point of the SECAP is Risk and Vulnerability Assessment (RVA), which is an analysis of the relevant risks and vulnerabilities, by analysing climate hazards and assessing vulnerability (of urban sectors): (1) Municipal buildings, equipment/facilities, (2) Tertiary (non-municipal) buildings, equipment/facilities, (3) Residential buildings, (4) Transport.

The assessment could address for instance risks related to floods, extreme low temperatures and heat waves, droughts and water scarcity, storms and other extreme weather events, increased number or intensity of forest fires, sea level rise and coastal erosion.

In a SECAP, a Baseline Emission Inventory and a Risk and Vulnerability Assessment are mandatory and identify a set of actions to be undertaken: one of these actions could be the introduction of resilience bonds to finance risk mitigation strategy by a more resilient infrastructural system.

A joint SECAP can be developed by a group of adjoining local authorities. This can even increase the effectiveness of the risk reduction plan by the definition of a regional common long-term vision.

3 A quantitative comparison among different risk management strategies

This paragraph will describe the financial schemes generated by three different strategies for dealing with flood risk by the public administration:

– the passive strategy provides for the payment of damages as they occur,
– the standard insurance strategy provides for the quantification of a premium with which to transfer the burden of compensation (in part or totally) to the insurance market,
– the innovative insurance resilient strategy, involves combining the standard insurance scheme with the financing of mitigating infrastructures, which will reduce risk exposure once completed.

It will therefore be a question of comparing the effectiveness of the different strategies, based on the time horizon that will be set, taking into account that the advantage of the resilient strategy will materialize after the mitigating infrastructures, which involved higher costs in the initial phase, will be completed. We consider a similar approach to one proposed in Reguero et al. (2020), but we assume a stochastic framework for the damages.

Flood risk reduction by an enhanced urban resilience means moving towards the improvement of mitigative infrastructures (e.g. hydraulic defence works, retaining dams, expansion tanks, …). Within this process is required the risk assessment through engineering modelling including the calculation of potential losses before and after the realization of a mitigation project and the overall costs of and time required to build the resilient infrastructure. This aspect is not trivial since each engineering solution and its risk reduction assessment is site specific and not always straightforward.

Within the proposed model, the authors refer to the original source of the flood risk in connection to , that is to rain levels and/or to those of river beds in the area exposed to the risk.

It would be a question of finding the form of dependence, through statistical inference issues, of the damages recorded starting from the data of this primary source of risk, which can be a not easy task since the quality of the databases linking the damages to corresponding climate phenomena are not so good, almost for many public administrations archives. Also other study Reguero et al. (2020), regarding the economic loss distribution for coastal damages, no reference is made to any database of actually recorded losses.

Therefore, it was decided to skip this aspect of the investigation, which would have removed us from the focus treated in the present work.

We will directly acquire the knowledge of a historical series of the damages recorded, with the temporal scan (year, season, month, …) which will be at the basis of the quantitative model: for simplicity and to avoid seasonality phenomena relating to the climatic events in question, we will consider an annual basis, which is a usual assumption in many actuarial models. In what follows, therefore, all the quantities will be considered defined on an annual basis.

3.1 The model of risk exposure

Let $X(h)$, i.i.d for $h = 1, 2, \ldots$, the yearly random payment for flood damages in year h, with distribution function $f(X)$, that is $f(X) = f(X(h))\ \forall h$, which can be estimated by the analysis of historical series of yearly damages, with moments $E[X^r]$, for $r = 1, 2, \ldots$.

Let assume an insurance premium function of $f(X)$, that is $P = g(f(X)), g : \Re \to \Re$, for which a standard assumption due to a risk aversion principle, is $P > E[X]$. We assume a full coverage of the damages by the insurance contract.

Assume that with a cost W and a completion time n, a mitigative infrastructure provides that the r.v. which describes the yearly damage for following years is X_R such that, $E[X_R] < E[X]$ and $\sigma[X_R] < \sigma[X]$, from which for the insurance premium with the same function g, it holds $g(f(X_R)) = P_R < P$.

The assessment of risk reduction by engineering expertise could be a hard task, since it cannot be evaluated using historical series of damages (the mitigative infrastructure did not exist before).

3.2 The comparison of strategies expected costs over a time horizon

In this paragraph, we will proceed to the comparison of the expected costs of the three different strategies, fixed the time horizon. Since the comparison must be made in terms of current values, a generic annual discounting factor v corresponding to the rate of i must be fixed, that is $v = (1 + i)^{-1}$.

For the passive strategy (indicated with the subscript P in the following symbols), the random present value of the total payment by the public administration, fixed a generic time horizon of m years, $C_P(0, m)$, is

$$C_P(0, m) = \sum_{h=1}^{m} X_h v^h$$

from which its expected value is a deferred annuity of instalment $E[X]$, that is

$$E[C_P(0, m)] = \frac{1 - v^m}{i} E[X].$$

For the standard insurance strategy (indicated with subscript I in the following symbols), the current value of the total expenditure for the public administration, which is deterministic in this case, is a deferred annuity of instalment P , that is

$$C_I(0, m) = \frac{1 - v^m}{i} P.$$

For risk aversion principle, from which it follows $P > E[X]$, we have

$$E[C_P(0, m)] < C_I(0, m) \tag{1}$$

but the passive strategy could incur in annual compensation so high as to endanger the financial solidity of the public administration, which instead, with the insurance strategy, can plan a constant yearly payment equal to P. The probability of very high compensation increases as the volatility of X increases, that can be deduced from the historical series, with which its distribution $f(X)$ is estimated.

The resilient strategy (indicated with subscript R in the following symbols) provides that for n years it will be necessary to pay the insurance coverage P and to finance the mitigating infrastructures for which the cost W was assumed, while after completion time the annual insurance cost decreases to the level P_R.

Therefore, let Q be the annual instalment assuming that it has to be paid for the entire duration of the construction of the mitigative infrastructure (but different durations could also be considered), that is n years, to finance the cost of the mitigating infrastructure, which satisfies the equation

$$W = \frac{1 - v^n}{i} Q,$$

from which we have the total expenditure, also in this case deterministic, incurred by the public administration for the first n years

$$C_R(0, m) = \frac{1 - v^n}{i}(P + Q)$$

and the following chain of inequalities

$$E[C_P(0, n)] < C_I(0, n) < C_R(0, n)$$

that is, in terms of expected values, in the first n years the passive strategy (albeit with a random result while the other are deterministic) is more convenient than the standard insurance strategy, which in turn is cheaper than the resilient one.

It is therefore a question of studying the break-even point problem in terms of time horizon, starting from which the resilient strategy becomes more convenient than the others, taking into account that for a generic value $m > n$ the present (deterministic) value of the expenditure overall for this strategy is

$$C_R(0, m) = \frac{1 - v^n}{i}(P + Q) + v^n \frac{1 - v^{m-n}}{i} P_R.$$

So the break-even point respect to the standard insurance strategy will be m_I^* that is the minimum value of the time horizon $m(> n)$ such that

$$m_I^* = \min_{m=n+1,n+2,\dots} C_R(0, m) < C_I(0, m) \tag{2a}$$

while one respect to the passive strategy will be m_P^* that is the minimum value of the time horizon $m(< n)$ such that

$$m_P^* = \min_{m=n+1,n+2,\ldots} C_R(0, m) < E[C_P(0, m)]. \tag{2b}$$

The evaluation of the cost W and completion time n of the mitigating work and the quantification of the risk reduction through an engineering expertise can be a complicated objective, above all because there is no real feedback on the exposure to risk following the completion of the work, but it is necessary to proceed only with hypotheses validated in contexts with some similarity.

A further development, which rests on such ability to estimate through engineering skills, could be to evaluate a possible range of mitigating infrastructures, with costs and times given by pairs $W(j)$ and $n(j)$, in the case of the generic j-th option, $j = 1, 2, \ldots, J$, from which the ex-post risk exposure distribution is described by the random variable $X_R(j)$ and the corresponding reduced premium $P_R(j)$.

In this case, the problem of optimizing the choice of the mitigating work could concern the minimum $P_R(j)$ fixed a maximum level of infrastructure cost, or the minimum in terms of break-even point provided by the different choices, that is the minimum $m^*(j)$, with $J \in, 1, 2, \ldots J$.

In this comparison of convenience of the different strategies, the role of Blockchain tools underlying the concepts of smart contracts, would be essential for the need of automatic contract passages, from one phase to the next, without wasting time, for example, from the completion of the mitigation infrastructure, to the certification of risk exposure reduction. Indeed, a smart contract can be defined as an automatic updating of contractual conditions upon the occurrence of certain conditions to be verified through Blockchain tools.

3.3 Numerical example: sensitivity analysis on the convenience of the resilient strategy

The aim of this section is to present the decision-making problems that may arise in terms of choosing the risk mitigation strategy, in case the distribution of the random damage is known. As already mentioned in the introductory part of section 3, no reference is made to any actual database of damage deriving from floods, but a classic assumption in the actuarial context of a lognormal distribution for the random damage is considered. In particular, we want to highlight what could be the key role of some parameters for the sensitivity analysis of the convenience of the resilient strategy compared to the others, on the basis of the model presented in the previous section.

For the random damage X, we assume a lognormal distribution characterized by the parameters μ and σ and we model risk reduction after mitigative infrastructures completion time, assuming for the residual risk X_R, a lognormal distribution with parameters $\mu_R = (1 - d_1)\mu$ and $\sigma_R = (1 - d_2)\sigma$.

The insurance premium loading is assumed a proportion $\alpha > 0$, of the volatility of the random damage, so the total premium is

$$P = E[X] + \alpha\sigma[X]$$

and analogously for the premium after the mitigative infrastructure has been built

$$P_R = E[X_R] + \alpha\sigma[X_R].$$

Considering a standard parameterization characterizing the original risk exposure and one after the construction of the mitigative infrastructure,

$$mu = 1, \sigma = 2, d_1 = 0.1, d_2 = 0.1, \alpha = 0.05,$$

note that it holds

$$E[X] = 20.08, \sigma[X] = 90.01, \quad \text{from which } P = 24.58$$

and

$$E[X_R] = 12.42, \sigma[X_R] = 38.09 \quad \text{from which } P_R = 14.33,$$

and that relating to the mitigation work and its financing

$W = 100$, $n = 5$, $i = 0.02$ from which $Q = 21.21$ (it has to be payed for the planned n years of completion time).

We proceed to a sensitivity analysis of the break-even points m_I^* and m_P^*, according to (2a) and (2b), that is the time horizon at which the resilient strategy begins to become advantageous compared to the others, respect to variations of the most significant parameters, that is the volatility of the original risk and those relating to the mitigative infrastructure. Disregarding the description of the volatility of the results and considering them only in terms of their expected values, the standard insurance strategy is always less convenient than the passive strategy, see (1).

It should be noted that as the volatility of the original risk increases, while the break-even point with respect to the standard insurance strategy is constantly approaching, there is no monotonous trend with respect to the passive strategy, which depends on the effect of loading the related insurance premium to this parameter, that the cost of the passive strategy, a function of the expected value alone, does not suffer in such a

Table 1 Break-even point sensitivity respect to volatility of the original risk σ

σ	m_I^*	m_P^*
2	16	27
2.1	13	24
2.5	7	22
3	6	89

Table 2 Break-even point sensitivity respect to mitigative infrastructures cost C

W	m_I^*	m_P^*
100	16	27
110	17	29
150	21	36
200	26	45

Table 3 Break-even point sensitivity respect to risk reductions deriving from mitigative infrastructures measured by $d_1 = d_2$

$d_1 = d_2$	m_I^*	m_P^*
0.1	16	27
0.11	15	25
0.15	13	20
0.2	12	17

Table 4 Break-even point sensitivity respect to mitigative infrastructures completion time n

n	m_I^*	m_P^*
5	16	27
6	17	29
8	19	33
10	21	37

significant way. Of course the higher is the volatility of the original risk, the less safe is the passive strategy, since the probability of huge claims increases, that may create serious difficulties to the general economic situation of the public administration.

The results are widely expected, that is the break-even point moves away as the cost of the mitigation work increases. It could be interesting to analyse a model such that as the cost of mitigation works increases, even their effectiveness, in terms of risk reduction, increases, which could lead to a not-monotonous trend in the break-even point. However, we may have to consider a minimum level of abatement required, in order not to make the break-even point the only decision-making element in terms of measuring the efficiency of the mitigating intervention.

As regards the sensitivity with respect to the reduction of risk deriving from the mitigative infrastructure, we assume that the reduction rates of the parameters that describe the original risk, μ and σ, have the same value, that is $d_1 = d_2$, whereas the effects of the mitigation works could impact the values of these parameters in very different ways, depending on the type of intervention.

It is interesting to note the effect of shortening the break-even point with increasing effectiveness, much more pronounced for the passive strategy rather than the insurance one.

It is quite clear that, given the higher cost of the resilient strategy until the completion of the mitigation work, if this period is longer, it also entails an obvious shift in the break-even point, of roughly the same magnitude compared to the standard insurance strategy and even more pronounced compared to the passive strategy.

4 Blockchain and the legal environment for smart contracts

Starting from the pioneering papers of Szabo (1997, 1998), there is no universally accepted definition of smart contract and for the purpose of our paper we can use one of the most used (r2), "an agreement whose performance is automatic, so an algorithm for computer transactions, which comply with the terms of the contract".

A more detailed definition, even thinking about the applicative scope of the paper was provided by the Italian IVASS (Italian Institute for Insurance Supervision), according to which smart contracts are contracts that are written in a specific language that can be understood, translated and executed by a computer, whose clauses can produce actions without external intervention based on information received in input and processed according to predefined rules, see Grasso (2018), and the information technology underlying this automation is just the Blockchain.

About the potential (and in same cases effective) role of Blockchain in insurance environment, for various purposes, see (Gatteschi et al. 2017, 2018; Sayegh 2019; Pagano et al. 2019a, b).

Hence, a smart contract can then be thought as a multiphase contract, in which the steps to be controlled to proceed to the next phase are set at the beginning, which seems exactly the case of the mitigating process through the resilient strategy described in this work.

The various steps of the process are: the initial data collection relating to climatic phenomena (and their consequences in terms of flood phenomena) and the damage caused by them, for which the Blockchain can act in terms of certifying that the data comes from reliable sources, the stipulation of the contract both in the insurance part and in the financing part of the mitigation work, the certification of the timetable for the construction of the mitigation work (contractual clauses may be linked to any delays with respect to the settled timetable), the change in the regime of the insurance contract once the completion of the works has been certified, without the need for a new agreement on the actual exposure to risk, once this had been fixed at the signing of the contract (perhaps to be validated ex post by engineering expertise).

Note that since these mitigation processes should be of various decades and in these lengths of time some trends in climate phenomena could be observed, then the multiphase contract can consider some refreshments in the assessment of some parameters of the model, for example, ones which describe the primary risk expressed by the distribution of the random damage, with the consequent adjustment of the premium level for insurance coverage.

5 Comments and further lines of research

This paper presents an innovative approach on how combines the effect of up-front risk reduction investment for public administration with a resilient insurance mechanisms.

This work presented a multidisciplinary analysis on possible flood risk coping strategies, for which the entire hydrogeological risk can be understood more generally, an increasingly pressing problem for public administrations also in relation to the evidence of increasingly accentuated manifestations. of extreme climatic phenomena in more recent years.

The regulatory context in which local public administrations can consider possible synergies within schemes at European level (Covenant of Mayors) and in other geographical areas was described.

In addition to the use of a classic insurance approach, an assessment scheme is described deriving from a resilient approach, that is, in addition to the economic coverage of the damages that are recorded, it provides for the financing of risk mitigation works, a structure used for the so-called resilience bonds.

This paper wants to provide a consistent approach on the application of international frameworks like the Paris Agreement, the Sendai Framework for Disaster Risk Reduction and the Agenda 2030 for Sustainable Development. Moreover is well integrated in the regulatory context of SECAP.

It was highlighted that the construction of this quantitative model must be based on engineering expertise, for the ex-ante and ex-post risk assessment and for the design of the most effective mitigation works in terms of cost–benefit ratio. Given the additional cost of the mitigation work, an indicator that seems appropriate to us to compare the resilient strategy to the others is that of the break-even point, which is very common in the context of investment evaluation.

A development of the research will consist in the analysis of the quantitative scheme considering also the element of the variability of the results, for example through the use of the Monte Carlo simulation, in order to highlight how the uncertainty of the cost of claims of the passive strategy may produce much more critical scenarios than other strategies, which provide a deterministic flow for hedging risk.

The necessary multiphase process that must be completed to implement the resilient strategy, can be guided and controlled in the various phases using Blockchain tools, both in the role of data collector and in the role of certifying the completion of the various steps of the process, according to an initially established protocol that does not have to be re-discussed by the counterparties at each step, according to the scheme of so-called smart contracts.

Compared to the theoretical model presented in this work, it will now be a question of carrying out the research through the possibility of having data relating to real contexts of this type of risk, as in Castelli et al. (2019) in which a quantitative study of the flood risk of the Arno river in the Florence area is presented. The necessary data are those relating to climatic phenomena combined with those of flood damage caused by rivers that insist on the same area. It will also be necessary to know the mitigation projects that the relevant authorities already have or plan to implement in the near future, and the risk reduction assessment they plan to obtain.

The proposed approach can be exploitable and consistently applied to several types of risk and for different types of mitigation strategy strengthening the resilience of urban infrastructures against river flooding. The proposed approach provides a solution to face against lack of financial capacity for public administration that would like to sustainable and viable manage their risks.

Further developments of the quantitative model can also be considered as a function of the quality of the data that will be available in the feasibility study of a resilient process in a real case.

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References

Bertoldi, P. (ed.): Guidebook 'How to develop a Sustainable Energy and Climate Action Plan (SECAP)'—Part 1—The SECAP Process, Step-by-Step Towards Low Carbon and Climate Resilient Cities by 2030. Publications Office of the European Union, Luxembourg (2018)

Buterin, V.: A next-generation smart contract and decentralized application platform. https://github.com/ethereum/wiki/wiki/White-Paper (2014)

Castelli, F., Galeotti, M., Rabitti, G.: Financial instruments for mitigation of flood risks: the case of Florence. Risk Anal. **39**, 462–472 (2019)

Galland, J.-P.: Critique de la notion d'infrastructure critique. (Criticism of critical infrastructure concept). Flux **81**, 6–18 (2010)

Gatteschi, V., Lamberti, F., Demartini, C., Pranteda, C., Santamaria, V.: Blockchain or not blockchain, that is the question of the insurance and other sectors. IT Prof. (2017). https://doi.org/10.1109/MITP.2017.265110355

Gatteschi, V., Lamberti, F., Demartini, C., Pranteda, C., Santamaria, V.: Blockchain and smart contracts for insurance: blockchain and smart contracts for insurance: is the technology mature enough? Future Internet **10–2**, 1–16 (2018)

Grasso, A.: Smart contracts: adoption value for enterprises and general use case. Digital Enterprise Magazine. https://www.thedigitalenterprise.com/ (2018)

Munich, R.: Economic consequences of natural catastrophes: emerging and developing economies particularly affected—insurance cover is essential. Position Paper, Munich, Germany (2013)

Pagano, A.J., Romagnoli, F., Vannucci, E.: Implementation of blockchain technology in insurance contracts against natural hazards: a methodological multi-disciplinary approach. J. Environ. Clim. Technol. (2019a). https://doi.org/10.2478/rtuect-2019-0091

Pagano, A.J., Romagnoli, F., Vannucci, E.: Flood risk: financing for resilience using insurance adaptive schemes. Agrochimica special issue. Pisa University Press, pp. 305–322 (2019b)

Quenault, B.: La résurgence/convergence du triptyque catastrophe-résilience-adaptation pour (re)penser la fabrique urbaine face aux risques climatiques. Développement durable et territoires **5**, 3 (2014)

Reguero, B.G., Beck, M.V., Schmid, D., StadtmÜller, D., Raepple, J., SchÜssele, S., Plifiegner, K.: Financing coastal resilience by combining nature-based risk reduction with insurance. Ecol. Econ. **169**, 106487 (2020). https://doi.org/10.1016/j.ecolecon.2019.106487

Sayegh, K.: Blockchain Application in Insurance and Reinsurance. Skema Business School, France (2019)

Serre, D., Heinzlef, C.: Assessing and mapping urban resilience to floods with respect to cascading effects through critical infrastructure networks. Int. J. Disaster Risk Reduct. **30**, 235–243 (2018)

Serre, D.: DS3 model testing: assessing critical infrastructure network flood resilience at the neighbourhood scale. In: Fekete, A., Fiedrich, F. (eds.) Urban Disaster Resilience and Security, pp. 207–220. Springer, Cham (2018)

Swiss, R.: Natural catastrophes and man-made disasters in 2013 (2014)

Szabo, N.: The idea of smart contracts. http://szabo.best.vwh.net/idea.html (1997)

Szabo, N.: Read related articles on Internet economics and security, pp. 1–24. https://firstmonday.org/ojs/index.php/fm/article/view/548/469 (1998)
UNISDR (The United Nations International Strategy for Disaster Reduction): Sendai framework for disaster risk reduction 2015–2030, 36 (2015)

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Quantitative and Financial Aspects of Resilience Bonds in the Context of Recursive Insurance Contracts. A Cost Benefit Analysis

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Abstract – **It is now well known that the world community must share the risks and hazards deriving from climate change and, more generally, from the environment. At the end of summer 2019, the European Bank for Reconstruction and Development (EBRD) issued the World's first dedicated climate resilience bond and this confirms the thesis according to which financial, social and economic instruments are always most necessary for the development of society and to avoid that natural hazards can, as occurred in the past, cause extremely heavy damage with negative repercussions on every single area of a community. Starting from the characteristics of resilience bonds and reinsurance, the paper seeks to highlight the potential advantages that would derive from a systematic application of recursive contractual instruments (smart contracts). The authors focused on the study of the projection of financial and quantitative data of resilience and catastrophe bonds on the basis of a determined timeline, a fixed insurance premium, mitigation works related and connected to the main contract (insurance). In particular, the study concerns the correlation of the urban implementation of risk mitigation works with the specific catastrophic flood risk. The paper implements a purely economic and social cost-benefit analysis (ACB) in the sense that includes, among others, a public approach and the goal of maximizing social welfare, according to efficiency economic criteria. In a nutshell, the authors highlight as the main result not only the possibility, but also the convenience of the joint and multidisciplinary application of the quantitative method (resilience bonds) to infrastructure resilience.**

Keywords – **Insurance; flood; public administration; quantitative method; resilience; risk mitigation; urban infrastructure**

1. INTRODUCTION

Preliminarily, using experience from the Italian context, albeit in the broader supranational scenario, it is absolutely essential and at least advisable to carry out a discussion on the methods for stipulating a legal transaction, in particular an insurance contract, with the public administration. This examination allows to verify the operating methods and necessary requirements to outline a possible contract such that, against a fixed premium, it is possible to guarantee the coverage of damages and at the same time the construction of a mitigative infrastructure.

Moreover, the paper outlines the concept of infrastructural resilience.

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In order to make urban areas more resilient, a novel risk reduction approach based on a strategic development of urban and infrastructural systems has been proposed within the last Sendai Protocol developed in 2015 based on the resilience concept. The Sendai Protocol also foresees building the capacity to learn and thus anticipate the effect of a catastrophe, which is a substantial element for increasing resilience against natural hazards [1].

For this purpose, the introduction of the term resilience has an important role, however the term itself is interpreted in many different ways depending on the field of science. This concept is "essential" to describe the functionality of the communities, infrastructures or any other type of systems under the effect of hazard. Based on the United Nations Office for Disaster Risk Reduction (UNISDR), disaster risk management resilience is used to describe "ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management". In this context resilience is also being actualized by the EU Commission to ensure appropriate planning and preparation for disaster risk management and sustainable development [2].

Secondly, the paper outlines the main characteristics of the financial instruments called resilience bonds (collateral), highlighting, in particular, the reference values inherent to the risk that affect the insurance premium, if any, and the uncertainty related and inherent in the contract itself.

In the third instance, the paper highlights the possible consequences on the calculation of the risk and, likewise, of the premium, in relation to the construction of mitigating infrastructures.

Subsequently, entering the focus of the paper, the authors highlight the possible correlations between the decrease in risk following construction of a mitigation infrastructure and the issue on the financial market of resilience bonds linked to the immovable assets de quibus.

In the fourth instance, the authors examine the supranational legislation inherent to Sustainable Energy and Climate Action Plan (SECAP), highlight the guidelines dictated by the European Union paying attention to a systematic framing of a financial system such as resilience bonds [3] in relation to the variations of adaptation and mitigation of environmental risk referred to in the same SECAP.

In particular, the authors, through a quantitative study projection with related cost benefit analysis, seek to first outline the financial effects in the issue of bonds, highlight the costs inherent to the infrastructures and perform a summary of the operation as a whole from one point from an economic and social point of view.

The motivations that led the authors to carry out such analysis are inherent, on the one hand, to the social implications in the sense that greater protection of assets and better awareness of the problem referred to natural disasters allow the community to be aware of the risk. Secondly, it was carried out in order to highlight the possible financial variations in the sense in which the implementation of mitigative works partially limits the damage to the same assets.

Third, the assets covered by recursive insurance, at the end of the mitigation implementation, are naturally subject to a greater interest on the market. Ultimately, any ex post damages, on the one hand limited as highlighted above, with a view to implementing a resilience bond, would be distributed among heterogeneous subjects, avoiding imbalances on the public economy. The cost-benefit analysis is necessary from a public law perspective in the sense in which, according to the authors, the proposed model, for the protection of the res publica, must be purely addressed to the public administration and, thus, such a careful analysis is prodromal and factual for the implementation and activation of the relevant bodies.

The choice to carry out an in-depth analysis of the possibility of implementing the method and of the practical application of the model to flood risk mitigation mainly concerns the seriousness of the damage caused by the aforementioned hazard on the territory of Italy, as can be seen from the last report called the yearbook of environmental data relating to 2017. The year 2017 was marked by fourteen paroxysmal events characterized by high quantities of rain often concentrated over the course of a day, which caused "flash floods" (sudden floods) in both urban and rural areas.

TABLE 1. HAZARD / GDP AND ALLOCATED SUMS ASSESSMENT AND ANALYSIS

Event period	**County**	**Victims and missing persons**	**Resources to restore, €**	**Total estimated damage / GDP, %**	**Funds allocated with executive provisions, €**
15–20/1/17	Molise	0	€ 99 006 314	0.005784	€ 5 400 000
15–18/1/17	Abruzzo	29 (landslide)	€ 772 000 00	0.045103	€ 42 536 321.59 (DPC funds € 63 000 000 (funds for Soil Defence Interventions -Reg. Abruzzo)
21–23/1/17	Sicilia	1	€ 30 879 578	0.001804	€ 8 000 000
22–25/1/17	Calabria	0	€ 108 758 274	0.006354	€ 22 000 000 (DPC) € 56 000 000 (Fiscal Law 2018)
26–28/4/17	Friuli Venezia Giulia	0	€ 1 600 000	0.000093	€ 800 000 (Ministry of the Environment and Protection of the Territory and the Sea) € 485 000 (Italian civil protection – Friuli Venezia Giulia)
25/6/17	Veneto	0	€ 12 312 842	0.000719	€ 6 700 000
28/6/17	Lombardia	0	€ 200 000	0.000011	
5/8/17	Veneto	1(landslide)	€ 12 312 842 (adding damages occurred on 28/6/17)	0.000719	€ 6 700 000
8/8/17	Valle d'Aosta	0	€ 7 887 156	0.00046	€3 000 000
9–10/9/17	Toscana	8	€ 56 188 554	0.003282	€ 15 570 000 (DPC funds) € 20 000 000 (Toscana)
5–7/11/17	Campania	0	€ 289 037 162.00	0.016886	
11–12/12/17	Emilia Romagna	0	€ 105 000 000	0.006134	€ 10 000 000

Table 1 reflects information extracted from the Higher Institute for Environmental Protection and Research (ISPRA) website on some of the most severe hazards which have occurred; the analytical description [4] relating to the damage and effects to the ground of the flood events that occurred in 2017, the assessment of the overall damage compared to GDP, and most of all, the funds allocated with executive provisions.

Some salient features can be deduced from this explanatory and highly significant table.

First of all, the total quantified value (€) of the damages occurred as a result of floods that occurred in Italy during the year 2017. The amount, truly significant, is greater than € 700 000 000 and the importance of the value is reflected by the fact that the total national public budget is equal to approximately € 27 000 000 000. Therefore, the value of damages exclusively for flood damage was almost 3 % compared to the entire allocated budget of the 2017 financial law.

The second focal point can be obtained from the sum of the respective values inherent in the ratio between estimated damage and GDP. The aforementioned value is equal to 0.1 % of the GDP of the entire nation and is inherent, as already highlighted above, only to the damage caused by floods which occurred in one year. This result is also extremely worrying.

But it is the third result that proves to be the most upsetting for cost benefit analysis or for any other public economy study, i.e. the relationship between the amount provided by public administrations and resources to restore any assets.

In fact, by adding the value of the amounts paid by public bodies for the ex post reconstruction of assets damaged by floods, the amount is only equal to € 260 191 322.

Therefore, the ratio between the value for the integral reconstruction of the assets and the loans is only 35.9 % and, therefore, for over 60 % of the value of the residual value of the assets, the administration was unable to carry out any reconstruction.

It is precisely from this elementary analysis that, in the authors' opinion, it no longer seems possible to think of a continuation of the classic method of contrasting against natural hazards, which is therefore capable of operating pro quota exclusively ex post.

The authors' perspectives are inherent to an implementation of urban resilience and the accounting and financial management of the risks of public administration assets

The conclusions pertain to the possible operational variations and effects of an application of the related insurance contract for mitigating constructions on the financial market, such as, for example cat bonds or preventive resilience bonds.

2. Methodology

The methodology proposed by the authors follows three guidelines:

- The first, preliminary, concerns a theoretical study of administrative and insurance regulations on the modality of stipulation of contracts between the public administration and private companies.
- The second concerns an engineering elaboration on urban resilience and, more particularly on flood risk. In particular this section involves a graphic projection of risk analysis.
- In the third instance, in the quantitative context, the authors propose the elaboration of a stylized quantitative model for a cost-benefit analysis, considering a traditional insurance scheme and a resilience approach with which the authors consider the opportunity of financing mitigative infrastructures.

3. Failure of Insurance Systems against Natural Disasters

The starting point in the drafting of the paper is represented by the analysis carried out by the authors regarding the insurance systems against natural hazards in some of the more developed countries on the basis of 2019 IVASS report [5].

As can be seen from the Table below, the system, although in some cases, more capable of withstanding catastrophic events, is always fallacious in the dual meaning of application that the paper aims to highlight and implement, that is, primarily the ex-ante prevention and not therefore, merely the ex post reconstruction, and secondly, the division of costs into heterogeneous subjects and not already exclusively to be charged to public entities.

TABLE 2. GENERAL FRAMEWORK OF FR/CH/UK/US INSURANCE SYSTEM AGAINST NATURAL HAZARDS

	France	**Switzerland**	**UK**	**USA**
Hazards	Floods, earthquakes, volcanic eruptions, tsunamis	Floods, landslides, earthquakes	Earthquakes, storms and floods	Specific policies for hurricanes, storms, other specific policies for floods and earthquakes. Flood coverage: mandatory for mortgages, with federal insurance program (public-private partnership)
Obligatory nature	System not mandatory, but insurance is compulsorily linked to a widespread, basic fire protection	System not compulsory, but for many natural risks insurance compulsorily linked to a very widespread, basic fire protection	System not mandatory. Optional insurance linked to relatively widespread basic coverages, generally provided in case of mortgages	Floods: compulsory coverage in flood risk areas and for buildings covered by mortgages. Earthquake: coverage not mandatory
System governance	Strong state regulatory role, unlimited public economic guarantee for the main reinsurer	Strong regulatory role of the local cantonal authorities. In most cantons, insurance is offered by a publicly-owned company.	No regulatory intervention by the state. No public compensation foreseen in case of natural disaster	Floods: role of the federal government in determining risk and tariffs. Fund grants subsidize policies. Earthquake: Partnership in California with the California Earthquake Authority CEA Fund which enjoys tax benefits and grant-subsidized policies
Role of insurance companies	Hedging offer, compensation management, creation of dedicated reserves in the financial statements	Insurance system offers coverage and manages compensation, in the form of a public monopoly or under free competition	Hedging offer, compensation management, and establishment of dedicated reserves in the financial statements, which might take advantage of tax breaks	Policies in collaboration with various forms of partnership, where applicable
Reinsurance	A state-guaranteed reinsurer is provided, with freedom to operate for other entities	It is provided by consortium systems that associate public and private insurers separately	Insurance companies operate freely on the market	Free reinsurance market, also issued cat bonds by the CEA fund

4. SECAP AND COVENANT OF MAYORS. NEW PERSPECTIVES

This section aims to relate the perspective of a cost benefit analysis for recursive insurance contracts against natural hazards and the legislation relating to SECAP (former SEAP) and covenant of mayors

In December 2008, the EU adopted an integrated energy and climate change strategy which sets ambitious targets for 2020. The aim is to steer Europe on the right path towards a sustainable future by developing a low carbon economy based on energy efficiency [6].

The EU has set three key deadlines, defined respectively: “2020 package”, “2030 package”, “2050 package”.

The 2020 package establishes the following objectives:

1. 20 % reduction in greenhouse gas emissions compared to 1990 levels;
2. 20 % of energy consumed in the EU is produced from renewable sources;
3. 20 % improvement in energy efficiency.

The 2030 package defines the following objectives:

1. at least 40 % reduction in greenhouse gas emissions compared to 1990 levels;
2. at least 27 % of the energy consumed in the EU produced from renewable sources;
3. 27 % improvement in efficiency energy [7].

The 2050 package sets the most ambitious goal, namely an 80 % cut in emissions compared to 1990 and a so-called "low-carbon economy" implemented in every country in the European Union.

It should also be said that each nation belonging to the European Union has set its own targets for reducing emissions, which may even be higher than those set by the EU. To achieve these goals, it is clear how each economic sector must contribute to the reduction in emissions.

This document (SECAP) must be submitted within two years of the ratification of accession to the Covenant of Mayors by the City Council (for Italy) or the equivalent decision-making body (for foreign municipalities). The SECAP is divided into six sections presented hereafter, each of which refers to a specific implementation process:

Strategy: Definition of the goal of reducing CO_2 emissions. The target can be set both in absolute terms and per capita reduction; the use of per capita reduction targets is used by cities that have a constant and / or rapid increase in population, so it is more complex and insignificant to set an absolute reduction target.

Emissions inventory: Definition of the final energy consumption of the municipality and the consequent CO_2 emissions, divided by energy carrier and sector in the reference year. It is highly recommended that this year be the same as the one for which the intervention strategy is to be defined, to avoid difficulties in interpreting the results. Other important data to include are number of inhabitants, type of measurement unit that will be chosen (whether tonne CO_2 or equivalent tonne CO_2, which integrates the emissions of other greenhouse gases), and any notes on the method. Finally, the results are listed on the final energy consumption, on the supply of the same and on the total emissions. Two approaches are provided for the total calculation of emissions: the first is the so-called standard, defined by the IPCCC (International Panel Convention for Climate Change),

Mitigation actions: Description of the actions that are intended to mitigate emissions; also with assignment of budget, attribution of responsibility, forecast of timing and reduction. It is important to also include comparison scenarios; usually the “Business as Usual” scenario is used to analyse what the emissions trend would be like if no reductive action was taken, and it is compared with a scenario in which instead contrast actions have been taken. This type of processing is graphical and also allows you to see the estimated effectiveness of the initiatives, and to understand which can be the most effective in terms of cost / benefit ratios. The impact of the actions on its own time span is estimated (2020 or 2030). For each action planned for implementation, it is useful to give an estimate of its economic cost and effectiveness. Within this section it is also possible to insert the examples of excellence; i.e. emission reduction actions that have been particularly successful; these initiatives must be already concluded or in progress [8].

Scoreboard: To understand the sectors where the actions and the adaptation cycle prepared in the action plan have been successful. In other words, the scoreboard Framework serves to provide a snapshot of the progress of the adaptation process in which the local administration is placed, according to an evaluation of this type. It is a self-assessment; each administration will then give a vote based on what it considers complete at each phase of the process.

Risk and vulnerability: This section is dedicated to the assessment of climate risk in the area, with impact and related assessments. In this case, it is necessary to specify the year in which this assessment was made; in addition, it is necessary to specify the territorial area on which the risk and the method used are assessed. Indications are also given on particularly significant climatic hazards. In addition to the risk and climate vulnerability assessments, the potential effects that these criticalities can bring in the various sectors are indicated (for example: drop in tourism, risk of water shortages, etc.). This section is present only in the new SECAP.

Actions for adaptation: Illustrates the actions taken to adapt to climate change in various sectors, with an indication of investors (stakeholders) and costs. The various actions are described on the basis of sectors of intervention (e.g. in the construction sector, an adaptation action is the ban on building in places particularly at risk to flooding / landslides). This section is also present only in the new SECAPs [9].

Established to involve cities in the pursuit of the objectives of the European Union, the Covenant of Mayors is characterized by a multi-level governance model and is based on the shared vision according to which local administrations, together with private partners, can accelerate ambitious energy strategies that lead to a future with low greenhouse gas emissions. The initiative encourages its signatories to draw up action plans and to direct their investments towards mitigation and adaptation measures to climate change. Joining this initiative represents an opportunity for local authorities to consolidate their efforts to reduce greenhouse gas emissions in the area, benefit from European support and recognition, and exchange experiences with European counterparts. In addition, the Covenant of Mayors can be seen not only as an initiative related to the energy sector, but also as a way to develop sustainable measures that allow their cities to achieve better urban planning and socio-economic development [10]. Even if initially it was designed for large urban centres, the Covenant of Mayors did not place requirements on the size of the signatories: everyone can participate, from small municipalities to major metropolitan areas. Today the Covenant of Mayors, which became global in 2017, has over 7500 local and regional authorities active in 121 countries, which can take advantage of the strength of a multi-stakeholder movement worldwide and the technical and methodological support offered by various dedicated offices

Therefore, in the regulatory context of local public administrations, in anticipation of adherence to the Covenant of Mayors, the paper seeks to show and to highlight possible operational variations on risk mitigation, in particular against floods, for the negotiation and development of insurance contracts [11].

5. Concept of Infrastructural Resilience

Due to the complexity and interdependency of infrastructure in urban areas, there is a higher risk to have cascading effects and also generate secondary effects in areas much further from the real flooded area [9], [10]. This is a key aspect to consider in order to minimize the secondary problems, such as financial and operative ones that are directly affecting the networks may have [10]. In order to make urban areas more resilient, a novel risk reduction approach based on a strategic development of urban and infrastructural systems has been proposed based on the resilience concept within the last Sendai Protocol developed in 2015 [10]. The Sendai Protocol also foresees building capacity to learn and thus anticipate the effect of a catastrophe, which is a substantial element for increasing resilience against natural hazards [14].

For this purpose, the introduction of the term resilience has an important role, however the term itself is interpreted in many different ways depending on the field of science. This concept is "essential" to describe the functionality of the communities, infrastructures or any other type of systems under the effect of hazards [15]. Based on the United Nations Office for Disaster Risk Reduction (UNISDR), disaster risk management resilience is used to describe "ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management" [2]. In this context, resilience is also being actualised by the EU Commission to ensure appropriate planning and preparation for disaster risk management and sustainable development.

Some studies suggest that infrastructure resilience has a direct connection with the term resilience proposed by Holling and used in ecology [15]. This definition is generalized as the capacity of a system to absorb disturbances and to recover after a major disruption and to restart an activity on the territory [11].

Based on this, different methods have been proposed to assess resilience and the role of the infrastructural resilience within it. For instance, in the scientific work of Serre *et al.* [11] urban/engineering networks able to propagate flood risk are proposed overall urban resilience, understood and identified into 3 main capacities namely: resistance capacity, absorption capacity and recovery capacity. A similar approach for looking at resilience was proposed by Bruneau *et al.* [16] with the introduction of the "4Rs" (i.e. Robustness, Redundancy; Resourcefulness; and Rapidity), according to which resilience of specific systems is described by qualities of the system matching these 4Rs.

Such conceptual and (semi) quantitative model approaches based on the selection of a set of proper indicators can serve as the base for the development of a framework for assessing the effectiveness of specific mitigation and/or adaptation strategies.

6. Insurance against Natural Disasters. The Reason behind its Limited Spread in Italy

In this context, Italy stands out on the international scene for the management of damage from natural disasters entrusted almost exclusively to state intervention during the ex post reconstruction phase. This factor, together with the "cultural" reluctance of individuals to acquire protection against natural disasters, explains the scarce diffusion of insurance coverage for these events, which can be acquired as a supplement to fire insurance policies on homes. The reduced propensity of Italian families, compared to other European countries, to purchase non-compulsory, non-life coverage also contributes negatively [17].

The spread of insurance against natural disasters is higher for industrial and commercial buildings, but its level is still unsatisfactory. For example, the 2012 Emilia earthquake caused a lot of damage to the dense industrial fabric of companies in the area affected by the event. However, even on that occasion the contribution of insurance compensation to the costs for the reconstruction was modest (around 10 % of the total costs, OECD 2017). While in the case in Italy the ratio between total damages and damages compensated by insurance was 10 to 1, during the 2005 hurricane Katrina, which happened in the United States, a country with a high degree of insurance coverage against natural disasters, the ratio was approximately equal to 3.5 [18].

In order to have an updated picture of the diffusion of the insurance instrument to protect itself against damage from natural disasters by homeowners, in the first months of 2017 the Italian Insurance Supervision Institute conducted a census survey [17], [18] with all the companies that on 30 September, 2016 would work on fire insurance field against fire the housing units located in Italy. The companies have reported the main characteristics of the individual contracts, including the possible extension of coverage to damage caused by earthquakes and floods. Fire coverage protects 12.2 million homes (35.4 % of the total similar properties in Italy). The percentage is extremely small compared to other EU countries.

As for Italy, as has already been analysed, there is no compulsory insurance on natural disasters and the implementation and level of policies covering damage from natural disasters are poor.

The current situation of the Italian insurance market for coverage against natural disasters sees the assets of private citizens not fully covered against disaster risks; only a limited part of medium-small companies is insured with specific policies covering earthquakes and floods; on the other hand, a significant part of medium-large companies is adequately insured against natural disasters, especially multinational companies.

According to Kunreuther [21], the scarce penetration of policies among private citizens is the result of a real disaster syndrome due to both distortions on the demand side and insufficient supply. In the following, we will analyse how the scarce diffusion of policies on a voluntary basis covering natural disasters is attributable to different types of causes: regulatory problems are added to the causes on the demand side and to the causes on the regulatory side.

In particular, with regard to the regulation referred to in public-private bargaining, the legislator never intervened precisely in outlining guidelines on these modalities.

In fact, as highlighted below, the stipulation of any insurance contract by a local authority must go through a rigorous discipline of public tender, as used in the broader context of public and administrative law [22].

Although the legislator has never provided for a specific discipline for the above type of insurance, this does not mean that this contractual scheme is prohibited by any law. Using a theoretical scheme and verifying what is referred to in the Italian and EU binding regulations, the authors have tried to outline the current operating methods to achieve a contracting and stipulation meeting point between public and private.

The point of interconnection between local authorities and insurance companies, in light of the results of the paper, can only be the covenant of mayors which, we would say, finally, grants greater autonomy to some bodies governed by public law.

7. Flood Risk and Resilience

As mentioned urban population increase and the consequential rise of the increase complexity of the CI represent factors that amplify the level of local vulnerability [16], [17]. In fact, there is a direct connection of the natural hazard losses to the number of people and complex infrastructure living in areas prone to hazards.

Thus, the assessment of the Risk losses is not a trivial task since both the engineering dimension as well as the social impact should be evaluated. Generally, the Risk to natural disaster including flood is defined within the probability perspective in terms of occurrence time of a certain hazards, factored by the severity of its consequences [25], according to the following formula:

$$\text{Risk} = \text{Probability} \cdot \text{Consequence} \tag{1}$$

Thus, Risk represents a key instrument and criteria leading to flood zone management policy, land and infrastructural development planning [26]. It is thus evident the important role of the engineering dimension to assess the potential cost/benefit in terms of decreased flood risk level once a specific (or other engineering system) is strengthened and/or newly built.

Risk formula presents also other expended description on where the probabilistic dimension of the Hazard is then related to the Exposure and Vulnerability. Both aspects are related to the intrinsic propensity of a certain asset to be at Risk. Thus, the engineering aspect to understand the effects of a hazard of a certain magnitude is essential. This general formula is reported below:

$$\text{Risk} = \text{Hazard} \cdot \text{Exposure} \cdot \text{Vulnerability} \tag{2}$$

Within the proposed Risk assessment there the need to use GIS-based system on which hazard (e.g. flood), vulnerability and assets maps are combined through the use a weighing process and normalization.

This task has to be replicated for each climate-related impact [27].

In this way the flood risk assessment is translated in terms of potential loss and damages costs. This is most of time impossible to be done for each infrastructure and/or asset at risk due to data scarcity. In these way insurance companies' databases are often using proxies to overcome this bottleneck.

As reported by Kaspersen and Halsnes [28] Danish Insurance Company define a damage function and unit damage costs based on flood levels for different buildings during extreme precipitation. In this case health costs (based on number of people exposed to mixed rain-sewage water) and expected costs for different rain patterns considering extremes climate event are calculated in monetary values as losses for each asset and damage costs.

Since quantitative and probabilistic approaches are not always possible to be used and converted into a monetary dimension (mostly in connection to the social dimension, the effectiveness of Risk Reduction scenarios through a Multicriteria Assessment (MCA) towards urban adaptation planning [29].

Normally with adaptation strategies are beneficial for the overall resilience of certain system and thus its risk reduction. According to [25] for physical systems can be identified in 2 types of measures namely hard and soft. The first referred to (semi)permanent installation within the area of the potential flood, the second ones are those relate to natural process for example like are tackling flood in terms of erosion decrease and or increase of roughness in the flooded areas [2], [11].

Despite the guidelines provide by Sendai Framework for strengthening resilience to disaster, several risk flood assessments have not fully implemented a resilience approach. Sometimes, only reduction measures to flood hazard are proposed as possible solution while in other only the perspective of the vulnerability is considered. Nevertheless, in both cases a range of solutions for maximum flood magnitude is offered. The main criticality is lying on not considering the time dependent concept of the resilience aspects such as the time of recovery.

Traditional flood risk analyses are mainly focused on hazard reduction and its impact as damages reduction in fact directly introducing structural and infrastructural measures. This approach is not addressing the attention to pre-flood hazard condition and recovery phase to return to the ex-ante situation.

There is a lack on real quantitative methods able to shave more tailored strategies to have more resilient infrastructure to flood resilience, and one of the main reasons is the because several disciplines and expertise should be involved (i.e. flood, resilience, and CI network interdependencies.

By using a resilience approach time dependency, such as recovery can be taken into account as and thus considering other characteristic component of the resilience such as robustness, redundancy and flexibility (see Fig. 1). While traditional approaches consider as the only utility function to be maximized the damage.

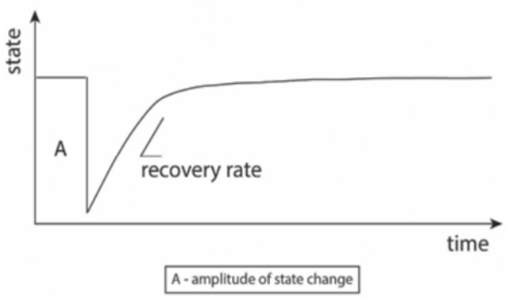

Fig. 1. System response to a shock [1].

The concept of resilience is also embedding the concept of state equilibrium and its threshold of stability, once that threshold is passed the recovery is not feasible. Fig. 2 highlights these aspects at different level of magnitude of a certain hazard and involving several components of the resilience.

For example, systems may need to be able to cope rigidly (resistance) to the most frequent hazards that they are exposed to or the hazard which causes the greatest damages and disruption (resilience).

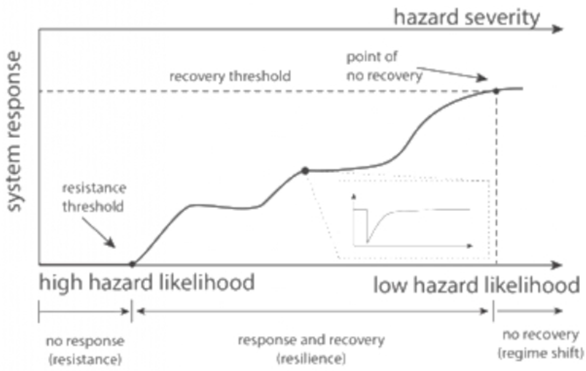

Fig. 2. System response as a function of disturbance magnitude [1].

Flood impacts are often quantified in terms expected annual damage (EAD) depending on evaluation of the exceedance probably related to certain hazard likelihood (Fig. 3).

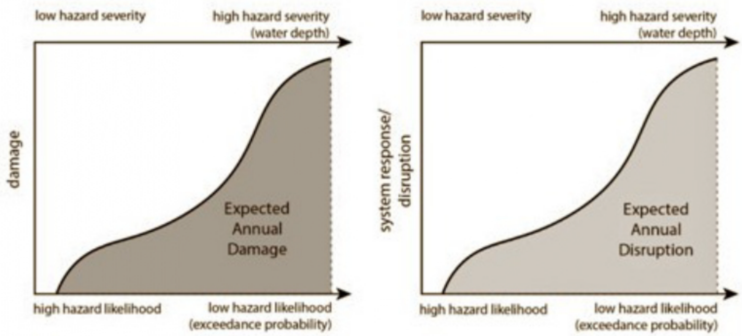

Fig. 3. Expected annual damage and expected annual disruption.

Moreover, the assessment of optimal and tailored strategies is related to the difficulty of the data availability.

Fig. 4 shows the effects on the application of CI resilient strategy applicable also to flood.

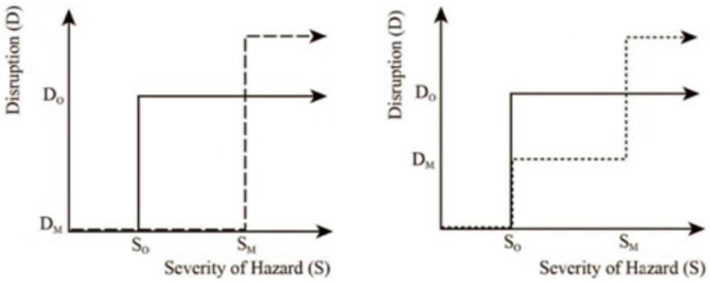

Fig. 4. Visualisation of the effect of resilience.

Data gathering is a key aspect on risk reduction of CI through a resilient strategy that should involve:

- Data collection from the gathering for CI networks;
- Flood hazard maps;
- Assessment of the exposure and vulnerability of CI to floods;
- Assessment of the cascading effects;
- Assess the recovery time.

It is essential to have create and inventory about the damages past events.

There are also other dimensions to be considered in the system response in terms of economic and social aspects in turn involving other vulnerability indicators.

In this context prevention measure like discouraging citizens from living in high-risk areas, or encouraging the uptake of mitigation measures has a great potential within the recovery strategy.

However, this aspect is still lacking on a real application due to lacks on existing legal frameworks to support these measures.

From the proposed approach on quantifying the reduction of Risk due to specific resilience measures it is possible to see how there is a need for the creation of an interdisciplinary and holistic approach.

8. The Actuarial Quantitative Cost-Benefit Analysis for Flood Risk. Insurance or Resilience Bonds

In this part of the paper, we introduce a stylized quantitative model for a cost-benefit analysis, considering a traditional insurance scheme and a resilience approach with which we may consider the opportunity of financing mitigative infrastructures [30].

The analysis has to be performed taking account of both the two viewpoints: one concerning the profit or loss account and the other the balance sheet, to which the mitigative infrastructures must be thought of as an additional value of the asset side.

Let consider that the flood risk could be expressed by the distribution of the claim amount in a fixed time unit, and that this risk must be faced throughout a fixed time horizon, at most even perpetual.

Let X be such r.v. with known density function and moments. Let consider a risk assessment based only on the first two moments of such r.v. E[X] = m_1 and sigma[X] = m_2, such that insurance premium P is a function of these two parameters f(m_1, m_2) = P.

We can consider a finite time horizon T (time units) or at least an infinite time horizon.

Assuming a fixed discount rate r and the relative discount factor $v = 1/r$, the actual total cost for flood risk insurance $C(T)$, is

$$C(T) = P(1+v^T)/r, \tag{3}$$

in case of time horizon T and

$$C(\infty) = P/r, \tag{4}$$

in case of infinite time horizon, that is a perpetual payment P.

Let consider a mitigative infrastructure with cost K and a building time duration S. Let assume $S < T$. Let consider that after this infrastructure is built, the exposure to flood risk is reduced, i.e. we have a new claim r.v. Y with the first two moments $E[Y] = n_1$ and sigma[Y] = n_2, such that insurance premium is a function of these two parameters f(n_1, n_2) = P_1 for which it is $P_1 < P$.

A resilience bond is composed by two parts, one relative to the insurance aspect and the other relative to infrastructure financing.

We can assume that for the insurance side the issuer has to pay a coupon equal to P and for the financing side an additional coupon of $Q = g(K)$, till time S, which can be the bond-maturity.

So the actual total cost in case of a resilience bond approach, $D()$, is

$$D(T) = (P+Q)(1+v^S)/r+v^S(1+v^{(T-S)})P_1 / r, \tag{5}$$

in case of time horizon T.

$$D(\infty) = (P+Q)(1+v^S)/r + v^S(P_{19} / r), \tag{6}$$

in case of infinite time horizon, that is a perpetual payment P_1 after time S.

Therefore we can compare the total cost for the two approaches, $C()$ and $D()$, both for a finite and for an infinite time horizon. It is even an easy task performing a sensitivity analysis on the model parameters: X, Y, r, K, … .

Some of them could be better and better be estimated using new data that arrives continuously.

So we can have full awareness of the cost-benefit analysis of using a classic insurance scheme or a more resilient approach financing the costs of the first time interval, till the mitigative infrastructure is ended, in our scheme time S, issuing a resilience bond with this maturity and with a coupon rate depending on the original risk measured by the premium P and the additional part linked to the infrastructure cost K, which would serve both for risk coverage and for infrastructure financing.

9. Conclusions

Given the mostly quantitative/mathematical declination, the first conclusion concerns, among other things, the usefulness of recalling the need for an assessment of investments for mitigation, also in terms of lower risk coverage costs in the future, for public administrations.

Secondly, it appears necessary to reiterate the absolute need for a desirably European, but at least national, platform to make the transfer of the risk outlined above to the financial markets fully operational.

Ultimately, in full compliance with what has been pre-written by the supranational treaties as well as by the Covenant of Mayors itself, it is fundamental to underline that the elements of the legislation that can govern all the steps of this process, should and could be agreed in a European way and not be the result of stunted harmonization of national regulations.

The proposed cost-benefit analysis highlights the possible implementation of the quantitative infrastructure resilience model and is subject to the need, extremely current in light of national regulations, to carry out a mathematical study prior to a political, business and financial choice such as that of a mitigative structure, and the related contractual insurance structure.

The final key point is to assess if the higher cost of a resilience bond, with the financing of mitigative infrastructures, could be convenient respect to a traditional insurance approach, i.e. only facing claims payments, for different time spans.

References

[1] UN General Assembly. Resolution 69/283 of 23 June 2015. Sendai framework for disaster risk reduction 2015–2030. United Nations, 2015.

[2] Uniddr. World Conference on Disaster Reduction. Building the Resilience of Nations and Communities to Disasters. Geneva: UNDDR, 2005.

[3] Trærup S. L. M. Informal networks and resilience to climate change impacts: A collective approach to index insurance. *Glob. Environ. Chang.* 2012:22(1):255–267. https://doi.org/10.1016/j.gloenvcha.2011.09.017

[4] Eventi Alluvionali. Report 1. 2019:D. (in Italian) https://annuario.isprambiente.it/sys_ind/79

[5] IVASS. Report Analisi Trend Offerta (Offer Trend Analysis Report). Rome: IVASS, 2019. (in Italian)

[6] Alberti M. Politiche e strumenti di sostegno allo sviluppo delle fonti di energia rinnovabili. Casi di studio in paesi dell' Unione Europea (Policies and tools to support the development of renewable energy sources. Case studies in European Union countries.). 2010:95. (in Italian)

[7] De Botselier B. How the EU covenant of mayors and climate-adapt strengthen local climate policy-making. A Case Study of the City of Bruges. IED, 2019.

[8] Berghi S. Energy use in Urban Transport sector within the Sustainable Energy Action Plans (SEAPs) of three Italian Big Cities. *Energy Procedia* 2017:126:414–420. https://doi.org/10.1016/j.egypro.2017.08.193

[9] Blazquez J., *et al*. Economic policy instruments and market uncertainty: Exploring the impact on renewables adoption. *Renewable and Sustainable Energy Reviews* 2018:94:224–233. https://doi.org/10.1016/j.rser.2018.05.050

[10] Melica G., *et al*. Multilevel governance of sustainable energy policies: The role of regions and provinces to support the participation of small local authorities in the Covenant of Mayors. *Sustainable Cities Society* 2018:39:729–739. https://doi.org/10.1016/j.scs.2018.01.013

[11] Cinocca A., Santini F., Cipollone R. Monitoring methodologies and tools for the Sustainable Energy Action Plans to support the Public Administration. *Energy Procedia* 2018:148:758–765. https://doi.org/10.1016/j.egypro.2018.08.135

[12] Pescaroli G., Kelman I. How critical infrastructure orients international relief in cascading disasters. *Journal of Contingencies Crisis Management* 2017:25(2):56–67. https://doi.org/10.1111/1468-5973.12118

[13] Lhommes S., *et al*. Analyzing resilience of urban networks: a preliminary step towards more flood resilient cities. *Natural Hazards and Earth System Sciences* 2013:13:221–230. https://doi.org/10.5194/nhess-13-221-2013

[14] Serre D., Heinzlef C. Assessing and mapping urban resilience to floods with respect to cascading effects through critical infrastructure networks. *International Journal of Disaster Risk Reduction* 2018:30(B):235–2423. https://doi.org/10.1016/j.ijdrr.2018.02.018

[15] Holling C. S. Resilience and stability of ecological systems. *Annual Reviews of Resource Economics* 1973:4:1–23. https://doi.org/10.1146/annurev.es.04.110173.000245

[16] Bruneau D. A framework to quantitatively assess and enhance the seismic resilience of communities. *Earthquake Spectra* 2003:19(4):733–752. https://doi.org/10.1193/1.1623497

[17] Swiss Re-Sigma. Natural catastrophes and man-made disasters in 2013: large losses from floods and hail; Haiyan hits the Philippines. Zurich: Swiss Re, 2014.

[18] Kunreuther H. C., Michel-Kerjan E. O. The Development of New Catastrophe Risk Markets. *Annual Review of Resource Economics* 2009:1(1):119–137. https://doi.org/10.1146/annurev.resource.050708.144302
[19] Statistico B. Bollettino Statistico 2012. Rome: Bank of Italy, 2012. (in Italian)
[20] Relazione sull'attività svolta dall'Istituto nell'anno 2017 (Report on the activity carried out by the Institute in 2017.). Rome: IVASS, 2018.
[21] Kunreuther H. Mitigation and Financial Risk Management for Natural Hazards. The Wharton School University of Pennsylvania Philadelphia, 2001.
[22] Asaro M., *et al*. 07 / 11 / 2017 - Le assicurazioni a copertura dei rischi degli enti pubblici e dei dipendenti pubblici tratto (07/11/2017 - Insurance covering the risks of public bodies and public employees tract.). Brescia: National Professional Association of Municipal and Provincial Secretaries, 2020. (In Italian).
[23] Roberts R. S. Economic Strategies for Coastal Disaster Risk-Reduction: A Case Study of Exmouth. Western Australia: Murdoch University, 2012.
[24] Botzen W. J. W., Van Den Bergh J. C. J. M. Insurance against climate change and flooding in the Netherlands: present, future, and comparison with other countries. *Risk Analysis* 2008:28(2):413–426. https://doi.org/10.1111/j.1539-6924.2008.01035.x
[25] Rumson A., *et al*. Coastal risk adaptation: the potential role of accessible geospatial Big Data. *Marine Policy* 2017:83:100–110. https://doi.org/10.1016/j.marpol.2017.05.032
[26] Filatova T. Veen A. Microeconomic Motives of Land Use Change in Coastal Zone Area: Agent Based Modelling Approach. Twente: University of Twente, 2006.
[27] Bertoldi P., *et al*. Guidebook "How to develop a Sustainable Energy and Climate Action Plan (SECAP)": PART 2 – Baseline Emission Inventory (BEI) and Risk and Vulnerability Assessment (RVA). Luxembourg: European Union, 2018.
[28] Kaspersen P. S., Halsnæs K. Integrated climate change risk assessment: a practical application for urban flooding during extreme precipitation. *Climate Services* 2017:6:55–64. https://doi.org/10.1016/j.cliser.2017.06.012
[29] EEA. Urban adaptation to climate change in Europe 2016. Transforming cities in a changing climate. No 12/2016. Luxembourg: Publications Office of the European Union, 2016.
[30] Bellieri dei Belliera A., *et al*. Flood risk insurance : the Blockchain approach to a Bayesian adaptive design of the contract. 2019.

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Insurance against Natural Hazards: Critical Elements on the Risk Premium Evaluation in the Italian Context

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Abstract **– The aim of this paper is to highlight the insurance dynamics in relation to catastrophic events and how the insurance companies approach the insured parties (contractors) for the definition of a tailored insurance policy contract. Within this study the emphasis has been addressed more on the regulatory situation in the Italian context as a key example of the existing contractual problems regarding the drafting of insurance contracts against natural hazards. In particular, the study defines the drawbacks of having information asymmetry between the parties towards several substantial elements of the policy agreement, including the definition of the overall risk, exposure, vulnerability and the consequential insurance premium. This study provides an overview of the possible calculation as a specific one based on the risk / premium assessment tool of the Exceedance Probability curve (EP curve) method used by insurance companies. This method focuses on some of the most important insurance parameters for determining the insurance premium and the possible indemnity in relation to the risk related to natural hazards. In the results and discussion, the research reports on how an information discrepancy on contractual transparency appears evident in fact creating an obstacle to facilitate the access to the data referred to in the risk calculation inherent in the asset and obviating the information discrepancy, allowing the private individual to use the information consciously. With the presentation of a risk calculation tool based on the EP curve and relative loss or exceedance, the study shows a possible correlation between insurance dynamics and the new environmental, social, governance (ESG) parameters for implementation on the financial markets.**

Keywords **– Insurance company; natural hazard; risk and resilience**

1. INTRODUCTION

In recent years, the insurance industry has undergone considerable losses due to extreme weather events. The year 2011 is considered a record year for natural disasters, with insured claims that have cost the industry more than 127 billion dollars. Moreover, according to one of the latest reports on Europe drafted in 2013, it has shown that EU has experienced a global amount of € $33 billion of losses, for which about 50 % have been paid by insurance companies [1].

A series of catastrophes in the late eighties and early nineties of the last century has placed a great challenge on the insurance industry.

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With an emphasis on the Italian context, the Italian Statistical Bureau Centre (ISTAT) revealed that in 2015, 19.61 % of the Italian population was exposed to flood risk (with peaks of 53.16 % in the North-East), 4.10 % to landslides, while in 2016 about 8.92 % of the territorial area of the Italian peninsula has been classified as a high seismic area. In front of such evidence it would be essential to better evaluate how the community could strengthening its capability to withstand against hazards triggering potential natural disaster [2]. In this light insurance represents an effective mechanism to move towards more tailored and customized risk reduction strategies.

If the dynamics, in terms of prevention within a territory, are addressed more towards government and administrative management, the role of insurance, in terms of limiting damage and mitigating the consequences of "weak contractors", is certainly paramount.

This study highlights the unfavourable position, [3] from a contract-definition perspective speaking, of the insured subject against the insurance company in order to denounce the disparity in the knowledge of the two parties involved in the contractual dynamics and to propose a constructive approach towards the total sharing of the data that insurance companies benefit from in preparing the very first draft of the contract *de quo*.

The approach, as outlined above, concerns the awareness, among others, of the weak party issue when entering into contracts and the lack of transparency in drafting the insurance contract. The proposition is inherent in the possible implementation of a general information model.

In particular, the insured person does not know the process that leads the insurance company to draft and draw up the contract. [4] With regard to the third methodological point of the methodology of the paper, i.e. the EP curve, the insured subject is not aware of the inherent and innate variables, such as the probabilities connected to the occurrence of an event, the maximum tolerable loss threshold of the insurance company or even the algorithmic dynamics referred to in the definition of the consideration to be charged to the insured party.

The study was motivated by the increasingly pressing need, as well as by the obligation, to date not yet respected, to provide the "weak" contractor with a complete picture of the legal and financial aspects that involve the contract itself. The aim concerns of contributing to highlight the responsibilities and duties attributable to the insurance company, as well as, consequently, the rights, continuously injured and limited, of the insured subject. In particular, the whole paper is in the light of according to a civil perspective to sensitize the mass media and the subjects involved to build the basis of a new systematic approach to defining and drafting insurance contracts against natural hazards.

The pressing need described in the above paragraph is highlighted as evidenced by the compulsive and continued production by European public bodies of directives and provisions in the insurance field on transparency and contracts, such as the Directive (EU) 2016/97 (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016L0097&from=EN) the so-called Insurance Distribution Directive or "IDD" that regulates the way insurance products are designed and sold both by insurance intermediaries and directly by insurance undertakings.

2. Research Methodology

The research approach within this paper is based on both a consistent analysis focused on relevant outcome from research and on grey literature.

Specifically for this paper, the methodology is addressed in four areas of study. The first one, concerns the analysis of data referred to natural disasters focused on the Italian context.

This analysis consists of research on specialized websites in data processing, in particular, with regard to the Italian theme, the authors are focused on the latest ISTAT (Italian Statistical Bureau) data [5].

The second part relates to the dissemination of insurance dynamics in Italy in general and, in particular in regard to natural hazards. The focus is oriented on the normative study and the explanation of the general methods of calculation of risk and premium and focused on the systematic study of insurance dynamics from the point of view of the company in the elaboration of the contract.

The third methodological step was addressed in the study of insurance dynamics in the elaboration of the drafting of the EP curve. The connection between the first two methodological areas and the drafting of the curve EP concerns the case in which the aforementioned curve allows the insurance company to calculate the risk, or rather, as explained more extensively below, the percentage of times in which a loss exceedance occurs. This aspect, in addition to highlighting the usefulness of this tool, also shows the information discrepancy and, above all, the advantages that the weak party could have in cases where the data referred to in the curve were available and clear.

The fourth area of study concerns the possibility, merely experimental and hypothetical, of the possible application of Environmental, Social, and Governance ESG parameters in the reduction of catastrophe risk. The last methodological aspect concerns the study of some of the most important parameters introduced in recent years in the insurance and financial sector, in particular the analysis focuses on ESG criteria, which are mainly used to screen potential investments. Environmental criteria consider how a company performs as a natural factor. Social criteria examine how it manages relationships with employees, suppliers, customers, and the communities where it operates. Governance deals with a company's leadership, executive pay, audits, internal controls, and shareholder rights. The analysis that has been carried out consists in establishing a parallel between the standard operations underlying the ESG criteria and the insurance dynamics, showing points of contact and new opportunities for private and public investors.

3. General Framework on Contractual Insurance Regulations in the Italian Context

In insurance matters, except for the Italian Insurance Supervisory Institute (IVASS) decisions and EU Directives, the information obligation on the truthfulness of the data inherent to the risk and insuring asset is generally recognized exclusively as a burden of the insured party. The insurance contract originates from the truthful information that the insured party is charged to communicate to the insurance company [6].

The insured party, during the transaction referred to as the negotiation for contractual completion, must comply with some duties, including the general one in order of the context of conducting the negotiation in good faith. With reference to that, during the pre-contractual phase pursuant to article 1337 of the civil code of Italy and by additional charges specifically determined for the stipulation of the insurance contract, both parties must respect the civil law determinations

In particular, the insured party must report clearly and without reticence to the insurance company all circumstances that may affect the probability of occurrence of a risk and its possible consequences, drafting, indeed, a description of the risk *tout court*. Articles 1892 and 1893 of the civil code of Italy (c.c.) describe in a clear and precise way the statements that must be complied to by the insured, delimiting the consequences for a possible breach of contract (non-fulfilment) [6]. These regulations provide that the insured is obliged to report to the insurer any relevant situation on the risk: if the subject is not intentionally culpably or intentionally grossly negligent the contract is voidable, while in presence of slight negligence the contract is valid and effective, but the insurer is granted a unilateral right of withdrawal. The insurer has a short period of forfeiture, to withdraw from the contract, if it occurs the awareness of the false declarations of the insured, before the loss should occur, or by the exemption from the obligation to pay, if the claim occurs before the false declaration is discovered.

These provisions on the subject of pre-contractual information have a ratio both of a "public" and "private" nature. The main question of the problem from the "*res publica* (public)" point of view is to give insurance companies the opportunity for an appropriate and early assessment of the risks they take.

Shortly, the insurance market that works correctly is the one in which any risks are divided and allocated among several parties. [7]

According to the Italian Supreme Court (Corte di Cassazione 13.3.2007, n. 5849), the knowledge of the risk is fundamental for the insurer in order to evaluate the insurable assets from the point of view of the insurance assessment, in order to provide the exact determination of the premium within the framework of the so-called "neutralization of risks" and allocate it in a category of homogeneous risks.

From the "private" side in the insurance contract there is the concrete possibility of an information asymmetry, in fact from some points of view the insured is the weak party of the negotiation, while for others the insurer can be considered the weak subject of the negotiation. From the contractor's point of view, being a subject that does not exercise the insurance business professionally might be considered as a disadvantage in terms of negotiations. Furthermore, it must be added that the contract is completely prepared by the insurer and therefore the margins for setting up a negotiation often do not take place for the contractor.

The insurance code can aid the contractor in terms of art. 166, paragraph 1, which declares that the contract must be drawn up in a clear and comprehensive manner, and further, in the second paragraph of the same article, it states that the clauses that indicate forfeitures, nullity or limitation of the guarantees and charges to be borne by the insured person, must be reported using characters and terms with particular evidence [8].

From the point of view of the insurer, despite the fact that the company itself prepares the contract, it is required to provide all the information regarding the risk. However, theoretically, such intel is in the hands of the contractor who may not make incorrect declarations in order to pay a lower premium.

In the insurance contract, the pre-contractual declarations represent a more important part than the other contracts, even if this contract is always subject to the general discipline of art. 1337 c.c.

In light of this, the insurance contract is defined as an *uberrimae bonae fidei* contract, i.e. a contract that requires the maximum sincerity, transparency and trust between the parties. There are several theories about the nature of the duty of the insured to describe and declare the entity of the risks inherent to the asset.

The prevailing thesis, confirmed also by the Supreme Court of Italy, declared that the description of the risk constitutes for assuring a real obligation arising from the law, as this obligation is of a precontractual nature as the declarations regarding the risk must be made during the negotiation for the stipulation of the insurance contract. As mentioned above, this orientation, was confirmed by the Supreme Court, which in several decisions argued that this is a pre-contractual obligation.

The uncertainty and the randomness about the actual occurrence of the event must be verified and measured, both by the insurer and by the insured so that it would be convenient.

From the insured person's point of view, it is fundamental to understand whether to pay the gross premium immediately and to acquire the right to any compensation for damages.

From the insurer's point view, it is equally fundamental to evaluate whether to immediately receive a fee, the net premium, and to pay, in the future, compensation for the damage connected with the occurrence of the event.

The first focal point that the author wanted to highlight in this paragraph is precisely represented by the clear information asymmetry that takes place whenever an insured person, in the first place, does not have full knowledge of the totality of the hidden and manifest risks with regard to the asset, secondly, when the insurance company presents a contractual, unilaterally drafted facsimile, in which the calculation of the risk and the premium are not known by-the weak party [9].

4. General Framework on Contractual Insurance Regulations against Natural Hazards in the Italian Context

The second part of the paper focuses on the application of the legislation and the information asymmetry when the asset and the insurance relate to natural hazard or, more generally, to risks related to natural hazard that can trigger catastrophic effects.

The risk related to the asset belongs to the insured person, who must fulfil the obligation of information by means of the aforementioned declarations, net of actual and presumed knowledge of an extremely complex risk like that of natural hazards.

For the purposes of the regulations referred to in art. 1892 of the Italian Civil Code, in order to define the risk, it is exclusively the insured party's reticence that has value and is sanctioned. In fact, if a harmful event occurs, even if these circumstances did not directly affect the occurrence of the risk, the application of the regulation in question shall stand and be binding, as there is a connection between the inaccurate declaration and the consensus of the company [10].

As regards the assessment and evaluation of the relevance of the inexact declaration or of the reticence, this assessment must be objective, therefore generally acceptable criteria must be used for the evaluation. Therefore, to carry out the assessment, only those inaccuracies that affect the representation of the risk must be taken into consideration. Therefore, the legislation does not take into consideration the actual causal link between the incorrect declaration and the harmful event, but rather the mere incorrect representation of the risk connected and correlated to the asset [11].

As for catastrophic events, from the point of view of the company the element of impossibility exists of gathering reliable information from the weak party and a similar possibility that the asset to be insured can be exposed in various degrees to one or more natural hazards, whereby insurance companies have difficulty to ascertain the demand for coverage and to have success in providing this coverage, due to the excessive cost of the premiums [12].

One of the first legislative measures put in place by the Italian legislator was introduced at the beginning of the 2000s and focused on the aspect of insurance coverage in the agricultural sector. The Legislative Decree 102/2004 wanted to incentivize the stipulation of insurance coverage in the agricultural sector, through the provision of state contributions. In addition to the use of state contributions, the Ministry of Agricultural, Food and Forestry Policies in Italy has approved the agricultural insurance plan.

The plan, renewed and proposed every year, aims to extend and make insurance coverage more accessible, to protect against atmospheric damage and weather.

Every year this plan establishes minimum standards for the stipulation of policies to cover the risks for breeding and agriculture. It also makes state grants available to make insurance premiums accessible.

A few years after this measure strictly directed towards agricultural policies was introduced, the legislator has ruled on the introduction of a policy measure in order to develop a more general regulation of insurance on immovable assets exposed to natural hazards. The legislative decree 59/2012 (converted with Law 12 July 2012, n. 100) allows the use of insurance policies against any type of damage to buildings against the risks deriving from natural disasters. The above regulation is understood to establish measures to encourage the stipulation of insurance policies, including the exclusion, even partial, of state intervention for damage to buildings and tax incentives [13].

The use of insurance policies against catastrophe risks can be useful to reduce public spending in the event of catastrophic environmental events, as well as a tool to limit lack of transparency in claims for compensation [14].

Moreover, in the policy conditions, according to the law, it is advisable to insert the conditions of insurability that can reduce the harmful events and encourage the quantification of the premium and of the same operation of compensation for damages.

In light of the general provisions, a specific case can identify a gap that is the case by which a subject may not legitimately be aware of the necessary and prodromal data to provide the mandatory information referred to in the declaration that the insuring must lend in favour of the insurance company [15].

Starting from the assumption that it has been possible to experiment and devise insurance instruments against natural hazards, it is possible to highlight some characteristics.

Preliminarily, it appears necessary to highlight that, apart from the obligation to ensure certain risks (as for the Civil Car Liability in Italy), the insurance contract assumes that there is convenience to its stipulation from both the point of view of the parties. At the base there must be uncertainty about the occurrence of well-defined events.

The problem of insurance of catastrophic risks is primarily a problem of being insurable in a technical sense, although it is also relevant from a legal point of view [16].

Technical insurance depends on an assessment of the insured risk carried out according to specific insurance parameters other than the judgment of insurability in a legal sense understood as the compliance of the insurance coverage with the legal system.

It must be said that this distance of concepts finds second thoughts on the part of the proponents of the theory that sees in the insurance company a structural element of the insurance contract, or a necessary tool for the realization of the contractual economic operation. In this way it is possible to conclude that the insurability in a technical sense, as a necessary condition for risk management by the insurance company, is also a prerequisite for the implementation of the proper function of the recognized insurance contract worthy of protection of the case. The relationship between technical insurability and legal insurability also arises with regard to coverage of catastrophic events, where the technical and economic risks of risk management find consideration, to some extent, by the legislative regulations [17].

With specific reference to the coverage of catastrophe risks, the Italian legislator opted for a reference to the autonomy of the predisposing party. In Article 1912 c.c. in fact, it is expected that "earthquake, war, insurrection, social turmoil" are excluded from coverage in non-life policies "unless otherwise agreed". The rule is placed within the title on "damage insurance".

Nothing is outlined in the area of life policies, if the Italian Insurance Supervisory Institute (ISVAP now IVASS) recently mentioned that, in setting the minimum contents of life insurance contracts linked to mortgages, it also provided for the exclusion of death due to catastrophic risks (see ISVAP Reg. 40/2012) [18]. The exclusion of these risks must therefore be considered as present in the contract, unless otherwise agreed, according to a legal integration mechanism. It follows that the subject covered by a policy for damages, where coverage of catastrophic events is not envisaged, will not claim any indemnity towards the insurer in the event of a claim caused by events of this nature. Something different can however be said where the insurer is found to be in breach of specific information obligations in favour of the contractor, the insured and the beneficiary. According to art. 31 of the ISVAP regulation 35/2010, as set in implementation of the art. 182 cod. ass. (Private Insurance Code - Legislative Decree No. 209/2005), it is envisaged that "in preparing the pre-contractual and contractual documentation the companies illustrate, with particularly evident graphic character, the clauses that provide for charges, obligations and exclusions" [19].

If it is considered that the law should also be extended to legal exclusions, according to the orientation recently followed also by the legislator, then also the exclusion pursuant to art. 1912 must be literally included and highlighted in the contractual and pre-contractual documents. It remains to be established which is the consequence of the violation of said rule of conduct.

According to the majority jurisprudential orientation, consequences will be on the compensation plan compensating the contractor (the insured or the beneficiary) for the failure to fulfil his / her own interests. In this case, the customer will be entitled to a sum of money corresponding to what he/she would have received if the exclusion had not been effective. It must be said that in general the insurance policies contain limitations of coverage. The problem is sometimes that of an "excess" of exclusion. Thus, in the presence of a contractual clause which provided for the exclusion of damage to buildings "due to settlements, collapses, landslides or vibrations of the ground from any determined cause", the Supreme Court of Italy ruled in the sense of the voidness of a similar limitation based on art. 1229 of the civil code, setting up the same, given the extent of its scope, an exemption from liability and not a causal delimitation of the risk [20].

Based on this analysis, it could be pointed out that, in accordance with the insurance dynamics against natural hazards, information asymmetry becomes more acute when the asset and the risk connected to it are not easily known and calculable by the weak party.

Within this scenario, which is heterogeneous and devoid of orderly and precise regulation, therefore, we highlight the case of a context in which the parties, in particular the insured, do not actually have the right to fully define the risk factors and damage inherent in an asset exposed to natural disaster [21].

5. Framework on Insurance Dynamics against Natural Hazards. Cat-Models

The insurance industry over the years has implemented so-called catastrophe models (CATMODELS) to mitigate and, within limits, control catastrophe-derived damages. The adoption of models for natural catastrophe scenarios, since the 1990s, has allowed the industry to analyse and measure risk more accurately.

Today, the use of these models became the norm. In particular, one of the most important models in regard to mitigation of risk against natural hazards corresponds to the drafting of the EP curve. In fact, the EF curve allows the insurance company to verify and outline: 1) the probability that a given hazard affects one or more portfolios of buildings or immovable assets; 2) the maximum loss borne by the insured person with regard to the data processed by the system [22].

Given the prevalence of templates for catastrophic scenarios in insurance and increasing costs of extreme weather events, the accuracy of the results of modelling is a primary concern for insurers.

It is worth noting and adding that the cost to be charged to the insurance in the event of a catastrophic natural event implies a considerable disbursement by the company itself, and also for this reason, as well as avoiding the physiological insolvency, the phenomenon of so-called reinsurance in recent years has grown considerably [23].

The possibility that climate change might facilitate changes in the gravity and probability of extreme weather events could affect the accuracy of the models for natural catastrophe scenarios [17]. This scientific paper assesses whether and how these models consider climate change through a series of case studies contributed by various providers to both academic and commercial models [24]. Catastrophe modelling approach contains a specific view of the operators for the hazards, risks and the vulnerability of the insured goods. This view has been designed using the observed data as a base [25]. The above approach facilitates the application of this risk to view records of a particular customer, in order to quantify the probability and magnitude of the potential loss. This is achieved by reducing the complexity inherent in the physical interaction between hazards and vulnerability, by parameterizing the features in a limited set of measurable units [26]. These units are applied systematically, consistently and repeatedly in a custom set of exposure data. Financial characteristics related to the insurance sector can then be superimposed to calculate a net loss tailored to the client using the tool. Use of the above approach is however only a small fraction of what is needed to optimize the use of catastrophe modelling within an activity [27].

As highlighted in the previous paragraphs, one of the sections of the paper is dedicated to one of the most popular tools in insurance companies for calculating risk and maximum loss, including the type of risk associated with natural hazards.

In the next sections an insight about quantitative aspects on the assessment of risk insurance is proposed through the description of the definition of the Exceedance Probability curve and its main bottlenecks.

6. Elaboration of the EP Curve as A Tool for Insurance Companies for Risk Reduction within a Contractual Case against a Natural Hazard

Catastrophe scenarios, here specifically in terms of natural hazards, can provide different financial results, the most common of which are the curve of average annual loss (Annual Average Loss, *AAL*) and curve of probability of exceedance (Exceedance Probability, *EP*) [28]. The *AAL* is sometimes called "pure" or "claims report award/awards" and can be incorporated into the pricing together with an allowance for expenses and the return on capital [29]. The curve *EP* is commonly described as a graphical representation of the probability that a loss produced by possible events, namely here natural hazards, exceeds a certain amount [30]. Reading points on the curve offer different interpretations in the frequency and severity of losses.

These curves are very useful to insurers and reinsurers to determine the size and distribution of potential losses of their portfolios. The *EP* curve allows insurers to determine the probable maximum loss (hereafter referred to as *PML* = Probable Maximum Loss) for a portfolio of buildings in a certain timeframe due to a natural hazard occurrence. The insurer determines first the percentage risk it deems acceptable then checks the total loss amount for that specific probability level on the curve *EP* [31].

It appears absolutely essential for continuation of the discussion that the authors conduct and deal with the theoretical questions described above in a table and a graph so that the way in which the insurance companies determine the risk and the price starting from a numerical base is, partially, clarified, i.e. the determination of the percentage of exceedance probability [32].

The practical example is the assumption that there is a set of catastrophic events (E_i) that can jeopardize an immovable asset's portfolio. Each event has an annual probability when it occurs (p_i), and a loss associated with it (L_i). Furthermore, it must be considered that there is the possibility that more than one event might occur the same year. The table below takes as assumption eight events which are ordered in accordance with decreasing total losses (L). The sum of the probabilities of all events must be equal to 1.

TABLE 1. HYPOTHETICAL EP CURVE DEFINITION

E_i, step	P_i, %	L_i, €	$EP(L_i)$, %	$E[L] = p_i L_i$, €
1	0.005	1 000 000	0.00500	5000
2	0.015	750 000	0.01993	11 250
3	0.02	500 000	0.03953	10 000
4	0,05	300 000	0.08755	15 000
5	0.1	200 000	0.17880	20 000
6	0.2	100 000	0.34304	20 000
7	0.25	50 000	0.50728	12 500
8	0.36	10 000	0.68466	3600
Total:	**1.00**			**97350**

The expected or predicted loss in relation to a given event (E_i) over a timeframe equal to a year is:

$$E(L) = p_i \cdot L_i \tag{3}$$

The total expected losses for the entire set of events, namely the average annual loss (hereinafter *AAL*, as also reported in Table 1), is substantiated by the weighted sum of expected losses for each event and the probability that event will occur. *AAL* is defined as below:

$$AAL = \sum_{i=0}^{n} p_i \cdot L_i \tag{4}$$

If only one event takes place during the year, it is possible to determine the EP curve, i.e. the expressed loss value, as follows:

$$EP(L_i) = P(L > L_i) = 1 - P(L < L_i) \tag{5}$$

$$EP(L_i) = 1 - \prod_{i=1}^{n} (1 - p_i) \tag{6}$$

From Eq. (6) it can be deduced that the *EP* as shown in Fig. 1 curve is the annual probability that a loss exceeds a certain value, which is equal to 1 the probability that all other natural hazards below this value will not occur.

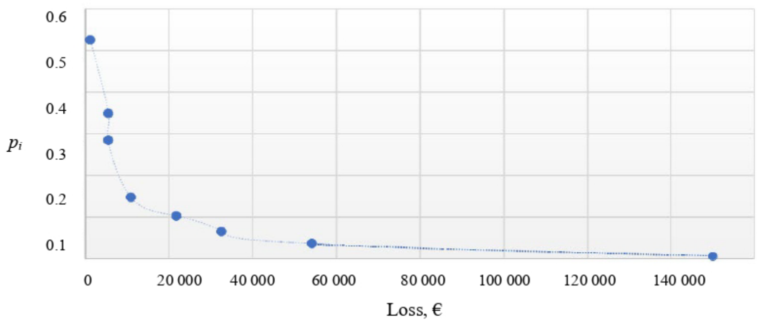

Fig. 1. Theoretical EP curve draft according to Table 1 data.

The elaboration proposed by the authors on the calculation of the *EP* curve concerns the calculation of the risk as well as the maximum loss drafted by the insurance company. In particular, the authors, as highlighted by illustrious colleagues, even in heterogeneous fields believe that to date there is a need for risk awareness, greater data sharing and implementation of the transparency referred to in the contracts [33].

It is necessary, in order to allow the weak party to have greater knowledge and awareness of the risks associated with natural hazards, that the insurance companies share the calculation method in a simple and clear manner also, among others, in full compliance with European and national regulations [34].

Ultimately, it is essential for the weak party to understand the incidence of *EP* curves in relation to the elaboration of the premium, in relation to the asset, the exposure and the perception of the risk against natural hazards [35].

The relationship between the empirical section referred to in the curve *EP* and the lack of information highlighted above underlies the possibility for the weak contractor, in conclusion, to obtain an equal, at least theoretically, contractual position with the insurance company

7. The ESG Experience. A New European Approach

The lack of experience and data relating to risk – to be used in the determination of premiums – is well known especially where a real insurance market is still lacking and underdeveloped [36] (for example, cyber risk or so-called NATCAT for some natural events) or when it is not possible to refer to comparable products. In the absence of reliable data for the evaluation of the premium, the subject appointed by the insurance company must be cautious in developing the rates in order not to compromise the overall balance of the portfolio and, subsequently, to verify over time the correctness of the choices made.

Data processing programs often do not include sustainability variables such as Environmental, social, governance (ESG): using these parameters can be very interesting for optimizing risk management and avoiding an excessively prudent and conservative attitude and making informed investment choices [37].

To undertake to reach a solution, a different cultural approach seems necessary, capable of deeply motivating the subjects involved in the insurance dynamics, developing in-depth knowledge, trying to understand the nature of these data and their close correlation with the possibility that the harmful event envisaged in the contract occurs [38]. The meaning of the cultural approach is inherent in the necessary regulatory-systematic change of direction described above as well as, of course, in better information on the rights of both parties in the drafting of the contract.

Looking towards a supranational context, the European Commission, for example, has promoted and developed the H2020 NAIAD project [39] to collect and analyse data and information for the creation of a platform in which new insurance instruments or investments are made - to counteract the risks deriving from floods and droughts - in which the prevention, management and resilience measures adopted (the so-called Nature based solution – NBS) are taken into account.

Similarly, in the same supranational context, even in non-related areas, it has been demonstrated already the correlation between "Sustainability", corporate governance, the value of the assets and the influence it has on a company's share performance [40].

In this respect, the 2014/95 / EU directive (in Italy transposed into law by Legislative Decree No. 254/2016) represents a focal opportunity to consolidate the transparency and publicity of "extra" financial information and hopefully could allow investors, consumers and, more generally, all stakeholders to have, in their respective areas and for their respective purposes, a clear framework for company activities. At the same time, the Financial Stability Board (FSB) has drafted some guidelines to encourage financial operators to provide greater disclosure of information regarding climate change as well as natural hazards, from the point of view of both investors and issuers, as it is clear that such a choice can help companies in the decision-making process and allows stakeholders to understand the impact of climate change on business operations. Reconnecting the last section to what was observed on information asymmetry, and the weak role from the contractual party point of view of the weak party, it is worth highlighting that during the climate change conference conducted in

Paris in 2015 (https://unfccc.int/process-and-meetings/conferences/past-conferences/paris-climate-change-conference-november-2015/paris-climate-change-conference-november-2015) on 8 December 2017, many of the major asset managers, pension fund and insurance companies signed a declaration to support the focal point of the importance of improving the transparency and public disclosure of the ESG rating by issuers, in addition to the Financial Rating [41].

8. Conclusion and Policy Implications

The conclusions of the paper can be defined as follows. In the first place, the paper tends to raise awareness of common sense, insurance companies and individuals with regard to information asymmetry in insurance contracts. In particular, by making a general criticism of the informative mode, the initial burden of which is on the weak party, today more than ever, this statement is even more anachronistic and inadequate in the light of a risk that is difficult for an individual to calculate or predict, such as a natural hazard.

Except for very rare exceptions, the insurance contract is seen as a "unilateral" contract in the sense that it is written in its entirety by the insurance company that composes it on the basis and studies of its own derivation, thus leaving the subject assured the mere possibility of outlining the risk, the premium and the object to be insured. Therefore, since the preparatory phase is always the responsibility of the insurance company, with all the consequences that this entails, what are the protections granted to the insured? Even today, a famous Latin phrase dominates the insurance world: *Quis custodiet ipsos custodes*? Who will guard the guards themselves?

The focal concept is inherent in the age-old problem of awareness that those who delimit the areas of rules and provisions are often not subject to similar checks. Thus, if the insurance company is well aware, or at least theoretically aware of the risks outlined above, outlining the preparatory scheme of the contract in relation to a cost benefit analysis, on the other hand, the weak party has no guarantee that effectively the same checks that were carried out on himself/herself and on the asset are then carried out in reverse on the company itself.

Another point of discussion of the paper concerns one of the methods of calculating the risk used by the companies, namely the *EP* Curve, highlighting the strengths and weaknesses of such a calculation, also in light of the unilateral nature of the same during the contracting phase. In particular, one of the focal points of discussion and results pertains to the EP curve as a tool for calculating the insurance premium. To date, in the opinion of the authors, this tool should be made understandable and available for the weak party to raise awareness and share the data of the connected risk. In fact, even in compliance with the implementation of supranational regulations, it is no longer acceptable that one or more parties referred to in a given contract have no right and the right to know every single aspect referred to in one or more essential elements of the latter. In particular, using the 2016/97 European directive as a guideline in correlation with the binding provisions of the Italian civil code, it seems appropriate to the authors that the calculation dynamics, including the *EP* curve, are shown and explained within the information sheet in the precontractual phase.

The final point concerns the Italian perspective of the use of new parameters in drafting contracts and financial/insurance instruments. In particular, the implementation of the aforementioned by means of the introduction of ESG criteria in order to allow greater awareness, product safety and rating reliability, as well as limiting the general information asymmetry exposed throughout the entire paper, seems to be fundamental from different aspects.

References

[1] Bevere L., Muelle L. Sigma. Natural catastrophes and man-made disasters in 2013: large losses from floods and hail; Haiyan hits the Philippines. Zurich: Swiss Re. 2014:1:52. [Online]. [Accessed 22.10.2020]. Available: https://media.swissre.com/documents/sigma1_2014_en.pdf

[2] NIBS. HAZUS: Hazards U.S.: Earthquake Loss Estimation Methodology. NIBS Doc. N. 5200. Washington, D.C. 1997.

[3] Giovagnoli R., Ravera C. Il contratto di assicurazione: percorsi giurisprudenziali. (The insurance contract: jurisprudential paths). *Giuffrè Editore* 2011:223. (In Italian).

[4] Crocitto M. Commentario al Codice delle assicurazioni private. (Commentary on the Private Insurance Code). Halley Editrice, 2006.

[5] Istituto Nazionale di Statistica. (National Institute of Statistics). [Online]. [Accessed 22.10.2020]. Available: https://www.istat.it/it/archivio/202943

[6] Bølviken E., Guillen M. Risk aggregation in Solvency II through recursive log-normals. *Insurance: Mathematics and Economics* 2017:73:20–26. https://doi.org/10.1016/j.insmatheco.2016.12.006

[7] Gambino A. La neutralizzazione dei rischi nella struttura e nella funzione giuridica unitaria del contratto di assicurazione. (The neutralization of risks in the structure and unitary legal function of the insurance contract). 1985. (In Italian).

[8] Amedeo M. Assicurazioni: nuovi precontrattuale obblighi d' informativa Il nuovo Set Informativo ed il DIP Aggiuntivo. (Insurance: new pre-contractual disclosure obligations. The new Information Set and the Additional DIP). 2018. (In Italian).

[9] Sangiovanni V. Dichiarazioni inesatte, reticenze e annullamento del contratto di assicurazione. (Inaccurate statements, reticence and cancellation of the insurance contract). 2014. (In Italian).

[10] Aa. Vv. L'Assicurazione dei Rischi Calamità Naturali. (Natural Disaster Risks Insurance). 7th R.I.B. Conf., November, 2000. (In Italian).

[11] Landini S. Reticenze dell'assicurato e annullabilità del contratto. (Obligations of the policyholder and cancellation of the contract). Resp. civ. e prev, 2011.

[12] Campobasso G. F. Diritto commerciale 3. (Commercial law) 3. Utet Editori Dal 1791, 2015. (In Italian)

[13] Grossi P., Kunreuther H. The role of uncertainty on alternative disaster management strategies. *International Geology Review* 2001:43(5):391–400. https://doi.org/10.1080/00206810109465020

[14] Lin S. K., Chang C. C., Powers M. R. The valuation of contingent capital with catastrophe risks. *Insurance: Mathematics and Economics* 2009:45(1):65–73. https://doi.org/10.1016/j.insmatheco.2009.03.005

[15] Landini S. Assicurabilità e indennizzabilità dei rischi catastrofali ambientali. (Insurability and indemnification of environmental catastrophe risks). *Assicurazioni* 2013:19–29. (In Italian).

[16] McAneney J., McAneney D., Musulin R., Walker G., Crompton R. Government Sponsored natural disaster insurance pools: A view from down-under. *International Journal of Disaster Risk Reduction* 2016:15:1–9. https://doi.org/10.1016/j.ijdrr.2015.11.004

[17] Nowak P., Romaniuk M. Pricing and simulations of catastrophe bonds. *Insurance: Mathematics and Economics* 2013:52(1):18–28. https://doi.org/10.1016/j.insmatheco.2012.10.006

[18] Porrini D., Schwarze R. Insurance models and European climate change policies: An assessment. *European Journal of Law and Economics* 2014:38(1):7–28. https://doi.org/10.1007/s10657-012-9376-6

[19] Cherubini M. C. Tutela del "contraente debole" nella formazione del consenso. (Protection of the "weak contractor" in the formation of consent). Torino: Giappichelli, 2005. (In Italian).

[20] Rossi Carleo L. Il diritto all'informazione: dalla conoscibilità al documento informativo. (The right to information: from knowledge to information document). *Rivista di Diritto Privato* 2004:349–375. (In Italian).

[21] Scoditti E. Regole di validità e principio di correttezza nei contratti del consumatore. (Rules of validity and principle of correctness in consumer contracts). *Rivista di diritto civile*, 2006.

[22] Kunreuther H. The Role of Insurance in Reducing Losses from Extreme Events: The Need for Public-Private Partnerships. *The Geneva Papers on Risk and Insurance - Issues and Practice* 2015:40(4):741–762. https://doi.org/10.1057/gpp.2015.14

[23] Motoyama T. Optimal disaster-preventive expenditure in a dynamic and stochastic model. *Journal of Macroeconomics* 2017:51:28–47. https://doi.org/10.1016/j.jmacro.2016.11.005

[24] Carr T., May A. Focus on alternatives: Catastrophe bonds explained. *Schroeders* 2011:1–4. https://www.schroders.com/globalassets/schroders/sites/pensions/pdfs/catastrophe-bonds-explained.pdf

[25] World Enviromental Forum. Rischi dei cambiamenti climatici: il ruolo delle assicurazioni. (Risks of climate change: the role of insurance). 2013.

[26] Stamovlasis D., Tsaparlis G. Applying catastrophe theory to an information-processing model of problem solving in science education. *Science Education* 2012:96(3):392–410. https://doi.org/10.1002/sce.21002

[27] Wu Y. C., Chung S. L. Catastrophe risk management with counterparty risk using alternative instruments. *Insurance: Mathematics and Economics* 2010:47(2):234–245. https://doi.org/10.1016/j.insmatheco.2010.04.002

[28] Gurenko E. N. Climate Change and Insurance: Disaster Risk Financing in Developing Countries. *Climate Policy* 2006:6:596–688.

[29] Grossi P., Kunreuther H., Windeler D. An Introduction to Catastrophe Models and Insurance. In: Grossi P., Kunreuther H. (eds) *Catastrophe Modeling: A New Approach to Managing Risk. Catastrophe Modeling*, vol. 25, 2005. Springer, Boston, MA. https://doi.org/10.1007/0-387-23129-3_2

[30] Surminski S., Bouwer L. M., Linnerooth-Bayer J. How insurance can support climate resilience. *Nature Climate Change* 2016:6(4):333–334. https://doi.org/10.1038/nclimate2979

[31] Le Quesne F, Tollmann J., Range M., Balogun K., Zissener M., Bohl D., Souvignet D., Schuster S., Zwick S., Phillip J., Wehnert B., Kreft S. The Role of Insurance in Integrated Disaster and Climate Risk Management: Evidence and Lessons Learned. GIZ Report no. 22, October 2017. Available: https://collections.unu.edu/eserv/UNU:6312/MCII_ACRI__1710020_Online-meta.pdf

[32] Subramanian A., Wang J. Reinsurance versus securitization of catastrophe risk. *Insurance: Mathematics and Economics* 2018:82:55–72. https://doi.org/10.1016/j.insmatheco.2018.06.006

[33] Montefiori M. Libertà di scelta e contratti prospettici: l'asimmetria informativa nel mercato delle cure sanitarie ospedaliere. (Freedom of choice and prospective contracts: the information asymmetry in the hospital healthcare market). Università di Genova, Dipartimento di Economia Pubblica, 2002. (In Italian).

[34] Avesani M. Le coperture assicurative nelle catastrofi naturali. (Insurance coverage in natural disasters). Universita di Pisa, 2014. (In Italian).

[35] Alpa G. Il diritto contrattuale comunitario. Un cantiere aperto. (Community contract law. An open construction site). *Rivista giuridica sarda* 2011:26(3):689–697. (In Italian).

[36] Charpentier A., Le Maux B. Natural catastrophe insurance: How should the government intervene? *Journal of Public Economics* 2014:115:1–17. https://doi.org/10.1016/j.jpubeco.2014.03.004

[37] Wrede P., Phily C., Wipf J. J., Tatin-Jaleran C., Garand D. Pricing for microinsurance: a technical guide. ILO's Impact Insurance Facility. 2016. [Online]. [Accessed 15.08.2020]. Available: http://www.impactinsurance.org/sites/default/files/MI%20Pricing%20Guide%20FINAL.pdf

[38] Braun A. Pricing catastrophe swaps: A contingent claims approach. *Insurance: Mathematics and Economics* 2011:49(3):520–536. https://doi.org/10.1016/j.insmatheco.2011.08.003

[39] NAIAD 2020 Nature Insurance value: Assessment and Demonstration [Online]. [Accessed 22.10.2020]. Available: http://naiad2020.eu/

[40] Müller-Fürstenberger G. Schumacher I. Insurance and climate-driven extreme events. *Journal of Economic Dynamics and Control* 2015:54:59–73. https://doi.org/10.1016/j.jedc.2015.03.002

[41] Keskitalo, E. C. H., Vulturius G., Scholten P. Adaptation to climate change in the insurance sector: Examples from the UK, Germany and the Netherlands. *Natural Hazards* 2014:71(1):315–334. https://doi.org/10.1007/s11069-013-0912-7

Publication 7

Flood risk: financing for resilience using insurance adaptive schemes

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Flood risk: financing for resilience using insurance adaptive schemes

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Keywords: flood risk, insurance, resilience, smart contracts, blockchain

ABSTRACT. – This paper shows how insurance markets can be used for mitigating the economic consequences of climate changes, in particular for facing flood risk. Not only providing financial compensation for losses, but also for financing resilience through mitigative infrastructures. This approach is similar to one allowed by the so called resilience bonds, financial instruments whose cash flows depend on the occurrence of contractually settled (catastrophic) events and part of the economic value of the investment is devoted to finance resilience actions. Our propose is based on an adaptive design of the insurance contract, based on information collected at each checking time and the (eventual) surplus of the premium paid respect to the payments occurred for damages has to be (automatically, settled in contractual conditions) used for financing mitigative infrastructures. The cost of these infrastructures, the time to build up, the implied risk reduction, have to be assessed by an engineering expertise and even we need a legal framework into which the actuarial quantitative model can be implemented. The periodic renewals of the contract (surplus evaluation, changing in risk exposure due to the infrastructures already built,…), can be interpreted as a sort of smart contracting and in this framework the novelty of blockchain technology could be used to collect new information from various sources.

INTRODUCTION. – Since the early 1970s extreme events associated to natural disaster have been growing both in frequency and intensity. Specifically during the last 15 years has been recorded an increase of 2% per year. This increase is reflected also on economic losses, in fact addressing the attention of the scientific and professional arenas to novel and effective methods of insurance as resilient management tools

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for risk reduction. In U.S. context the devastating impact of Hurricane Katrina in 2005 was quantify in more than 1,800 people losses within an area of 230,000 km^2 of the U.S. The recovery phase investment from the federal government were quantify on 100 billion $.

These trends highlights the need to strengthen the interdisciplinary aspect towards the disaster risk management involving policy and law makers, engineers, insurance company and researchers in difference disciplines able to create tailored community resilience strategies.

Since now there have been several example on how singularly each expertise community was proposing the implementation of both mitigation and adaptive solution in *ex-ante* and *ex-post* disaster occurrence. Engineers tried to promote innovation diffusion meantime redefine more specific codes and standards to have more resistant structure. Planners were reorganizing and reassessing the land use for the development of the urban area prone to hazards.

In this context the need to have a more resilient insurance system is essential in order to be more flexible and optimizing the management of the residual risks. The example of the CAT bonds is going in this direction in fact strengthening the key role of insurance as one of the key Disaster Risk Reduction (DRR) measure with a consist effect during the recovery phase of the built environmental and the social dimensions.

Nevertheless there is evidence of a relevant decrease of the ratio of insured losses *vs* uninsured losses due to the increased exposure and which may be partly limited financial availability. Several authors stressed on how insurance plays a key role in food risk management like in France and UK. During the post disaster has been highlighted how insurance can substantially decrease the recovery phase in fact provide a more quick way to have repayment of the losses compared to government support.

More in specific as stated in a recent document from European Commission, for insurance in adaptation to climate change, the role of insurance should be more and more effective in the future, respect to what happened in the past. Insurance mechanisms can provide financial compensation for large disaster losses, so that those affected can recover faster. The sooner and more comprehensive the recovery, the smaller the impacts of a disaster are likely to be in the long run, which helps to make society more resilient.

Insurance companies can play a large role in assessing, communicating and signalling risk through premiums, deductibles and payments.

Stakeholders involved in the insurance sector can generate incentives or requirements for risk management, which in turn can limit the potential impacts of an extreme weather event. Another option would be to include requirements that relate to resilience in the insurance policy: if an insurance-taker does not take any measures against the risk to which he/she is exposed, the pay-out will be lower. So, the role of insurance could be considered not only for financial compensation for losses after an extreme weather event, but also providing incentives for risk reduction as, for example for flood risk, the building of mitigative infrastructures.

Some features that allow to make an insurance scheme more efficient are an interaction between public and private sectors with a commonly stated and understood objective. Governments and the insurance sector exchange data, set common objectives and divide responsibilities.

One key point for increasing resilience against extreme weather events, as floods, is the construction of mitigative infrastructures which has to be financed by the stakeholders, as public administrations. There is an important novelty in the finance-insurance market precisely regarding this kind of need, that are the so-called resilience bonds.

They provide a transfer of the insurance risk, from the insurance to the financial market, as already done by the more famous cat-bond, bonds whose payments are linked to a contractual cat-event (storm, flood, earthquake,…), but they add also a project financing of infrastructures which can mitigate the original risk. For example, focusing on flood risk, the costs of such infrastructures has to be assessed using an hydraulic engineering expertise. Then the time necessary to finish such buildings, more than one year, which is the typical duration of an insurance contract, is a constraint which implies the consideration of multi year contracts, which is the natural environment for bonds.

During this period, we need to collect data of different nature, climatic, insurance (damages), engineering… and one instrument which seems useful to this aim is the so-called "Blockchain technology", which is raising up a lot of interest for applications in a wide range of fields. The key function of its use is to collect reliable information that could be used for a dynamic updating of contracts, that is one of the main opportunity given by smart contracting, with an adequate support of law's context in which such contracts are merged, that is one of the main issue to be developed for the full functioning of this kind of innovative business model.

Blockchain and the connected smart contracting, seem very interesting even for insurance business, in particular for the bayesian adaptive approach which is a classic issue of actuarial science, based on the updating of premium evaluation using the collection of new information of risks phenomena.

The new opportunity of collecting offered by the so-called big data even for classic insurance risks as for example, health, driving, climate and seismic events, together with the validating role of Blockchain approach, seem to be the perfect scenario for a massive use of smart contracting in insurance business.

In this paper we describe the scheme of a flood risk insurance, the bayesian adaptive design of the contract, using Blockchain to validate both new data of risk phenomenon and the effect of mitigation of the faced risk due to infrastructural works.

In the first paragraph the engineering point of view of measuring and mitigating flood risk is presented. In the second we provide an overview of the legal aspects of smart contracts in a multiperiodic scenario. In the third paragraph the bayesian adaptive design of the contract according to an actuarial approach is proposed. Then we propose some conclusions and mainly some comments of possible developing lines of this multidisciplinary research.

ASSESSMENT OF FLOOD RISK FOR CRITICAL INFRASTRUCTURAL SYSTEMS. – *FLOOD AND CRITICAL INFRASTRUCTURE.* – Since the early 1970s extreme events associate to natural disaster have been growing both in frequency and intensity. Specifically during the last 15 has been recorded an increase of 2% a year [see 1].

The same increased trend was also reflected on the number of disaster flood events more than 600 from the year 2007 [let see 2]. What happened in the year 2013 in the Central Europe was particularly impactful: 16.5 billion in economic losses (large-scale damage across Germany, the Czech Republic, Hungary and Poland) for 4.1 billion in insurance paid claims. The year 2013 has a record of the increasing flood damages of approximately 50% respect the period 2003-2012 and to show for first time three consecutive losses exceeding 100 billion in a 10 years period time [see 1, 3]. These figures represent an evidence how the increase of the population in urban areas [let see 1] and the consequential increase of their complexities of both social and technological dimensions define a bottleneck within flood risk management.

In fact, the rapid growth of human concentration and urbanized areas has increased the exposure to the existing flood recurrence time making more difficult the realization of proper mitigation measures such as the availability of the land to be settled as potential flood risk zone. Among different assets which flood risk increased, exposure of Critical Infrastructures (CI) needs to be highlighted.

Critical infrastructures represent body of systems, networks and assets that are essential for the functioning of a society, public's health and/or safety and economy of a nation. CI are thus engineering and technological networks, such as energy/water supply, transport services, water supply, oil and gas supply, banking and finance, and ICT (information and communication technology) systems. All these systems are important (and thus critical) to maintain essential functions of society, and their failures can heavily seriously affect the population, economy, and national security [see 4, 5]. Such CI systems, facing with the increase of the population in urban systems must increase the service there are providing in turn increasing both the interconnection of the CI and thus the overall vulnerability [see 5, 6].

This is the reason that addressed the attention of policy-makers, economist, urban planners, engineers, insurance companies and scientist to find innovative Risk Management frameworks to more sustainable and more resilient approaches towards decreasing the negative effects of climate change and natural hazards [see 7]. A new approach has thus been gradually developed, based on the concept of urban resilience, nowadays implemented within the Sendai Framework for Disaster Risk Reduction [see 8], however a robust methodology that is based on scientific research for quantitative assessment of benefits to flood risk reduction from mitigating infrastructural solutions is still not well defined and is the next desired improvement for risk management field.

Regarding the flood impact during the last decade the disruption and damage to the urban context increased $21 billion in 2015 to US $25 billion in 2016.

It is this essential to implement proper tool, mechanism and strategy able to reduce Risk mostly in term of strengthened infrastructural resilience. It is of utmost importance how to properly quantify the risk to most effectively apply the optimal strategy for strengthening the Critical Infrastructural resilience.

The concept of Infrastructural Resilience. – Due to the complexity and interdependency of infrastructure in urban areas there is higher risk to have cascading effects in fact generating secondary effects in areas much more far from the real flooded area [see 6, 9]. This is a key aspect to consider in order to minimize the secondary problems that are directly affecting the networks may have [see 10].

In order to make urban areas more resilient a novel risk reduction approach based on a strategic development of urban and infrastructural systems has been proposed within the last Sendai Protocol developed in the 2015 based on the resilience concept [see 11]. Sendai Protocol also foresees building the capacity to learn and thus anticipate the effect of a catastrophe, which is a substantial element for increasing resilience against natural hazards [see 1].

For this purpose the introduction of the term resilience has important role, however the term itself is interpreted in many different ways depending on the field of science. This concept is "essential" to describe the functionality of the communities, infrastructures or any other type of systems under the effect of hazard [let see 12]. Based on the United Nations Office for Disaster Risk Reduction (UNISDR), in disaster risk management resilience is used to describe "ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management". In this context the resilience is also being actualised by EU Commission to ensure appropriate planning and preparation for disaster risk management and sustainable development.

Some studies suggest that infrastructure resilience has direct connection with term of resilience proposed by Holling [10] and used in ecology. This definition is generalized as capacity of a system to absorb disturbances and to recover after a major disruption and to restart an activity on the territory. Based on this, different methods have been proposed to assess resilience and role of the infrastructural resilience within it. For example, in the work of Serre *et al.* [1] is proposed for urban/engineering networks are able to propagate flood risk the overall urban resilience is identified into 3 main capacities namely: Resistance capacity, Absorption capacity and Recovery capacity. Similarly approach for looking at resilience was proposed by Bruneau *et al.* [11] with the introduction of the "4Rs" (*i.e.*, Robustness; Redundancy; Resourcefulness;

and Rapidity), according to which resilience of specific system is described in by qualities of the system matching these 4Rs.

Such conceptual and (semi) quantitative model approaches based on the selection of a set of proper indicators can serve as the base for development of a framework for assessing the effectiveness of specific mitigation and/or adaptation strategies.

Flood Risk and Resilience. – As mentioned urban population increase and the consequential rise of the increase complexity of the CI represent factors that amplify the level of local vulnerability [see 12, 13]. In fact there is a direct connection of the natural hazard losses to the number of people and complex infrastructure living in areas prone to hazards.

Thus the assessment of the Risk losses is not a trivial task since both the engineering dimension as well as the social impact should be evaluated. Generally the Risk to natural disaster including flood is defined within the probability perspective in terms of occurrence time of a certain hazards, factored by the severity of its consequences [see 14], according to the following formula:

$$Risk = Probability \ x \ Consequence \quad \rangle \quad \rangle \quad \rangle \ (1)$$

Thus Risk represents a key instrument and criteria leading to flood zone management policy, land and infrastructural development planning [see 15]. It is thus evident the important role of the engineering dimension to assess the potential cost/benefit in terms of decreased flood risk level once a specific (or other engineering system) is strengthened and/or newly built.

Risk formula presents also other expended description on where the probabilistic dimension of the Hazard is then related to the Exposure and Vulnerability. Both aspects are related to the intrinsic propensity of a certain asset to be at Risk. Thus, the engineering aspect to understand the effects of an hazard of a certain magnitude is essential. This general formula is reported below:

$$Risk = Hazard \ x \ Exposure \ x \ Vulnerability \quad \rangle \quad \rangle \quad \rangle \ (2)$$

Within the proposed Risk assessment there the need to use GIS-based system on which hazard (*e.g.*, flood), vulnerability and assets maps are combined through the use a weighing process and normalization. This task has to be replicated for each climate-related impact [see 16].

In this way the flood risk assessment is translated in terms of potential loss and damages costs. This is most of time impossible to be done for each infrastructure and/or asset at risk due to data scarcity. In these way insurance companies' databases are often using proxies to overcome this bottleneck.

As reported by Kaspersen and Halsnes [17] Danish Insurance Company define a damage function and unit damage costs based on flood levels for different buildings during extreme precipitation. In this case health costs (based on number of people exposed to mixed rain-sewage water) and expected costs for different rain patterns considering extremes climate event are calculated in monetary values as losses for each asset and damage costs.

Since quantitative and probabilistic approaches are not always possible to be used and converted into a monetary dimension (mostly in connection to the social dimension, the effectiveness of Risk Reduction scenarios through a Multicriteria Assessment (MCA) towards urban adaptation planning [see 18].

Normally with adaptation strategies are beneficial for the overall resilience of certain system and thus its risk reduction. According to [19] for physical systems can be identified in 2 types of measures namely hard and soft. The first referred to (semi)permanent installation within the area of the potential flood, the second ones are those relate to natural process for example like are tackling flood in terms of erosion decrease and or increase of roughness in the flooded areas [see 1, 20].

An overview of the legal aspects for conventional and multi-phase smart contract. – To highlight the scientific and applicative gap of a specific smart insurance contract against natural hazard, the first methodological approach, specifically the legal one, leads to an overview of the state of the art of the thematic areas of implementation of smart contracts themselves.

Our focus is to propose how a Smart Contract could act in an insurance scheme and let see Lamberti *et al.* [21, 22] and Sayegh [23] to have an overview of the application of Blockchain approach to the insurance sector. There is no universally accepted definition of Smart Contract, due to its recent appearance on the scene and its technological complexity [see 24].

A simple definition is that of an agreement whose performance is automatic, so an algorithm for computer transactions, which comply with the terms of the contract [see 25]. Perhaps a more correct definition, even thinking about the applicative scope of the paper was provided by the Italian IVASS (Italian Institute for Insurance Supervision), according to which smart contracts are contracts that are written in a specific language that can be understood, translated and executed by a computer, whose clauses can produce actions without external intervention based on information received in input and processed according to predefined rules [see 26].

As regards and more closely related to the development of the paper, the most analysed state of the art, to obtain a link to the current regulatory substrate referred to in the blockchain, was clearly that of the insurance dynamics. In the insurance sector, forms of insurance have developed that use Smart Contracts. The first example is InsureETH, an UK startup, in the field of airline reimbursements/compensations. Another case is that of the pilot project of the American International Group (AIG) together with IBM and Chartered Bank who worked together for a multinational insurance coverage, preparing a blockchain insurance Smart Contract.

It is worth adding that recently AXA insurance in order to refunds following delay or cancellation of the flight, has developed an extremely interesting smart contract. The insurance called Fizzy, appears revolutionary because, as described in the AXA portal, it excludes any kind of negligence, typical instead of the traditional insurance dynamics. The smart insurance, regardless of any external event or subjective/objective liability, automatically compensates in case of flight delay.

In order to the title section, what would be the difference of a standard smart insurance contract, therefore with instant effect, compared to a multi-phase contract? One of the main differences was highlighted at the end of the section just ended, and it is quite clear that the main difference is about multiphase.

The desired multiphase implementation within the smart insurance contract is subject to the fact that, periodically, through the storage of data from external certified sources, using the blockchain technology, the contractual structure can change, such as the insurance premium, the sum of compensation or the determination of the percentage of risk. In the title of this paper we make a clear recall to this kind of insurance adaptive scheme and therefore, even if in a perspective about natural disasters, the scanned periods may be related to prolonged periods, the determination of multi-mode concerns the scanning of temporal phases in which it is possible to change and modify essential elements of the contract without the latter termination or requiring a new agreement between the parties.

The second difference concerns the method of using the blockchain technology. Picking up one of the smart contracts mentioned above in the insurance field, the blockchain is simply used in two steps: 1) validation of the insured event, such as the hours of flight delay, and 2) the payment of the sum of money [see 27].

In other words, in the very few applicative experiences that took place in the last few years, insurances first of all made use of blockchain technology as an instrument to verify the insured event. The information, using as an example the AXA contract, deriving from the airline are stored within the blockchain data flow and any event of delay beyond the allowed limit "unblocks" and acts as a check and authorization for the second step.

The one-dimensional perspective of the contract in relation to the uniqueness of the period, understood as a contractual phase, emerges clearly. The data entered and the "transformation" of these through blockchain technology into legal effects, such as compensation, are contained in a single phase, without any possibility, that extends or changes the contractual structure. Therefore, in a one-dimensional perspective, the will of the parties, the economic agreements, regardless of information, external events, blockchain technology acts exclusively as a verifying agent of the insured event, relegated to a kind, using a parallel with civil law, of contract for future effects.

On the other hand, the contract that, hopefully, should be implemented, involves a completely different dimension, that of periodic data scanning, aimed not at the termination of the contract, but at its evolution, change and adaptation.

It is essential to delineate, first, the minimal and necessary features of a multi-phase contract mentioned above, and secondly, to highlight if there are examples, even partials that can be joined from a regulatory point of view to the latter.

As regards the specific legal section, it is possible to summarize the fundamental features of the insurance contract to be implemented, in possession of the technical and legal requirements, as well as in compliance with national and supranational regulations, such as written form of the contract, multiperiod scan and related termination of the contract, initial risk, determination of the premium and possibility to use eventual surplus in risk mitigation assets.

Some of the previous point have already been clarified, then down below, it shall be pointed out the residual parts and, in general, summarized the whole framework.

First of all, in accordance with Italian and European regulations, some points, that is the essential and fundamental minimum requirements emerge clearly, and from these latter the foundations must be laid for practical implementation.

In particular, the contract includes, with a view to an initial Italian implementation, the following rules: Art. 1882 *et seq*. Italian Civil Code, Article 8-*ter* of Legislative Decree 135.2018 converted into L 12/2019, Article 41 of Regulation (EU) n. 910/2014 of the European Parliament and of the Council, of 23 July 2014, EU Regulation 2017/1129 of the European Parliament and of the Council, of 30 June 2019, Directive 2016/97, recently implemented in Italy with Legislative Decree May 68/2018 EU Regulation of the European Commission (EU) 2017/1469 of 11 August 2017.

The second focal point relates to the mandatory written form, prescribed for all insurance contracts. in compliance with article 8-ter of Decree Law 135.2018 converted into L 12/2019 Smart contracts meet the requirement of written form subject to the IT identification of the interested parties, through a process having the requirements set by the Digital Agency for Italy (AGID) with guidelines to be adopted within ninety days from the date of entry into force of the law converting this decree. On the one hand the written form is prescribed, or rather the recognition of the validity of the smart contract in all the contracts that require the written form, on the other the guidelines of the AGID, recently diffused, say nothing against the prescriptions of the written form.

In a supranational context, in accordance with the regulations 910/2014, 2017/1129 and 2017/1469, if on the one hand the written form is prescribed, or rather the recognition of the validity, on the one hand of the information content of the insurance contract, compulsorily in writing, on the other hand as regards the smart contract, or more generally, any electronic document lacks the guidelines of individual member states.

The second profile is related to multi-periodality. This profile is allowed in the sense in which the contract is intended as a *unicum* in order not to incur the prohibition of which, in the event of a risk reduction, as originally calculated, the insurer must apply the lower premium starting from the deadline following the related communication, or, as an alternative, the express right of the contractor to withdraw from the agreement within two months of notification and with effect from the following month is reserved. In the reverse case, of an increase, therefore, of the ab initio established risk, the insured is, on the one hand obliged to give immediate notice to the insurer, and on the other, the latter has the right to withdraw from the contract with effect to date from the following month, while he cannot, continue the agreement by raising the premium or reducing the sum insured, without the express consent of the insured. The multi-period must be understood, therefore, as a multiple temporal scan within a single contractual period.

Even in the supranational panorama it seems plausible to be able to give the same conclusions as in the legislation concerning Italy, with the specification that the supranational provisions of the information content do not seem to obstruct the desired declination.

In accordance with the provisions of the Italian civil code, in compliance with the guarantees granted to the parties, it does not seem possible to change the premium without the express consensus at the time of determination of the same. Both from what can be deduced from the contrary in the provision of the Regulation of 11 August 2017 in the payment execution section, and from the provisions of the major European civil law systems, it seems that a variation, in order to the performance of the contractual, assumed as an unicum, is not feasible. Because of this, the premium, shall remain the same during the entire duration of the contract.

As regards the possible destination of a sum for mitigative infrastructures, the multi-period, and not the multi-year, therefore framing the contract as a unicum time scan, could grant the expedient of the initial fixed premium, potentially higher than a standard quantification. The allocation of part of the premium, at fixed intervals, according to the data flow, within the single time period scan, referred to in the contractual life, does not seem to suffer any prohibition. It seems therefore that this financial and environmental tool can be implemented in the sense that, since a payment by the weak party (insured) of a fixed premium, there do not seem to be any impediments to the disbursement of part of it, at certain periods and in certain circumstances, for the implementation of mitigative infrastructures.

THE ACTUARIAL MODEL: AN INSURANCE ADAPTIVE SCHEME. – In the first subsection we present the basic model to face flood risk, which implies the choice of the stakeholder, for example the public administration responsible for flood risk in a certain area, among no insurance for such risk, insurance or insurance and investment in mitigative infrastructures. In this subsection we don't consider the role of new information, collected after choice time, which can be considered into contract design, for example in terms of trend variations of the risk exposure, of the registered losses, of comparison between the premium paid and the registered losses till a certain time, and so on. This last point could be considered in order to generate potential surplus which can be invested in mitigative infrastructures.

THE BASIC MODEL: NO INSURANCE, INSURANCE OR INSURANCE AND RESILIENCE. – In this paragraph we describe the multiphase insurance adaptive scheme facing flood risk in a certain area. Let consider a random variable Y which describes the risk level in the insured area. Such random variable could describe or the rainfall registered in a fixed unit of time (hours, days, weeks,…) or the water level of one or more rivers which flow in the insured area, or some other indexes measuring the primarily source of flood risk. We assume to have historical series of the observations of this random variable, yi, with i=1,2...n, from which we can estimate the distribution of r.v. Y, FY.

Let X the random variable which describes the random loss due to flood risk in a fixed unit of time into insured area without any mitigative infrastructures. We also assume to have historical series of the observations of this random variable, xi, with i=1,2...n, from which we can estimate the distribution of r.v. X, FX.

In that case, applying a premium principle based on the distribution of X, we can determine a premium P[X] in the unit of time.

The insurance contractual conditions have to take count of the estimates relative to r.v. X, but it should be interesting even to estimate a regression model between X and Y, from which contractual conditions could be directly linked to the original source of risk, that can be useful (or necessary), for example, in case of losses data scarcity.

Let l be the regression function between X and Y without any mitigative infrastructures, that is X=l(Y).

From hydraulic engineering expertise we can estimate the regression function between X and Y in case of various mitigative infrastructures are built.

Let assume Ci, with i=1,2...m, an increasing sequence of infrastructures costs, more and more efficient, such that the regression functions li, with i=1,2,...m, describe a decreasing risk exposure, given the distribution of Y.

So, let P[Xi], i=1,2...m be the premium in the unit of time, in case of infrastructures i is built, with the same premium principle applied before, in this case to r.v. $X_i = l_i(Y)$. From the previous assumption on the efficiency of mitigative infrastructures we have, $P[X_i] < P[X_{i+1}]$, for each i.

If ti is the time necessary to build up infrastructures i, let assume that before the infrastructures is not finished, the risk exposure remains the original one, even if from an engineering point of view we can have a more detailed assumption in term of the evolution of risk exposure during the building time. With some further refinements to the quantitative model is possible to take count even of these aspects, but we prefer to focus on a simplified version.

The fundamental choices of the stakeholder, for example the public administration responsible of the flood risk in the area, are three:

- no insurance (and no resilience action) and payment of the random losses (in average E[X] for each unit of time);
- no insurance and resilience action through mitigative infrastructure i and payment of the random losses (in average E[X] for each unit of time) plus the constant amount ci/ti;
- insurance and no resilience action and payment of a constant amount P[X];
- insurance and resilience action through mitigative infrastructures i and payment of a constant amount P[X] + ci/ti till time ti, after that the premium $P[X_i] < P[X]$ for each unit of time.

Indeed we have to take count that the possible infrastructures are m, and so strategies II and IV have m different scenarios.

The comparison between I and III only depends by the randomness of future losses respect to the average value estimated for the past. Roughly the same comparison of II and IV, but we have to consider that we don't have observation of the losses relative to r.v. X_i, for each i=1, 2… m, since the historical series cannot take count of risk mitigation given by infrastructures i. So the estimation relative to r.v. Xi, is founded only in engineering expertise.

So we focus on the crucial choice between III (in average is the same of I) and IV (in average is the same of II), for each infrastructures i, with i=1,2,… m, that is between no resilience and resilience.

Let consider the present value (PV) of the total cost, with a discount rate r, which can be fixed with many types of assumptions that we don't explore now. We have to assume a time horizon which can be + ∞ or a fixed time T. Let consider this second choice.

So the present value of the total cost in case of strategy III

PV (III) = Σ j =1,2,..., T P[X] (1+r) -tj

While the present value of the total cost in case of strategy IV with infrastructure i (ti is the time to build it), for i=1,2,...,m

PV (IV, i) = Σ j =1,2,..., i (P[X]+ ci/ti)(1+r) -tj + Σ j=i +1, i +2,..., T P[Xi] (1+r) -tj

So the optimal strategy is one that minimizes this total cost.

The adaptive scheme: surplus for financing mitigative infrastructures. – Given the scenario described in the previous subsection, let consider a regular time grid si, i=0, 1, 2 … k at which we reset the insurance contract in such a way.

We start without any infrastructure and we know the engineering expertise estimation on infrastructures costs and their risk reduction effects.

If P is the constant total premium paid from si to si+1, i=0, 1, 2,… k-1, and X(i, i+1) is the total loss paid in the same interval, we have two different cases.

The first P < X(i, i+1) and in that case the larger losses is covered by the insurance system.

In the second we have a surplus P – X(i, i+1) and the adaptive design of the contract could provide that part of it, a in (0,1), is given back to the insured.

These surplus are summed up and the insured, the public administration, have to choice in which kind of infrastructure invest it. In case the decision is for infrastructure i, the stakeholder has to wait to accumulate a total surplus equal to its cost, ci.

At the time, one of the regular grid introduced before, a new contract starts: the premium paid by the insured has to be estimated using information collected till that time, for a contract of further duration ti, the time necessary to build up infrastructure i. After this further duration the insurance contract will proceed with premium E[Xi], given the expected loss with infrastructure i.

Let observe that with this adaptive model the starting premium P has to be higher than the expected loss, since it has to produce the surplus necessary to finance the mitigative infrastructure. Only when the necessary surplus is raised up, then the insurance premium has to be fair compared to expected losses.

We remark that this design with a fixed premium and the distribution of the surplus is allowed by the law environment of smart contracts. For the new definition of the premium is necessary a new deal between the 2 counterparts, as stated by the same law environment.

So the optimization problem in this adaptive insurance scheme has to determine the strategy that minimizes the total cost as seen in the previous subsection. The optimal strategy has to be defined in terms of the couple P and infrastructure i. Let consider that even in this optimization problem we have to compare also the equivalent strategies no insurance or only insurance (without resilience).

The total cost for the stratey (P*, i*) is given by, let si the expected time at which the necessary surplus ci is collected.

$$PV (P^*, i^*) = \Sigma\, j =1,2,..., i\ P\ (1+r)\ -sj + \Sigma\, j=i +1, i +2..., i+ti\ P[X]\ (1+r)\ -tj +$$
$$+ \Sigma\, j = i +ti +1, i +ti +2,..., T\ P[Xi]\ (1+r)\ -\ tj$$

The role of blockchain for this insurance adaptive scheme, is to certificate the information (data relative to the source of risk, to losses, to surplus, to infrastructure building) in order to allow for automatic renewals of the contract when it is not necessary a new deal between the counterparts to the contract.

COMMENTS AND FURTHER RESEARCH RECOMMENDATIONS. – This paper has presented an insurance contract facing flood risk in a multiperiodic scenario, based on an adaptive bayesian scheme, pointing out the opportunities and the criticisms by the point of view of the disciplines which are involved: actuarial, engineering, law. We disregard to detail the informatics aspects linked to the blockchain technology, leaving this issue to the specialist informatics literature. We underline that a classical actuarial approach, the bayesian adaptation due to the collection of new reliable information on the considered risk, could be inserted in a smart contract approach, with the support of blockchain technology.Since the risk is the flood one, we remark that an automatic updating scheme of the contract could concern also the infrastructures which have the role of risk mitigation and that also such component of the contract could be linked to the certification of blockchain approach.

Develops of this research could be imagined in various directions. The engineering and the actuarial approach have to dialogue in order to make their own analyses usable and useful one for the other and the legal overview has to clarify all the aspects such that the automatism provided by smart contracts in multiperiodic scenarios can be effectively conceivable in real cases.

REFERENCES

1. Serre D., Heinzlef C. (2018). Assessing and mapping urban resilience to floods with respect to cascading effects through critical infrastructure networks. International Journal of Disaster Risk Reduction 30: 235-243.
2. Zevenbergen C., Cashman A., Evelpidou N. *et al.* (2010). Urban Flood Management. CRC Press, 340 pp.
3. Swiss Re Institute (2014). Natural catastrophes and man-made disasters in 2013. *https://www.swissre.com/institute/library/sigma-2014-01-en.html.*
4. Galland J.P. (2010). Critique de la notion d'infrastructure critique. Flux 81: 6-18.
5. Serre D. (2018). DS3 model testing: assessing critical infrastructure network flood resilience at the neighbourhood scale. In: Fekete A., Fiedrich F. (Eds), Urban Disaster Resilience and Security. Springer: 207-220.
6. Pescaroli G., Kelman I. (2017). How critical infrastructure orients international relief in cascading disasters. J. Contingencies Crisis Manag. 25: 56-67.
7. Quenault B. (2014). La résurgence/convergence du triptyque «catastrophe-résilienceadaptation» pour (re)penser la «fabrique urbaine» face aux risques climatiques. Développement durable et territoires 5(3) - *https://journals.openedition.org/developpementdurable/10683.*
8. UNISDR (The United Nations International Strategy for Disaster Reduction) (2015). Sendai Framework for Disaster Risk Reduction 2015-2030. - *https://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf.*
9. Lhomme S., Serre D., Diab Y. *et al.* (2013). Analyzing resilience of urban networks: a preliminary step towards more flood resilient cities. Nat. Hazards Earth Syst. Sci. 13: 221-230.
10. Holling C.S. (1973). Resilience and stability of ecological systems. Annu. Rev. Ecol. Syst. 4: 1-23.
11. Bruneau D., Chang M., Eguchi S. *et al.* (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. Earthquake Spectra 19: 733–752.
12. Roberts R.S. (2012). Economic Strategies for Coastal Disaster Risk-Reduction: A Case Study of Exmouth. Ph.D. thesis, Murdoch University, Western Australia. - *https://pdfs.semanticscholar.org/70c3/8ec47c84a99baba0e0ab6ad6c2eea6d77354.pdf.*
13. Botzen W.J.W., van den Bergh J.C. (2008). Insurance against climate change and flooding in the Netherlands: present, future, and comparison with other countries. Risk Anal. 28: 413-426.
14. Rumson A., Hallett S., Brewer T. (2017). Coastal risk adaptation: the potential role of accessible geospatial Big Data. Marine Policy 83: 100-110.
15. Filatova T., Veen A. (2006). Microeconomic motives of land use change in coastal zone area: agent based modelling approach. In: Voinov A., Jakeman A. & Rizolli A. (Eds.), Proceedings of the 3rd Summit on Environmental Modelling and Software, Burlington, Vermont, USA.
16. Bertoldi P. (Ed.) (2018). Guidebook How to develop a Sustainable Energy and Climate Action Plan (SECAP) – Part 2 - Baseline Emission Inventory and Risk and Vulnerability Assessment. EUR 29412 EN, Publications Office of the EU, Luxembourg.
17. Kaspersen P.S., Halsnæs K. (2017). Integrated climate change risk assessment: a practical application for urban flooding during extreme precipitation. Climate services 6: 55-64.
18. EEA (2016). Urban adaptation to climate change in Europe 2016. Transforming cities in a changing climate. European Environmental Agency report, No 12/2016, 140 pp.
19. Rumson A., Hallett S., Brewer T. (2017). Coastal risk adaptation: the potential role of accessible geospatial Big Data. Marine Policy 83: 100-110.

20. UNISDR (2011). Global Assessment Report on Disaster Risk Reduction – Revealing Risk, Redefining Development - Geneva.
21. Lamberti F., Gatteschi V., Santamaria V. (2017). Blockchain or not blockchain, that is the question of the insurance and other sectors. Computer Science doi:10.1109/mitp.2017.265110355.
22. Lamberti F., Gatteschi V., Demartini C. *et al.* (2018). Blockchain and Smart Contracts for Insurance: Blockchain and smart contracts for insurance: Is the technology mature enough? Future Internet 10(2): 20.
23. Sayegh K. (2018). Blockchain application in insurance and reinsurance. Skema Business School, *www.researchgate.net/publication/327987901*.
24. Buterin V. (2014). A Next-Generation Smart Contract and Decentralized Application Platform, *https://github.com/ ethereum/wiki/wiki/White-Paper*.
25. Grasso A. (2018). Smart Contracts: Adoption value for enterprises and general use case - *https://www.researchgate.net/publication/330115021*.
26. IVASS (2016). Relazione sull'attività svolta dall'Istituto nell'anno 2016 - . *https://www.ivass.it/pubblicazioni-e-statistiche/pubblicazioni/relazione-annuale/*.
27. Macrinici D., Cartofeanu C., Gao S. (2018). Smart contract applications within blockchain technology: A systematic mapping study. Telemat. Informatics 35: 2337-2354.

Publication 8

Flood risk insurance: the Blockchain approach to a Bayesian adaptive design of the contract

Flood risk insurance: the Blockchain approach to a Bayesian adaptive design of the contract.

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Abstract

Informatics tools underlying cryptocurrencies markets, the so-called Blockchain, is raising up a lot of interest for applications in a wide range of fields. The key function of its use is to collect reliable information that could be used for a dynamic updating of contracts, that is one of the main opportunity given by smart contracting, with an adequate support of law's context in which such contracts are merged, that is one of the main issue to be developed for the full functioning of this kind of innovative business model. Blockchain and the connected smart contracting, seem very interesting even for insurance business, in particular for the bayesian adaptive approach which is a classic issue of actuarial science, based on the updating of premium evaluation using the collection of new information of risks phenomena. The new opportunity of collecting offered by the so-called big data even for classic insurance risks as for example, health, driving, climate and seismic events, together with the validating role of Blockchain approach, seem to be the perfect scenario for a massive use of smart contracting in insurance business. In this paper we describe the scheme of a flood risk insurance, the bayesian adaptive design of the contract, using Blockchain to validate both new data of risk phenomenon and the effect of mitigation of the faced risk due to infrastructural works.

Keywords: Blockchain, smart contracts, flood insurance, bayesian inference.

Introduction

The insurance sector, among many others, has an increasing interest for the application of blockchain technology, introduced by the milestone paper by the inventor Nakamoto [1], to its business, as shown by many documents of main insurance groups (let see [2], [3]) and consultancy firms ([4],[5],[6],[7]) and we have arrived to the creation, in 2016, of the B3i, the first blockchain-centered insurance consortium (as described in [8]). The key point for the use of blockchain for insurance business is the feasibility of smart contracts in this sector and the answer seems to be positive almost for the so-called instantaneous insurance, i.e. contracts with short duration which imply an automatism in issuing and in paying the eventual benefit settled in the contract as, for example, the flight delay insurance proposed by AXA, called Fizzy, completely developed on a blockchain platform.

In Gatteschi et al. ([9],[10]), there is a complete resume of the potential advantages of blockchain in many processes characteristics of insurance business, for instance the increase of speed of claim processing, data entry for identity verification, collecting reliable data for fraud prevention, use of mobile devices for instantaneous insurance (as the case mentioned before). One of the potential application field which still has to be investigated is peer-to-peer insurance or reinsurance (let see, [11], [12]), though it must be said that, at present, they are not real peer-to-peer models, as they have a traditional insurance model or risk carrier behind them, supporting the heavy part of the insurance business. In this context, smart contracts could represent an important innovation and a prototype solution based on the Ethereum blockchain has already been implemented [13]. It should be underlined, however, that the adoption of peer-to-peer insurance models by the wider public is not imminent yet since a large part of customers still considers necessary the interaction with intermediaries [14].
Our paper is focused on the analysis of the potential use of blockchain technology for smart contracts which consider a multiperiodic insurance coverage, exploiting the automatism allowed by blockchain technology for updating the contractual conditions, based on new reliable information collected while time passes. Up to our knowledge this is a new issue in the literature and our aim is to underline opportunities and criticisms of this kind of contracts.
This periodic updating of the contract is a well-known approach in actuarial science, e.g. the so-called credibility theory, which is based on a bayesian adaptive scheme.
Among the possible fields for applying a bayesian adaptive scheme in a multiperiodic insurance coverage, we choose one of large current interest, that is the risk connected to extreme climate events and, in particular, we analyze the flood risk. To pursue this kind of research we need a multidisciplinary approach, since the macro-fields which are involved are the actuarial science for the quantitative analysis, an engineering expertise for evaluating the flood risk in a certain area, the legal point of view in order to give a proper law support for smart contracts in a multiperiodic scenario and, finally, the informatics expertise to explain the process provided by blockchain technology.
Considering the current instruments for an economic mitigation of extreme risks due to climate events, traditional reinsurance, cat-bonds and resilience bonds, we propose an approach similar to one implicit in resilience bonds scheme, that is not only a coverage of eventual damages, but also the opportunity of financing infrastructures for mitigating the risk. Our propose is based on the calculation of the insurance premium at issue date and at every updating time, based on information collected at each time in a classic bayesian adaptive scheme, such that the premium level may automatically change time by time. Furthermore, at each renewal time, part of the eventual surplus of the premium payed respect to the payments occurred for damages has to be (automatically, settled in contractual conditions) used for financing mitigative infrastructures. Blockchain technology has the role of certifying reliable new information and also the state of mitigative infrastructures, which can vary according to the use of the surplus as mentioned before.

This paper has the following structure. In the first paragraph the engineering point of view of measuring and mitigating flood risk is presented. In the second we present an overview of the legal aspects of smart contracts in a multiperiodic scenario. In the third paragraph it is presented the bayesian adaptive design of the contract according to an actuarial approach. Then we propose some conclusions and mainly some comments of possible developing lines of this multidisciplinary research.

1. 1. Assessment of flood risk of critical infrastructural systems

1.1 Flood and critical infrastructure

Since the early 1970s extreme events associate to natural disaster have been growing both in frequency and intensity. Specifically during the last 15 has been recorded an increase of 2% a year [15] . The same increased trend was also reflected on the number of disaster flood events more than 600 from the year 2007 [16] . What happens in the year 2013 in the Central Europe was particularly impactful: 16.5 billion in economic losses (large-scale damage across Germany, the Czech Republic, Hungary and Poland) for 4.1 billion in insurance paid claims. The year 2013 has negative record of the increase of flood damages of approximately 50% respect the period 20032012 [3] and to show for first time three consecutive losses exceeding 100 billion in a 10 years period time [15, 18]. These figures represents an evidence how the increase of the population in urban areas [15] and the consequential increase of their complexities of both social and technological dimensions define a bottleneck within flood risk management. In fact the rapid growth of human concentration and urbanized areas has increased the exposure to the existing flood recurrence time making more difficult the realization of proper mitigation measures such as the availability of the land to be settled as potential flood risk zone. Among different assets that increased their risk to flood due to an increased exposure Critical Infrastructures (CI) need a specific emphasis. Critical infrastructures represent body of systems, networks and assets that are essential for the functioning of a society, publics health and/or safety and economy of a nation. CI are thus engineering and technological networks, such as energy/water supply, transport services, water supply, oil and gas supply, banking and finance, and ICT (information and communication technology) systems. All these systems are important (and thus critical) to maintain essential functions of society, and their failures can heavily seriously affect the population, economy, and national security [19, 20]. Such CI systems, facing with the increase of the complexity of urban systems must strengthen their interactions among people, activities, and properties. In fact this represents an increase of the vulnerability without the possibility to build new infrastructures in risk areas mainly due to lack of land [20, 21]. In other words the complexity of infrastructures and urban systems lessens the activities of components in a crisis period. This is the reason that addressed the attention of policy-makers, economist, urban planners, engineers, insurance companies and scientist to find innovative Risk Management frameworks to more sustainable and more resilient cope with climate changes effect and natural hazards [22]. A new approach has thus been gradually developed, based on the concept of urban resilience, nowadays implemented within the Sendai Framework for Disaster Risk Reduction [23].

1.2 The concept of Infrastructural Resilience

Due the complexity and independency of infrastructure in urban areas there is an higher risk to have cascading effects in fact generating secondary effects in areas much more far from the real flooded area [21, 24]. It is a key aspect to minimize the secondary problems that flooding of networks may have [25]. In order to move towards these directions a novel risk reduction approach based on a strategic development of urban and infrastructural systems has been proposed within the last Sendai Protocol developed in the 2015 based on the resilience concept [26]. Based on the United Nations Office for Disaster Risk Reduction (UNISDR) within the term resilience was introduced a time reference respect the disaster event (i.e. ex-ante, during, ex-post) and the concept of essential functionality of the communities, infrastructures or any other type of systems under the effect of an hazard [27]. In this way resilience it can be seen as as the capability to withstand a shock or stress, resisting and adapting, in order to restore the initial functionality [1]. This is also involving the definition of absorption/resistance, adaptation, recovery capacities to (re) create or maintain a balance functionality of the system [15]. In this definition there is the proactive capacity to learn and thus anticipate the effect of a catastrophe [15]. Resilience has direct connection with ecological dimension as proposed by Holling [27]. The definition can be thus generalized as capacity of a system to absorb disturbances and to recover after a major disruption and to restart an activity on the territory [15]. Different methods have been proposed to assess resilience and role of the infrastructural resilience within it. For example in the work of Serre et al. [15] is proposed for urban/engineering networks are able to propagate flood risk the overall urban resilience is identified into 3 main capacities namely: Resistance capacity, Absorption capacity and Recovery capacity. Similarly like in the concept proposed by Bruneau et al. [28] with the introduction of the 4Rs (i.e. Robustness, Redundancy; Resourcefulness; and Rapidity) approach. It is thus evident how conceptual and (semi) quantitative model approaches based on the selection of a set of proper indicators must be developed for assessing the effectiveness of specific mitigation and/or adaptation strategies within an overall Risk Reduction framework.

1.3 Flood Risk definition

As mentioned urban population increase and the consequential rise of the increase complexity of the CI represent factors that amplify the level of local vulnerability [29, 30]. In fact there is a direct connection of the natural hazard losses to the number of people and complex infrastructure living in areas prone to hazards. Thus the assessment of the Risk losses is not a trivial task since both the engineering dimension as well as the social impact should be evaluated.

Generally the Risk to natural disaster including flood is defined within the probability perspective in terms of occurrence time of a certain hazards, factored by the severity of its consequences [31] , according to the following formula:

Risk =Probability x Consequence (1)

Thus Risk represents a key instrument and criteria leading to flood zone management policy, land and infrastructural development planning [32]. It is thus evident the important role of the engineering dimension to assess the potential cost/benefit in terms of decreased flood risk level once a specific CI (or other engineering system) is strengthened and/or newly built. Risk formula presents also other expended description on where the probabilistic dimension of the Hazard is then related to the Exposure and Vulnerability. Both aspects are related to the intrinsic propensity of a certain asset to be at Risk. Thus, the engineering aspect to understand the effects of an hazard of a certain magnitude is essential. This general formula is reported below:

Risk = Hazard x Exposure x Vulnerability (2)

Within the proposed Risk assessment there the need to use GIS-based system on which hazard (e.g. flood), vulnerability and assets maps are combined trough the use a weighing process and normalization. This task has to be replicated for each climate-related impact [33]].

In this way the flood risk assessment is translated in terms of potential loss and damages costs. This is most of time impossible to be done for each infrastructure and/or asset at risk due to data scarcity. In these way insurance companies databases are often using proxies to overcome this bottleneck. As reported by Kaspersen and Halsnes [34] Danish Insurance Company define a damage function and unit damage costs based on flood levels for different buildings during extreme precipitation. In this case health costs (based on number of people exposed to mixed rain-sewage water) and expected costs for different rain patterns considering extremes climate event are calculated in monetary values as losses for each asset and damage costs. Since quantitative and probabilistic approaches are not always possible to be used and converted into a monetary dimension (mostly in connection to the social dimension, the effectiveness of Risk Reduction scenarios through a Multicriteria Assessment (MCA) towards urban adaptation planning [35]. Normally with adaptation strategies are beneficial for the overall resilience of certain system and thus its risk reduction. According to [36] for physical systems can be identified in 2 types of measures namely hard and soft. The first referred to (semi)permanent installation within the area of the potential flood, the second ones are those relate to natural process for example like are tackling flood in terms of erosion decrease and or increase of roughness in the flooded areas [15, 37].

1.4 Holistic resilience approach for Risk reduction: a new paradigm for adaptation and mitigation strategies

Within the presented perspective there is a need to move towards an holistic risk reduction to areas prone to natural disaster not only including the engineering infrastructural system but also the social and territorial dimensions in terms of human, environmental, financial and political system which could increase or decrease the overall resilience. Consequently there is need to assess how potential CI infrastructure improvements including hard and/or soft measures together with financial and insurance mechanisms can optimize the overall territorial resilience. In this context there is a need to develop quantitative or semi quantitative approaches that could evaluate the optimization in a sort of cost/benefit analysis among the capacities characterizing the resilience of an urban system and/or community. In this respect over the last decade particularly attention was devoted to the selection of specific on risk assessment with an emphasis on the measure of vulnerability areas and community at risks [38]. In fact on this extend the select of specific vulnerability indicator for food risk can have a real effect on the formula used to define the local risk. Nowadays most of the common indicators are addressed to characterized vulnerability in terms of susceptibility, fragility sometime even embedding specific resilient aspect such as adaptability [15]. The aspect to move towards a new paradigm of the disaster risk reduction emphasis the multidisciplinary of the resilience thus including ncluding the social, economic, institutional, infrastructure/engineering and community structure and all the connected information [15, 39]. Thanks to the indicators methodology, it is now possible to explore social, urban, technical phenomena and to determine which area is more or less resilient by a comparative work [39] normally within a Multi Criteria Analysis (MCA) approach. The technical dimension and thus the engineering perspective within this approach highlight the importance of taking into account the assessment of the critical infrastructure vulnerability, and more specifically urban networks facing with natural disaster such flood risk. The study of Serre et al. [15] proposes an assessment on the impacts of potential disruption of urban networks based on the evaluation of the capacities that characterized the level of resilience of a urban environment from a technical perspective. In this the methodology is able to identify resilience characteristics at the urbane scale and to plan for enhancing strategies. The contribution of the use of MCA model identified factors that would lead to increase urban resilience, highlighting the importance of urban networks and critical infrastructure. As reported in the work of Feofilovs et al. [40] the approach Mayunga [41] provide also a consistent holistic method resulting in an index score for the measure of communitys disaster resilience taking into account both the different phase of a disaster (i.e. mitigation, preparedness, response, and recovery) and the potential dimensions of resources (so called capitals including the infrastructural) that can be mobilized (i.e. social, human, economic, physical, environmental) or affected by an occurred hazard.

1.5 The need of multidiscipline interface: the implementation of the block chain

Several examples of urban disasters show the challenges still actual in urban flood management, especially in an uncertain context, driven by as strategic and innovative approaches to build urban resilience strategies. It is thus clear how within risk assessments, hazards need to be identified, together with estimations of their probability, and quantification of the impacts these hazards will have on vulnerable areas. This enables adaptive management strategies to be developed. This becomes even more a crucial aspect towards sustainable development plans and strategies according to the framework of the so called Sustainable Energy and Climate Action Plans (SECAPs) for Municipality. Within it Risk, Vulnerability assessments represent aspect that must assessed, evaluated and improved [33]. Within the definition of measures addressed to enhance the infrastructural resilience for the engineering dimension must be emphasized how preparation, resistance and adaptation capacities to flood Risk are spatial and time dependent. All these aspect suggest how there is a need of a new and innovative technology toward the direction of an integrated Risk Management toward strengthening resilience to flood at urban level In this direction is going the latest development advances in computing power within the processing of Big Data that can anyway create a criticalities once there is a need of analysis and processing of several dataset such as environmental, flooding, geological, weather, satellite obervations, topography/cadastral location, corporate, specific insurance, social economic, Risk/Hazard [42] specifically addressed for the flood risk evaluation. In this direction is going the use of Big-Data and the latest development of computing power that can anyway create criticalities once there is a need of analysis and processing of several dataset such as environmental, flooding, geological, weather, satellite obervations, topography/cadastral location, corporate, specific insurance, social economic, Risk/Hazard [42] specifically addressed for the flood risk evaluation. Rumson [42] underlines the need to better assess risk flood thanks to improved ability of programming device to store, process and analyse aggregated and disaggregated data, combining database and real-time streaming data [43]. In this way is highlighted the need of an holistic approach on data collection, analysis and processing with different types of analytical tools involving Geographical Information Systems (GIS), probabilistic modelling and definition of the damage curve thus in connection of engineering aspects relied to the vulnerability of physical assets exposed to Risk (e.g. any type of networked critical infrastructure as key instrument proposed. This interconnection and multidisciplinary aspect can thus support the development of proper insurance-based mechanisms as an option of adaptation able to increase local resilience to flood Within this view blockchain technology represent a good platform to mitigate risk and vulnerability towards the collection and analysis of different data source (i.e. Big data related to GIS systems, Environmental variables, Exposure data, Social media data, etc..) a real time risk assessment and thus a better definition of a risk-based pricing of insurance policies facing with potential losses. The article of Hokey Min [44] emphasis how within a blockchain platform Big Data and any other types of distributed database can be more efficiently share and more fast confirmed and validated. Within the same article the author explains the potential of blockchain to categorize and assess vulnerability and risk associated to a certain occurrence probability, and how consequently develop contingency plan for risk mitigation.

2. An overview of the legal aspects for multi-period smart contracts

To highlight the scientific and applicative gap of a specific smart insurance contract against natural hazard, the first methodological approach, specifically the legal one, leads to an overview of the state of the art of the thematic areas of implementation of smart contracts themselves. The most important implementation of the Bitcoin protocol is without any doubt Ethereum, with its cryptocurrency Ether (second to bitcoin by capitalization and by currency/dollars exchange). This platform allows the use of the so-called Smart Contracts.[45] These "smart contracts" are the development of the research carried out by Nick Szabo, who in the nineties was a reference author in the data encryption landscape. In 1997 he published two papers [46] in which he theorized a system of transfer of rights in execution of a mathematical algorithm, inspired by the sales system of vending machines.[47] The following year he released the third paper in which he formalized the concepts outlined in previous works. In his scheme a specific property right is included in a title intended to circulate, together with related information.
The transfer is put into a mathematical-cryptographic security and the ownership title is placed in a logical chain of previous similar securities as a guarantee of the continuity of operations.[48] Thanks to the invention of the Blockchain, in 2014, the twenty year old Vitalik Buterin, outlined the characteristics of what then became the main platform for the development and performance of smart contracts: Ethereum. The purpose of this platform is to provide a Blockchain tech-tool with a built-in programming language, which can be used to build "contracts" and to encode functions, so that these contracts are self-executed in accordance with the pre-set rules: all this simply by writing the logic of their operation in a few lines of code.[49]
There is no universally accepted definition of Smart Contract, due to its recent appearance on the scene and its technological complexity. A simple definition is that of an agreement whose performance is automatic, so an algorithm for computer transactions, which comply with the terms of the contract. [50] Perhaps a more correct definition, even thinking about the applicative scope of the paper was provided by the Italian IVASS (Italian Institute for Insurance Supervision), according to which smart contracts are contracts that are written in a specific language that can be understood, translated and executed by a computer, whose clauses can produce actions without external intervention based on information received in input and processed according to predefined rules.[51]
In accordance with the fact that the characteristics of any good or data can be digitized and represented by a code, each of these informations can be stored and secured in a distributed register, not only from a static but also a dynamic point of view .The operations and the agreements between the nodes of the network can be tracked and their execution can be automatically performed by the Blockchain itself without the intervention of intermediaries. All this has become possible thanks to the Smart Contracts which, as IT protocols, formalize the elements of an agreement and automatically execute the terms of the agreement

(terms that are therefore predefined) when the conditions foreseen by the agreement are fulfilled (even the conditions are therefore predefined and codified). In a nutshell, to provide a significative statement in order to understand the operation of smart contracts a smart contract is a piece of code which is stored on an Blockchain, triggered by Blockchain transactions, and which reads and writes data in that Blockchains database [52] The development and evolution of Smart Contracts have been sudden, their application is expanding day by day. In addition to Ethereum, other open source projects were born to create increasingly sophisticated Smart Contracts (like Counterparty and Mastercoin). To date, they have been created to automatically execute derivatives, futures, swaps and options. They have also been used to build platforms for the sale of goods on the internet, among unknown people, without the help of central authorities. [53]

As regards and more closely related to the development of the paper, the most analysed state of the art, to obtain a link to the current regulatory substrate referred to in the blockchain, was clearly that of the insurance dynamics. In the insurance sector, forms of insurance have developed that use Smart Contracts. The first example is InsureETH, an UK startup, in the field of airline reimbursements/compensations. Another case is that of the pilot project of the American International Group (AIG) together with IBM and Chartered Bank who worked together for a multinational insurance coverage, preparing a Blockchain insurance Smart Contract.

It is worth adding that recently AXA insurance [54] in order to refunds following delay or cancellation of the flight, has developed an extremely interesting smart contract. The insurance called Fizzy, appears revolutionary because, as described in the AXA portal, it excludes any kind of negligence, tipycal instead of the traditional insurance dynamics. The smart insurance, regardless of any external event or subjective / objective liability, automatically compensates in case of flight delay. [55]

And therefore, summarizing the two research questions, it is possible to determine that, firstly, the smart contracts have had a rapid development and evolution, and secondly, in the insurance sector, the blockchain technology is used and relegated to the automation of the mechanism of compensation. This huge implementation gap leaves the way for the use of blockchain data storage technology and modification of the contractual structure. In practice, it's time to move from a purely refund insurance blockchain to a big data management one.[56] In order to the title section, what would be the difference of a standard smart insurance contract, therefore with instant effect, compared to a multi-period contract? One of the main differences was highlighted at the end of the section just ended. and it is quite clear that the main difference is about multiperiod. And, in this case it is appropriate to clarify this aspect, because multiperiod is not necessarily synonymous with a long term as the smart standard contract is not synonymous with short term.

The desired multiperiod implementation within the smart insurance contract is subject to the fact that, periodically, through the storage of data from external certified sources, using the blockchain technology, the contractual structure can

change, such as the insurance premium, the sum of compensation or the determination of the percentage of risk.[57]
And therefore, even if in a perspective about natural disasters, the scanned periods may be related to prolonged periods, the determination of multi-mode concerns the scanning of temporal phases in which it is possible to change and modify essential elements of the contract without the latter termination or requiring a new agreement between the parties. The second difference concerns the method of using the blockchain technology. Picking up one of the smart contracts mentioned above in the insurance field, the blockchain is simply used in two steps: 1) validation of the insured event, such as the hours of flight delay, and 2) the payment of the sum of money.[58] In other words, in the very few applicative experiences that took place in the last few years, insurances first of all made use of blockchain technology as an instrument to verify the insured event. The information, using as an example the AXA contract, deriving from the airline are stored within the blockchain data flow and any event of delay beyond the allowed limit "unblocks" and acts as a check and authorization for the second step.
The one-dimensional perspective of the contract in relation to the uniqueness of the period, understood as a contractual phase, emerges clearly. The data entered and the "transformation" of these through blockchain technology into legal effects, such as compensation, are contained in a single phase, without any possibility, that extends or changes the contractual structure. Therefore, in a one-dimensional perspective, the will of the parties, the economic agreements, regardless of information, external events, blockchain technology acts exclusively as a verifying agent of the insured event, relegated to a kind, using a parallel with civil law, of contract for future effects.[59]
On the other hand, the contract that, hopefully, should be implemented, involves a completely different dimension, that of periodic data scanning, aimed not at the termination of the contract, but at its evolution, change and adaptation.
In the perspective of a multi-phase contract, the relevant data, in accordance with the insurance dynamics against natural hazards, for example, rainfall, the height of the rivers, the damage previously incurred, not only serve to create a network of useful information to counteract the harmful phenomenon of risk, but also serves to store information using blockchain technology. The implementation, in addition to the aforementioned characteristics of a smart insurance standard contract, involves the perpetuation of the contract, step by step, following the flow of data and the physiological modification of the initial parameters to which the parties have expressed their consent.
It is essential to delineate, first, the minimal and necessary features of a multiphase contract mentioned above, and secondly, to highlight if there are examples, even partials that can be joined from a regulatory point of view to the latter. What are the minimum and essential characteristics imputable to such a contract?
Onerous, and therefore, taking up the standard scheme of an insurance contract, the agreement is based on the bilateral provision by which the insured

party pays, at agreed intervals, a sum called insurance premium, to the company, which, in the case which the event occurs compensates the damaged party.[60]
Aleatory, in the sense that the insured event, even if determined, described and outlined, is uncertain in its occurrence.[61] IT, in the sense that the stipulation of the contract occurs through an online platform through blockchain technology. In particular, the methods of signature are constituted by the expression of consent through the use of a digital signature device. Blockchain Technology.
Real time data flow, in the sense of an IT contract structure able to receive data and information related to the insured asset and related environment able to modify time by time the initial parameters set out in the stipulation of the contract. [62]
Automatic renegotiation, automatic consensus, in the sense that the contract, considering the flow of data, capable of physiologically modifying the initial parameters of the contract, is legitimated, in relation to the flow, to change economic conditions even when the new conditions result "in peius" for the so-called weak party, the insured subject.[63]
An analysis of the contracts disseminated with the individual characteristics mentioned above can be carried out by determining some cases that are widespread within the Italian regulatory system.
As far as the cost of the contract is concerned, this is meant as the one in which a subject receives an advantage in exchange for a non-gratuitous disbursement, defined as performance. There is a close relationship between advantage and performance, a causal link. A typical example in the Italian civil code panorama is represented by the sale, regardless of whether it concerns movable or immovable assets, in which a subject pays a sum to another party and the latter, as a counter-claim, sells the asset de quo. [59]
The dynamics inherent in the concept of "aleatory", on the other hand, pertains to the uncertainty of the occurrence of a determined event. Remaining in the specific theme of research and paper, clearly the insurance contract is the perfect example. IT technology is inherent in the numerous chaos of digital contracts. In particular, a digital contract is an agreement entered into on an online platform through which legal effects desired by both parties emerge. one of the best known digital contracts is certainly the one related to e-commerce platforms, through which the buyer, in exchange for a payment, in most cases by credit card or similar means, purchases one or more assets on a website, which can act as a vendor tout court (Nike store, Ticketone) or as a mere intermediary (Amazon, Ebay).
The technical definition of blockchain is "decentralized ledger and cryptographically secure transaction" [64]. More generally, it is a technology that makes it possible to exchange not only information on the internet, but, for the first time, properties as well. Not therefore the simple payment or exchange of goods and services, but, thanks to this innovation, any other form of collaboration between men can take advantage of the possibilities offered by the network. So, when we talk about blockchain, we refer to an international safe register, shared by all the subjects acting within a specific computer network, based on peer-to-peer technology.

The chain has the peculiarity of recording and archiving all the transactions that are carried out within that network, not requiring the presence of third parties, so-called trusted. The name blockchain originates from the nature of the structure: each node of the network has a specific function in ascertaining the information entered, which is transmitted to the next node in a chain formed by blocks, the blockchain indeed. All transactions carried out to date and verified directly by the system are recorded in it. In fact, transactions are only possible if they are approved by 50% + 1 of the nodes.[65] The European association of credit institutions has, in one of its reports, expressed a positive opinion about the reliability of the system. The main characteristic of the whole IT structure can be synthesized with a single term: decentralization. In fact, there is no central repository in the blockchain but a peer-to-peer between users, by entering transactions in blocks.[66]
In a standard blockchain architecture, transactions are created from active components inserted in the network: the active user is called node and transfers Bitcoin to another node inserted in the network. The blocks of the network are created, in a chain, by other participants in the architecture that are defined miners. Miners to create blocks must solve complex algorithms and, if they succeed, they are rewarded with some Bitcoins. The newly created transaction is distributed and validated following a rigid one verification protocol to avoid, among others, the problem of "double spending problem ". In practice, the validity of one transaction is confirmed with the consent of the nodes of the network on the basis of parameters set for the operation of the network itself; the nodes that validate they are rewarded with Bitcoins. When the validity of the transaction is verified, the miners put it in a block and the transaction is executed (performed) in full respect of privacy.[49]
The flow of data, in the sense of the mere consecution of information entered in an IT platform, can be understood thinking of what is set out above regarding the smart insurance contract on air delay. the peculiarity of this contract is the discrepancy between the initial condition, and therefore the uncertainty inherent in the event, and the event itself. In practice, following the random logic of the insurance contract, the peculiarity consists in the input of data in real time and the consequent immediate simultaneous supply of the sum established in favour of the insured subject. The change of facts, the occurrence itself, modifying the conditions and using IT produces legal effects.[50] In the determination of a new possible contract the flow of data, albeit with different purpose, that is exclusively that relating to the change of the editorial, risk and insurance premium parameters, and therefore excluding the provision of any sum, it would have exactly the same functioning.
The last single feature inherent to the possible implementation of the contract de quo, concerns the forecast and contextual acceptance of the parties, of the modification in fieri of the economic conditions. This profile is closely linked to the data flow above. In particular, a data entry could be envisaged as per the insured asset, as well as the surrounding environment, capable of modifying the economic conditions, and therefore the insurance premium.[67] A contract to refer to and to use as a potential analogy tool certainly concerns the so-called

variable interest rate mortgage. A variable rate mortgage is a type of mortgage whose interest rates vary based on the performance of certain parameters indicated in the contract.
The reference parameters to which the interest rates are linked are usually the Euribor (EURo Inter Bank Offered Rate, ie the average interest rate of the financial transactions in Euro between the main European banks) the IRS (Interest Rate Swap) - EuroIRS or the Official ECB Reference Rate. The Euribor (Euro Interbank Offered Rate) is the interest rate used as an indexing parameter for variable-rate mortgage loans. The Euribor has replaced the national indexes since January 1, 1999. It is calculated daily as a simple average of the quotations recorded by a group of banks representing the European and world credit panorama selected by the European Banking Federation.
The reference rate for variable-rate mortgages is published daily at 11 am by a group of banks representing the European credit landscape. There are currently 20 institutions that contribute to taking over the Euribor.[68]
Summarizing the main section, regardless of the will of the parties that have signed the contract, the data coming from a third party, an external and independent entity, the economic characteristics may undergo changes. and so, if the Euribor, with the flow of data, is capable of modifying, inaudita altera parte, with the increase or decrease of the interest rate, the economic conditions, imposing on the parties, as above, with a view to an insurance smart contract against natural hazard, the flow of data entered into the digital blockchain platform is capable of modifying the parameters, such as risk and insurance premium, regardless of the parties will.[69]
For the purposes of drafting the paper, it is worth highlighting that almost all the features, some of which are inherent ex se, such as compensation and the "alea", others for subsequent implementation, such as IT, the flow of data and blockchain, are adaptable to our contract implementation project. As regards the dynamics of the renewal of the consensus to change the initial parameters, it seems appropriate to briefly outline a double scenario. Prima facie, the dynamics of the variable rate inherent to the loans, by structure and contractual framework do not seem to coincide with the insurance dynamics, and therefore, and this is the trait d'union with the section of engineering mitigation risk, [70] it appears extremely prudent to operate a contract in which a high premium insurance is envisaged, above the real initial risk. In particular, when the initial conditions change into peius, the prize in any case continues to be suitable from the point of view of the insurance company for the continuation of the activity, and when, with defined time scans, reconnecting to the theme of the multiperiod, the risk conditions reduce the difference between the bonus paid and the premium that, ideally, would have been corrected from a mathematical point of view, could be used to create risk mitigation structures.[71]

3. The actuarial model: a bayesian adaptive design of the contract

In this paragraph the bayesian adaptive design of the multiperiodic contract is described according to an actuarial scheme. Let $H(0)$ be the set of data representing information collected at time 0 starting from time $-m$ and let

$W(0) = f(H(-m, 0) \equiv f(H(0)$

the premium which has to be paid for one unit of time until the first updating time. Among such data we have the damages due to the insured risk and other information relative to flood risk, mitigative infrastructures and so on.

Let $m_1, m_2, ...$ be the sequence of updating times settled in the contract. At the generic time m_i, with $i = 1, 2, ...$, exploiting the collected information starting from$-m$, that is $H(-m, m_i)$, the new premium becomes

$W(i) = f(H(-m, m_i) \equiv f(H(i)$

and has to be payed until updating time m_{i+1}.
Let assume that the collected information $H(0)$ is the historical series of the damages $x(i)$, with $i = -m, -m+1, ...0$, in each time unit starting from $-m$ to issue date 0

$H(-m, 0) = x(-m), x(-m+1), ...x(-1), x(0)$

and let assume $H_r(0)$, for $r = 1, 2, ...$, the estimate of the $r-th$ moments of this random variable. If we assume a premium principle based on a variance style charge, we are interested only in $H_1(0)$, $H_2(0)$ and so the premium for a time unit starting from issue date, $W(0)$, could be expressed as

$W(0) = f(K_1(0), K_2(0))$.

Starting from issue date the contract provides the payments of the premium $W(0)$ for each unit of time, until the contract will have a first update, at time m_1, based on the arrival of new information, that is $H(1, m_1) = x(1), x(2), ..., x(m_1)$. At time m_1, using all the information registered in the interval $(-m, m_1)$ we have new estimates of $H_1(m_1)$, $H_2(m_1)$ and consequently the premium becomes

$W(m_1) = f(K_1(m_1), K_2(m_1))$

which has to be payed for each time unit from $m_1 + 1$ to next updating time m_2.
Let $n_i = m_i - m_{i-1}$ with $i = 1, 2, ...$ be the number of time units between m_i and m_{i-1}, so the total premium payed in such interval is $n_i W(i)$. The difference between such total premium and the total claim in the same time interval $C(i)$

$n_i W(i) - C(i) = U(i)$

is a profit or a loss for the insurance company.
The contract could provide that in case of profit, i.e. $U(i)$ is positive, part of the surplus obtained by the company will be shared with the insured, that is, used for infrastructural investment for risk mitigation. The evaluation of mitigative infrastructures costs and their impact in term of risk reduction, has to be assessed by an engineering analysis as described in paragraph 1.
The effect of this infrastructural investment on this numerical model could be introduced by a not decreasing sequence of thresholds $L(i)$, with $i = 1, 2, ...$, in the interval $m_{i-1}i$,m_i, which have an impact on the damages in the same time: the higher is $L(i)$, the lower we expect the total damage $C(i)$.
The assessment of the relationship between surplus and threshold increase has

to be implemented using engineering issues. It seems reasonable to consider a delay between the arise of the surplus and the effect on threshold, due to the time necessary to accomplish the infrastructures.

The role of blockchain technology is the certification of the collected information and the automatism with which the contractual terms (i.e. the premium level and the sharing of the surplus) should change at each updating time. Such automatism is the core of the concept of smart contracting, that is an update of the contract without a new bargain between the two counterparties. The legal aspects such that smart contracting is really admissible for this kind of insurance contract, has been analyzed in paragraph 2.

4. Comments and further lines of research

This paper has presented an insurance contract facing flood risk in a multiperiodic scenario, based on an adaptive bayesian scheme, pointing out the opportunities and the criticisms by the point of view of the disciplines which are involved: actuarial, engineering, law. We disregard to detail the informatics aspects linked to the blockchain technology, leaving this issue to the specialist informatics literature. We underline that a classical actuarial approach, the bayesian adaptation due to the collection of new reliable information on the considered risk, could be inserted in a smart contract approach, with the support of blockchain technology.
Since the risk is the flood one, we remark that an automatic updating scheme of the contract could concern also the infrastructures which have the role of risk mitigation and that also such component of the contract could be linked to the certification of blockchain approach.
Develops of this research could be imagined in various directions. The engineering and the actuarial approach have to dialogue in order to make their own analyzes usable and useful one for the other and the legal overview has to clarify all the aspects such that the automatism provided by smart contracts in multiperiodic scenarios can be effectively conceivable in real cases.

5. References

1. Nakamoto, S. Bitcoin: A Peer-to-Peer Electronic Cash System; 2008, Available online: https://bitcoin.org/bitcoin.pdf (accessed on 19 February 2018).
2. Higgins, S. Insurance Giant Allianz France Exploring Blockchain Potential. Available online: http://www.coindesk.com/allianz-france-exploring-use-cases-with-blockchain-startup/ (accessed on 30 June 2016).
3. Insurance Times Newsdesk. AXA leads 55m investment in blockchain. Available online: http://www.insurancetimes.co.uk/axa-leads-55m-investment-in-blockchain/1417270.article (accessed on 29 June 2016).
4. Ramada, M. For insurers blockchain is the new black. Available online: http://blog.willis.com/2016/12/for- insurers-blockchain-is-the-new-black/ (accessed on 29 December 2017).
5. Shelkovnikov, A. Blockchain Applications in Insurance; Deloitte Report; Deloitte LLP: London, UK, 2016; pp. 12.

6. Lorenz, J.-T.; Mnstermann, B.; Higginson, M.; Olesen, P.B.; Bohlken, N.; Ricciardi, V. Blockchain in Insurance-Opportunity or Threat?; McKinsey Company Report; McKinsey Company: New York, NY, USA, 2016; pp. 19.
7. McKinsey Company. Blockchain Technology in the Insurance Sector. In Proceedings of the Quarterly Meeting of the Federal Advisory Committee on Insurance (FACI), McKinsey Company: New York, NY, USA, 2017.
8. Higgins, S. European Insurance Firms Launch New Blockchain Consortium. Available online: http://www.coindesk.com/europe-insurance-blockchain-consortium/ (accessed on 29 December 2017).
9. Lamberti, F.; Gatteschi, V.; Demartini, C.; Pranteda, C.; Santamaria, V. Blockchain or not blockchain, that is the question of the insurance and other sectors. IT Prof. 2017, doi:10.1109/MITP.2017.265110355.
10. Lamberti, F.; Gatteschi, V.; Demartini, C.; Pranteda, C.; Santamaria, Blockchain and Smart Contracts for Insurance: Blockchain and smart contracts for insurance: Is the technology mature enough? In: FUTURE INTERNET, vol. 10 n. 2, 2018, pp. 1-16. - ISSN 1999-5903.
11. de Broglie, L.; Mury, E.; Corbeaux, L. insPeer.
Available online: http://www.inspeer.me/ (accessed on 29 December 2017).
12. Kunde, T.; Herfurth, S.; Meyer-Plath, J. Friendsurance: The P2P Insurance Concept. Available online: http://www.friendsurance.com/ (accessed on 29 December 2017).
13. Davis, J. Peer to Peer Insurance on an Ethereum Blockchain. Available online: http://www.dynamisapp.com/whitepaper.pdf (accessed on 29 December 2017).
14. Ernst Young. Voice of the CustomerTime for Insurers to Rethink Their Relationships: Ernst Young Report; Ernst Young: London, UK, 2012; pp. 136.
15. D. Serre, C.Heinzlef. Assessing and mapping urban resilience to floods with respect to cascading effects through critical infrastructure networks. International Journal of Disaster Risk Reduction 30 (2018) 235243.
16. C. Zevenbergen, A. Cashman, N. Evelpidou, E. Pasche, S. Garvin, R. Ashley, Urban. Flood Management, CRC Press, 2010.
17. G. Pescaroli, M. Nones, Cascading Events, Technology and the Floods Directive: future challenges. E3S Web of Conferences, 7, 7003, 2016. 18. Swiss Re, Natural catastrophes and man-made disasters in 2013, 2014.
19. J.-P. Galland, Critique de la notion d'infrastructure critique. (Criticism of critical infrastructure concept), Flux (81) (2010) 618.
20. D. Serre, DS3 model testing: assessing critical infrastructure network flood resilience at the neighbourhood scale, in: A. Fekete, F. Fiedrich (Eds.), Urban Disaster Resilience and Security, Springer International Publishing, Cham, 2018, pp. 207220.
21. G. Pescaroli, I. Kelman, How critical infrastructure orients international relief in cascading disasters, J. Contingencies Crisis Manag. 25 (2) (2017) 5667.
22. B. Quenault, La rsurgence/convergence du triptyque catastrophe-rsilienceadaptation pour (re)penser la fabrique urbaine face aux risques climatiques. (The resurgence / convergence of the triptych "disaster-resilience-adaptation" to (re) think

the "urban factory" in the face of climate risks.) Dveloppement durable et territoires, 5, 3.
23. UNISDR (The United Nations International Strategy for Disaster Reduction), Sendai Framework for Disaster Risk Reduction 2015 - 2030, p. 36, 2015.
24. S. Lhomme, D. Serre, Y. Diab, R. Laganier, Analyzing resilience of urban networks: a preliminary step towards more flood resilient cities, Nat. Hazards Earth Syst. Sci. 13
25. S. Lhomme, D. Serre, Y. Diab, R. Laganier, Analyzing resilience of urban networks: a preliminary step towards more flood resilient cities, Nat. Hazards Earth Syst. Sci. 13.
26. S. Lhomme, D. Serre, Y. Diab, R. Laganier, Analyzing resilience of urban networks: a preliminary step towards more flood resilient cities, Nat. Hazards Earth Syst. Sci. 13.
27. C.S. Holling, Resilience and stability of ecological systems, Annu. Rev. Ecol. Syst. 4 (1) (1973) 123. 28. D. Bruneau, M., Chang, S., Eguchi, R., Lee, G., ORourke, T., Reinhorn, A., Shinozuka, M., Tierney, K.,Wallace,W., von Winterfelt, A framework to quantitatively assess and enhance the seismic resilience of communities, EERI Spectra J., vol. 19, no. 4, pp. 733752, 2003.
29. R.S. Roberts, Economic Strategies for Coastal Disaster Risk-Reduction: A Case Study of Exmouth (Ph.D.), Murdoch University, Western Australia, 2012.
30. W.J.W. Botzen, J.C.J.M. van den Bergh, Insurance against climate change and flooding in the Netherlands: present, future, and comparison with other countries, Risk Anal. 28 (2008) 413426.
31. A. G. Rumson, S. H. Hallett, T.R. Brewer. Coastal risk adaptation: the potential role of accessible geospatial Big Data. Marine Policy 83 (2017) 100110.
32. T. Filatova, A. Veen, Microeconomic Motives of Land Use Change in Coastal Zone Area: Agent Based Modelling Approach, 2006.
33. Bertoldi P. (editor), Guidebook 'How to develop a Sustainable Energy and Climate Action Plan (SECAP) Part 2 - Baseline Emission Inventory (BEI) and Risk and Vulnerability Assessment (RVA), EUR 29412 EN, Publications Office of the European Union, Luxembourg, 2018.
34. Kaspersen, P.S. and Halsns K. (2017), Integrated climate change risk assessment: a practical application for urban flooding during extreme precipitation. Climate services 6, pp.55-64.
35. EEA (2016), Urban adaptation to climate change in Europe 2016. Transforming cities in a changing climate. European Environmental Agency report, No 12/2016, pp.140.
36. A. G. Rumson, S. H. Hallett, T.R. Brewer. Coastal risk adaptation: the potential role of accessible geospatial Big Data. Marine Policy 83 (2017) 100110.
37. UNISDR, Global Assessment Report on Disaster Risk Reduction Revealing Risk, Redefining Development, Geneva, 2011.
38. S.L. Cutter, L. Barnes, M. Berry, C. Burton, E. Evans, E. Tate, J. Webb, A place-based model for understanding community resilience to natural disasters, Glob. Environ. Change 18 (4) (2008) 598606.
39. A. Mller, J. Reiter, U. Weiland, Assessment of urban vulnerability towards floods using an indicator-based approach a case study for Santiago de Chile,

Nat. Hazards Earth Syst. Sci. 11 (8) (2011) 21072123.
40. Maksims Feofilovs, F. Romagnoli. Measuring community disaster resilience in the Latvian context: an apply case using a composite indicator approach. Energy Proceedia, 2016.
41. J. Mayunga, Measuring the measure— A multi-dimensional scale model to measure community disaster resilience in the US Gulf Coast region, no. May, pp. 1 247, 2009.
42. A.G. Rumson, Stephen H. Hallett. Innovations in the use of data facilitating insurance as a resilience mechanism for coastal flood risk. Science of the Total Environment 661 (2019) 598612.
43. Jagadish, H.V., 2015. Big Data and Science: Myths and Reality. Big Data Res. 2, 4952.
44. H. Min. Blockchain technology for enhancing supply chain resilience. Business Horizons (2019) 62, 3545.
45. M. A. Khan and K. Salah, IoT security: Review, blockchain solutions, and open challenges, Futur. Gener. Comput. Syst., vol. 82, pp. 395411, 2018.
46. N. Szabo, The Idea of Smart Contracts, http://szabo.best.vwh.net/idea.html, 1997.
47. N. Szabo, Read related articles on Internet economics and Security, http://firstmonday.org/ojs/index.php/fm/article/view/548/469, pp. 124, 1997.
48. M. L.?; D. C. P. Perugini, Introduzione agli Smart Contracts, http://ssrn.com/abstract=2729545, 2015.
49. V. Buterin, A Next-Generation Smart Contract and Decentralized Application Platform, https://github.com/ethereum/wiki/wiki/White-Paper, 2014.
50. A. Grasso, Smart Contracts: Adoption Value for Enterprises and General Use Case, 2018.
51. IVASS, Relazione sullattivit svolta dallIstituto nellanno 201, 2016.
52. G. Greenspan, Beware of the Impossible Smart Contract, http://www.theblockchain.com/2016/04/12/beware-of-the-impossible-smart-contract, 2016.
53. P. Wright, A. -De Filippi, Decentralized Blockchain technology and the rise of Lex Cryptographia, https://ssrn.com/abstract=2580664, 2015. 54. AXA Is Using Ethereum s Blockchain for a New Flight Insurance Product This website uses cookies, 2019.
55. AXA - Comunicato Stampa, AXA fa decollare in Italia Fizzy, la prima assicurazione viaggio al mondo basata su tecnologia blockchain che rivoluziona lesperienza cliente, 2018.
56. W. Viriyasitavat and D. Hoonsopon, Blockchain characteristics and consensus in modern business processes, J. Ind. Inf. Integr., no. June, pp. 01, 2018.
57. W. E. Forum, Rischi dei cambiamenti climatici?: il ruolo delle assicurazioni, 2013.
58. D. Macrinici, C. Cartofeanu, and S. Gao, Smart contract applications within blockchain technology: A systematic mapping study, Telemat. Informatics, vol. 35, no. 8, pp. 23372354, 2018.
59. Campobasso-Diritto commerciale. 3.pdf.

60. Aa. Vv., L Assicurazione dei Rischi Calamit Naturali, 7th R.I.B. Conv., no. November, 2000.
61. D. Porrini and R. Schwarze, Insurance models and European climate change policies: An assessment, Eur. J. Law Econ., vol. 38, no. 1, pp. 728, 2014.
62. I. Makhdoom, M. Abolhasan, H. Abbas, and W. Ni, Blockchains adoption in IoT: The challenges, and a way forward, J. Netw. Comput. Appl., vol. 125, no. October 2018, pp. 251279, 2019.
63. M. Andoni et al., Blockchain technology in the energy sector: A systematic review of challenges and opportunities, Renew. Sustain. Energy Rev., vol. 100, no. February 2018, pp. 143174, 2019.
64. H. Vranken, Sustainability of bitcoin and blockchains, Curr. Opin. Environ. Sustain., vol. 28, pp. 19, 2017.
65. H. Min, Blockchain technology for enhancing supply chain resilience, Bus. Horiz., vol. 62, no. 1, pp. 3545, 2018.
66. Banche , la sfida pi grande la blockchain.
https://www.startupbusiness.it/banche-la-sfida-della-blockchain/86184/, 2019.
67. K. Sayegh, Blockchain Application in Insurance and Reinsurance, no. October 2018, 2019.
68. Banca dItalia Tassi di interesse Analisi E Approfondimenti, 2019.
69. A. Jobst, What is Securitization?, Finance Development , IMF. p. Vol 45, 3, 2008.
70. M. Breckner, F. Englmaier, T. Stowasser, and U. Sunde, Resilience to natural disasters Insurance penetration, institutions, and disaster types, Econ. Lett., vol. 148, pp. 106110, 2016.
71. J. McAneney, D. McAneney, R. Musulin, G. Walker, and R. Crompton, Government-sponsored natural disaster insurance pools: A view from down-under, International Journal of Disaster Risk Reduction, vol. 15. 2016.

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Implementation of Blockchain Technology in Insurance Contracts Against Natural Hazards: A Methodological Multi-Disciplinary Approach

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Abstract – **Risk insurance for disasters plays a relevant part in the implementation of risk reduction strategies during the pre-disaster phase. This is essential to support risk management towards decreasing the marginal risk allowing policy holders to transfer risk to avoid considerable financial loads from the costs incurred during the recovery phase in a post-disaster phase. There is evidence that the introduction of an integrated risk insurance strategy for community resilience planning is still lacking. Thus, this undermines the possibility to have proper optimized holistic risk management; on the one hand this strengthens pre-disaster risk mitigation measures, mostly relying on mitigative infrastructural solutions, and on the other hand it better defines risk prevention strategies mostly connected to land planning and urban development. This paper will show how insurance markets can play a key role towards mitigating the economic consequences of natural and climate change disasters, and how essential it is to better quantify the beneficial effects and costs of engineer-based mitigative solutions. In this context, the legal framework into which the actuarial quantitative model can be implemented will support the creation of an integrated multidisciplinary approach with potential implementation on a novel platform capable of collecting and processing information from different sources and dimensions such as blockchain technology. The scientific community is, in fact, increasingly interested in implementing blockchain technology to overcome problems linked to the contractual dimension of natural disaster risk insurance which can be interpreted as a sort of smart contracting. Through a study that involved four distinct areas, namely: law, environmental engineering, insurance and IT, this paper proposes a specific multidisciplinary methodology to achieve the drafting and implementation of a digital insurance contract on a blockchain platform against natural hazards. This paper proposes the basis to advance a quantitative concept to optimize the impact of catastrophe risk insurance onto the community resilience; in fact providing a key synergy for definition of pre-disaster conditions.**

Keywords – **Blockchain; insurance; natural hazard; risk mitigation; risk reduction; smart contract**

1. INTRODUCTION

Since the early 1970s, extreme events associated with natural disaster have been growing both in frequency and intensity. Specifically, during the last 15 years there is a recorded

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increase of disasters at a rate of 2 % [1]. This increase is reflected in economic losses [2], gaining the attention of the scientific and professional communities to find novel and effective methods of insurance as a resilient management tools for risk reduction.

According to the study of Paleari [2], there are several factors affecting the overall benefits and sustainability of insurance mechanisms when coping with natural disasters that are only in part directly insurance-related. The first one is related to the time reference. In fact, insurance works only in an ex-post situation in terms of compensation to minimize the effects of natural disasters. This perspective by Paleari [2] identifies an interesting dynamic affecting the demand for insurance coverage from citizens: the lower the insurance penetration is, the higher the pressure is on governments to finance disaster losses. In this context, if governments offer full compensation, there is less incentive for citizens to get insured, in turn decreasing the overall demand for insurance coverage.

The second one relies on the concept of disaster risk management [3] in connection with the prioritization of recovery [4] or risk reduction strategies [5]. In fact, prevention and mitigation are defined by insurance companies during risks and potential loss assessments creating a cap for the level of insurability (or re-insurability) faced with insurance accessibility and affordability [6]. Several studies highlight this very aspect also in terms of the moral hazard potentially undermining any economic benefit [7].

Moral hazards occur at the governmental level, where existing private insurance schemes reduce the priority to prevent risks at the individual level [2]. The drawback of moral hazard by insurance policyholders is reflected in mandatory schemes applying flat premiums [8]. Governments normally distribute uniform packages of catastrophe benefits generally as ex-post public compensation.

At the EU level, two main insurance schemes against natural hazards can be identified [2]. The first one is defined in terms of voluntary add-on insurance schemes where the coverage for natural hazards is optional and it is proposed by private insurers. This has the consequence of having low penetration and thus supporting ex-post Government assistance.

The second scheme applied is mainly based on the mandatory extension of property insurance to disaster risks. In this context, a model of using non-risk-based premiums is normally used in high-risk area risk-averse to guarantee affordability and availability. The second scheme type has the consequence to have higher insurance penetration, but with a bigger loss potential [6], [8].

Rumson [9] defines insurance as the proper mechanism to deal with the issue of information asymmetry among the insurer and the insured. In this dynamic, insurance can trigger a risk-transfer between clients, the global insurance and capital markets [10], [11]. This could create a worldwide and interconnected risk transfer and (re)insurance markets from catastrophic losses occurring in a specific locality [11], [12] but shared globally.

By using this shared catastrophe information, in a non-speculative and competitive market, the price would be set upon the assessment of risk-reflective pricing [13]. For this reason, both sides within the stipulation of an insurance contract (i.e. underwriters and actuaries) need up-to-date access and availability of detailed and accurate information about the nature of the risks [14]. Bin et al. [15] identify how the price fixed by the insurance market represents a mechanism to raise awareness and potentially encourage risk-reluctant behaviour. If market alterations happen, these mechanisms can be weakened, resulting in negative societal effects [16].

Governments (and consequently legal entities) have a key connection to insurance. One example is flood insurance, which can be related to land planning, investments in adaptation, and coverage for some of the most vulnerable assets. [17] In this context and under the light of a growing increase of economic losses from disasters [18] in relation to weather/climate change (most evident for non-insured losses) [19], [20] more accurate risk evaluations need an enormous amount of data to be processed from different types of dimensions (e.g. environmental, geological, weather, insurance-specific, engineering, legal, socio-economic). Consequently, proper data platforms and the use of 'Big Data' need to be considered for pricing optimal insurance premiums [14]. In this way will be possible to lowering the risk of community prone to hazard in turn increasing the overall community resilience with a direct effect on the insurance premiums, in fact providing the possibility to allocate economic resources to more vulnerable locations. This aspect would be essential to create a solution to the problem on non-insured assets [13], and potentially result in an increased investment contributing to sustainable development in more resilient areas against weather/climate change-related disaster.

In this direction, informatics tools like "blockchain" are raising interest for applications in a wide range of fields including insurance. The key function of their use is to collect reliable information that can be used for a dynamic updating of contracts; this is one of the main opportunities presented by smart contracting, with an adequate support of legal context in which such contracts are merged, and one of the main issues to be developed for the full functioning of this kind of innovative business model.

The key point for the use of blockchain technologies for the insurance business is the feasibility of smart contracts in this sector and the answer seems to be positive for the so-called instantaneous insurance, i.e. contracts with short duration which imply an automatism in issuing and in paying the eventual benefit settled in the contract. One example of this is the flight delay insurance proposed by AXA, called Fizzy, completely developed on a blockchain platform.

The insurance sector, among many others, has an increasing interest for the application of blockchain technology, introduced by the milestone paper by the inventor Nakamoto [21], to its business, as shown by many documents of main insurance groups [22], [23] and consultancy firms [24]–[27] and we have arrived to the creation, in 2016, of the B3i, the first blockchain-centred insurance consortium [28].

One of the potential fields for application which still has to be investigated is peer-to-peer insurance or reinsurance [29], [30], though it must be said that, at present, they are no "real" peer-to-peer models, as they have a traditional insurance model or risk carrier behind them, supporting the heavy lifting of the insurance business. In this context, smart contracts representing an important innovation and a prototype solution based on the Ethereum blockchain have already been implemented [31]. It should be underlined, however, that the adoption of peer-to-peer insurance models by the wider public is not imminent since many customers still consider it necessary to interact with intermediaries [32].

This interconnection and multidisciplinary aspect can thus support the development of proper insurance-based mechanisms as an option of adaptation able to increase local resilience against different types of disasters. In this scope, blockchain technology represents a good platform to mitigate risk and vulnerability towards the collection and analysis of different data sources (i.e. Big data related to GIS systems, Environmental variables, Exposure data, Social media data, etc.) providing a real-time risk assessment, and thus a better definition of a risk-based pricing of insurance policies faced with potential losses.

This study would like to propose a novel approach as opportunity to decline risk-pricing of policies. These relate to a novel type of data collection technique and processing aiming to strengthening blockchain platform-based solutions merging information derived from inclusive and holistic data sources. In this way it would be possible to have predictions and pricing of risk on more extended and up-to-date empirical datasets.

This article also reveals how the adoption of blockchain technology involving a multidisciplinary framework can improve overall community resilience to natural disasters favouring adaptation strategies. The study proposes a consistent methodological approach identifying the role of insurance on risk adaptation, multi-dimensional data provision, and data processing for insurance price definition and the potential role played within a consistent legal framework.

Specific emphasis will be dedicated to highlight the capacity constraint that relates to the application of smart contracts to insurance against natural hazards. This paper will emphasize the potential use of blockchain technology for smart contracts which consider multi-periodic insurance coverage, exploiting the automatism allowed by blockchain technology for updating the contractual conditions, based on new and reliable information collected over time.

2. Method

When examining the issue on how to increase community resilience with novel insurance-based mechanisms, a systematic literature review was finalized. This part was mainly made on the analysis of scientific papers and grey literature.

In order to more consistently move towards the clarification of the research objectives, the research has been organized into these main steps:

- Role of insurance as adaptation measure to natural disaster;
- Smart contracts as insurance mechanisms against natural hazards;
- Blockchain overview;
- Blockchain and smart contracts: how they work.

The main results following the literature review will be implemented in a multidisciplinary manner that will serve as a framework to address the main challenges over the use of different data sources for the definition of a more updated and focused catastrophic (CAT) model for an optimized risk/premium evaluation.

Specifically, chapter 2 will better clarify the following main questions:

- What is a smart insurance contract?
- What are the experiences of implementing the blockchain technology in the insurance sector?
- What would be the difference of a standard smart insurance contract?
- Is there a regulatory framework capable of "accepting" smart multi-period insurance contracts? Possible multi-phase contracts with constant data flows. Analysis of the individual characteristics of the new contract;
- Is it possible to find any contractual declination to implement a multi-period smart contract?
- What structure could a smart multi-period contract have against natural hazard risk mitigation?
- What other aspects could it involve (e.g. Bayesian-quantitative and engineering profiles)?

2.1. Role of Insurance as Adaption Measure to Natural Disaster

Insurance dynamics have a focal role in human progress and efforts to predict, mitigate, and adapt to natural disasters [19]. Effective insurance can be a tool to spread the communication of risk related to a certain geographical location. In order to perform successfully, premiums, coverage, and types of insurance must be risk-based and determined according to accurate information. Insurance dynamics against natural disasters have been evolving for several years [33] including theoretical and practical aspects from several fields of expertise. This multifaceted interaction is embracing classical risk assessment perspectives, environmental engineering and insurance dimensions, as well as from adaption and mitigation strategies in the administrative area of municipalities to contract determination.

In the global insurance dynamics context, the insurance instrument used most frequently today also uses a risk mitigation method related to natural disasters [34].

The mitigation methods can consist of different implementation declinations. For the purposes of this paper, clearly, the most interesting profile is related, on the one hand, to the supervision and the constant study of the area in which the immovable asset is placed, and on the other, to the creation of adaptation tools capable of decreasing the risk itself.

Specific examples of the use of insurance as dynamic mitigation tool to disaster are provided in the car insurance sector where the initial policy stipulated and the premium proposed within it can be dynamically be adjusted on the constant verification of the information implying a change of the asset *de quo*.

Risk mitigation, in compliance with this profile, consists in determining the topicality and the exposure of an asset according to the eventual occurrence of a hazard where the asset itself is placed [35].

In other cases, with a constant analysis and verification of an insured asset respect its initial status would be able to allocate part of the insurance premium to the implementation of mitigative measures due to a decreased risk affect the asset. In accordance with this second perspective, mitigation is effective, through the modification and improvement of the structure itself, is also expressly agreed [36].

2.2. Smart Contracts as Insurance Mechanisms against Natural Hazards

To highlight the scientific and practical gap of a specific smart contract insurance against a natural hazard, the first methodological approach, specifically legal, leads to a literature review of the state of the art of the thematic areas of implementation of smart contracts themselves.

"Smart contracts" are the development of the research carried out by Nick Szabo, who, in the 1990s was a reference author in the data encryption landscape. In 1997, he published two papers [37] in which he theorized a system of transfer of rights in the execution of a mathematical algorithm, inspired by the sales system of vending machines [38]. The following year he released the third paper in which he formalized the concepts outlined in previous works.

In his scheme, a specific property right is included in a title intended to circulate, together with related information.

The transfer is put into mathematical-cryptographic security and the ownership title is placed in a logical chain of previous similar securities as a guarantee of the continuity of operations [39].

The most important implementation of crypto-currency is the Bitcoin that is implemented in different protocol like Ethereum and its cryptocurrency Ether (second to bitcoin by capitalization and by currency/dollars exchange) [40].

This platform allows the use of the so-called smart contracts [41]. Thanks to the invention of the blockchain, in 2014 Vitalik Buterin outlined the characteristics of what then became the main platform for the development and performance of smart contracts: Ethereum. The purpose of this platform is to provide a blockchain – a tech-tool with built-in programming language, which can be used to build "contracts" and to encode functions, so that these contracts are self-executed in accordance with the pre-set rules: all this simply by writing the logic of their operation in a few lines of code [42].

There is no universally-accepted definition of smart contract, due to its recent appearance on the scene and its technological complexity. As described by Grasso et al. [43] the smart contract is defined as an agreement that is automatic updated finding the optimal condition among the parties involved in the insurance contract. This definition is showing the need to have a proper platform for providing the correct transactions which comply with the terms of the contract. Another definition was provided by the Italian IVASS (Italian Institute for Insurance Supervision) describing smart contracts as on-line modifiable contracts processed according to predefined contract rules, based on the creation of continuous updated depository of information of the insured assets [44].

In accordance with the fact that the characteristics of any good or data can be digitized and represented by a code, all this can be stored and secured in a distributed register, not only from a static but also a dynamic point of view; the operations and the agreements between the nodes of the network can be traced and their execution can be automatically performed by the blockchain itself without the intervention of intermediaries. All this has become possible thanks to smart contracts which, as IT protocols, formalize the elements of an agreement and automatically execute the terms of the agreement (terms that are therefore predefined) when the conditions foreseen by the agreement are fulfilled (even the conditions are therefore predefined and codified). In a nutshell, to provide an important statement in order to understand the operation of smart contracts "a smart contract is a piece of code which is stored on a blockchain, triggered by blockchain transactions, and which reads and writes data in that blockchain's database" [45].

The development and evolution of smart contracts has been sudden, their application is expanding day by day. In addition to Ethereum, other open source projects were born to create increasingly sophisticated smart contracts (like Counterparty and Mastercoin). To date, they have been used in the financial sector to automatically execute derivatives, futures, swaps and options. They have also been used to build platforms for the sale of goods on the internet, among unknown people, without the help of central authorities [46].

2.3. Blockchain Overview

The technology called "blockchain" is at the top of financial and political dynamics. It pertains to different areas, completely heterogeneous, often with reference to legal problems as well. However, there is no such thing as a globally recognized and summarized text that fully describes the potential and the areas of application that this technology can have. Literally the word "blockchain" means "concatenated blocks" and, even if there is no single one definition, it is possible to delineate it as a concatenation of blocks constituted by the set of verifiable transactions, with vertical or tree structure, able to connect different nodes, which are formed physically from the servers of each participant that are used by the subjects to take part and consciously adhere to the decision. The great versatility of the system is explained because there are different definitions and "blockchain"explanations that also depend on usage.

According to the first definition, a blockchain is a database of transactions: "The blockchain is a technology which allows the creation and management of a large distributed database for transaction management shareable between multiple nodes on a network" [47].

This definition therefore refers to a database structured in connected blocks, each of which contains multiple transactions, which are validated by the network itself in the analysis that is made of each block. Each node of the chain is physically constituted by the server through which each participant has access to the blockchain; sees, controls and approves all transactions.

For others, however, the blockchain best expresses the evolution of the concept of a "ledger" [48]. Before the advent of the blockchain, in relation to the systems that already allowed the exchange of transactions and information, the idea of centralized logic prevailed, in which everything was referred and managed by a single unit or authority, about which parties had confidence. With the concept of a decentralized ledger, it has become a phenomenon of decentralization of information: data is no longer guarded by a single central unit, but moves to external locations, which have become increasingly important in the transactions [49].

Internationally, the most important sector inherent in the implementation of this new technology is finance. More generally and always related to money transfer transactions, the blockchain has brought enormous new developments. In fact, blockchain technology makes it possible to provide a more direct flow of payment between the payer and the payee, even if the transaction lies beyond the borders of the same country, without the need for intermediaries and with advantageous costs and almost instantaneous speed. Today, there is a real financial revolution through the implementation of systems that are based on the blockchain and that will perhaps allow for solving issues such as fraud, threat detection or identity theft, ensuring a high level of safety [50].

2.4. Blockchain and Smart Contracts: How they Work?

In the insurance sector, forms of insurance have developed that use smart contracts. The first example is *InsureETH*, a UK startup, in the field of airline reimbursements and compensations. Another case is that of the pilot project of the American International Group (AIG) together with IBM and Chartered Bank, who worked together to develop multinational insurance coverage, preparing a blockchain insurance called smart contract. It is worth noting that recently AXA insurance [51], in order to deliver refunds following the delay or cancellation of flights, has developed an extremely interesting smart contract. The insurance called Fizzy, is revolutionary because, as described in the AXA portal, it excludes any kind of negligence, typical in traditional insurance dynamics. Smart insurance, regardless of any external event or subjective/objective liability, automatically compensates in case of flight delay [50]. This is happening thanks to the combination of parametric insurance and blockchain technology, which ensure the inviolability of data and contracts and can preview of the amount of compensation. An "ad hoc" protection that could not be simpler or more accessible: should the flight be more than two hours late; the customer is immediately and automatically compensated. AXA representative Jean-Baptiste Mounier, in talking about the essence of the smart contract, points out that "*The smart contract is the party that decides whether or not we should indemnify the policy holder and triggers a payment request to our system. The use of a smart contract to trigger claims will add trust in the insurer/policy holder relationship*" [51].

Therefore, the first two research questions concerning the implementation of smart contracts in the insurance sector offer room for some reflection. First, it is correct to highlight a propensity of the insurance world for technological experimentation, and, likewise, the contractual determination of AXA-Fizzy on the voluntary exclusion of any objective and subjective element in relation to the payment of compensation seems extremely interesting. Secondly, and this is the fundamental element, the key factor of the research, is that the implementation of blockchain technology in the insurance field is still firm and static to the consent mechanism element determined even if the future is uncertain. The gap therefore consists in the absence of a smart insurance contract capable and able to modify elements and parameters that are inherent to the accidents, to the probabilities, and therefore to the subjective element of the contract and its *causa contrahendi*, [52] at the same time without changing the consent of the parties.

To summarize the two research questions, it is possible to determine that smart contracts have had a rapid development and evolution, and that blockchain technology is being used and relegated to the automation of the mechanism of compensation in the insurance industry [53]. This huge implementation gap leads the way for the use of blockchain data storage technology and modification of the contractual structure. In practice, it is time to move from a purely refund insurance blockchain to a big data management one [54].

2.4.1. The Difference Between a Standard Smart Insurance Contract and a Multi-Period Contract

What would be the difference between a standard smart insurance contract, one with instant effect, compared to a multi-period contract? One of the main differences was highlighted at the end of the previous section. It is quite clear that the main difference is in the term "multi-period". In this case it is appropriate to clarify this term, because multi-period is not necessarily synonymous with long-term just as the smart standard contract is not synonymous with short-term.

The desired multi-period implementation within smart insurance contracts is subject to the fact that, periodically, through the storage of data from external certified sources, using blockchain technology, the contractual structure can change, i.e. the premium, the sum of compensation, or the determination of the percentage of risk [55].

Therefore, even if facing with insurance to natural disasters, the determined periods may be related to prolonged periods. In this way, the determination of multi-mode concerns the scanning of temporal phases in which it is possible to change and modify essential elements of the contract without the latter termination or requiring a new agreement between the parties.

The second difference concerns the method of using blockchain technology. Picking up one of the smart contracts mentioned above in the insurance field, blockchain is simply used in two steps: i) validation of the insured event, such as the hours of flight delay, and ii) the payment of the sum of money.

In other words, in the very few applicative experiences that have taken place in the last few years, insurance companies first made use of blockchain technology as an instrument to verify an insured event. The information, using as an example the AXA contract, deriving from the airline are stored within the blockchain data flow and any event of delay beyond the allowed limit "unblocks" and acts as a check and authorization for the second step.

The one-dimensional perspective of the contract in relation to the uniqueness of the period, understood as a contractual phase, emerges clearly. The data entered and the "transformation" of this data through blockchain technology into legal effects, such as compensation, are contained in a single phase, without any possibility, that extends or changes the contractual structure. Therefore, in these one-dimensional insurance dynamics, blockchain technology performs as verifying agent, regardless of the will and the consensus of the parties or external events [56].

Nonetheless, the contract that, hopefully, will be implemented in the future, may involve a completely different dimension – that of periodic data scanning, aimed not at the termination of the contract, but at its evolution, change, and adaptation.

In the perspective of a multi-phase contract, using blockchain the relevant data, in accordance with the insurance dynamics against natural hazards, might able to create and store a network of useful information to counteract the harmful phenomenon of risk. The implementation, in addition to the aforementioned characteristics of a smart insurance standard contract, involves the perpetuation of the contract, step by step, following the flow of data and the physiological modification of the initial parameters to which the parties have expressed a consensus.

2.4.2. Regulatory framework for Smart Multi-Period Insurance Contract and Possible Multi-Phase Contracts with Constant Data Flows

The minimal and necessary features of a multi-phase contract are described as follows:

- Onerous, and therefore, taking up the standard scheme of an insurance contract, the agreement is based on the bilateral provision by which the insured party pays, at agreed intervals, a sum called the insurance premium, to the company, which, in the case that the insured event occurs, compensates the damaged party [53];
- Aleatory, in the sense that the insured event, even if determined, described, and outlined, is uncertain in its occurrence [5];
- information technology (IT), in the sense that the stipulation of the contract occurs through an online platform through blockchain technology. In particular, the methods of signature are constituted by the expression of consent through the use of a digital signature device;
- Blockchain Technology. A blockchain consisting of nodes and arcs can be fixed in the typical supply chain structure comprised of nodes and arcs and thus can be used to capture both organizational and network risks associated with the supply chain;
- Real time data flow, in the sense of an IT contract structure able to receive data and information related to the insured asset and related environment able to modify time after time the initial parameters set out in the stipulation of the contract [57];
- Automatic renegotiation, automatic consensus, in the sense that the contract, considering the flow of data, capable of physiologically modifying the initial parameters of the contract, is legitimated, in relation to the flow, to change economic conditions even when the new conditions result *in peius* for the so-called weak party, the insured subject.

An analysis of the contracts disseminated with the individual characteristics mentioned above can be carried out by determining some cases that are widespread within the Italian regulatory system.

As far as the cost of the contract is concerned, this is meant as the one in which a subject receives an advantage in exchange for a non-gratuitous disbursement, defined as performance. There is a close relationship between advantage and performance, a causal link. A typical example in the Italian civil code is represented by the sale, regardless of whether it concerns movable or immovable assets, in which a subject pays a sum to another party and the latter, as a counter-claim, sells the asset *de quo* [56].

The dynamics inherent in the concept of "aleatory", on the other hand, pertain to the uncertainty of the occurrence of a determined event. Remaining in the specific theme of research and paper, clearly the insurance contract is a perfect example [58].

IT technology is inherent in the inevitable chaos of digital contracts. In particular, a digital contract is an agreement entered into on an online platform through which legal effects desired by both parties emerge. One of the best-known digital contracts is certainly the one related to e-commerce platforms, through which the buyer, in exchange for a payment, in most cases by credit card or similar means, purchases one or more assets on a website, which can act as a vendor tout court (*Nike store*, *Ticketone*) or as a mere intermediary (*Amazon*, *Ebay*). More generally, IT technology makes it possible to exchange not only information on the internet, but, for the first time, properties as well. Not therefore the simple payment or exchange of goods and services, but, thanks to this innovation, any other form of collaboration between people can take advantage of the possibilities offered by the network. All transactions carried out to date and verified directly by the system are recorded in it. In fact, transactions are only possible if they are approved by 50 % + 1 of the nodes [59].

The European association of credit institutions has, in one of its reports, expressed a positive opinion about the reliability of the blockchain system. The main characteristic of the whole architecture of computer science can be synthesized with a single term: decentralization. In fact, there is no central repository in any blockchain but a peer-to-peer between users, by entering transactions in blocks [60]. In standard blockchain architecture, transactions are created from active components inserted in the network: the active user is called "node" and transfers Bitcoin to another node inserted in the network. The blocks of the network are created, in a chain, by other participants in the architecture that are defined as miners. To create blocks, miners must solve complex algorithms and, if they succeed, they are rewarded with bitcoins. The newly created transaction is distributed and validated following a rigid verification protocol to avoid, among other issues, the problem of "double spending". In practice, the validity of one transaction is confirmed with the consent of the nodes of the network on the basis of parameters set for the operation of the network itself. The nodes that validate a transaction are rewarded with Bitcoins. When the validity of the transaction is verified, the miners put it in a block and the transaction is executed (performed) with full respect to privacy [42].

The data flow, as consecution of information entered in an IT platform, can be understood thinking of what is set out above regarding the smart insurance contract on air delay. The peculiarity of this contract is the discrepancy between the initial condition, and, therefore, the uncertainty inherent in the event, and the event itself. In practice, following the random logic of the insurance contract, the peculiarity consists in the input of data in real time and the consequent immediate simultaneous supply of the sum established in favor of the insured subject. The modification of the facts as well as the occurrence of any event, are elements able to produce legal effects directly embedded within the blockchain technology [43].

In the determination of a new possible contract, the flow of data excluding the provision of any sum, it would have exactly the same function previously proposed.

The last single feature inherent to the possible implementation of the contract *de quo*, concerns the forecast and contextual acceptance of the parties, of the modification *in fieri* of the economic conditions.

This profile is closely linked to the data flow above. In particular, a data entry could be envisaged as per the insured asset, as well as the surrounding environment, capable of modifying the economic conditions, and therefore the insurance premium [61].

A contract to refer to and to use as a potential analogous tool is the so-called "variable interest rate mortgage".

A variable rate mortgage is a type of mortgage where interest rates vary based on the performance of certain parameters indicated in the contract.

The reference parameters to which the interest rates are linked are usually the Euribor (EURo Inter Bank Offered Rate, i.e. the average interest rate of the financial transactions in Euros between the main European banks), the IRS (Interest Rate Swap) – EuroIRS or the Official ECB Reference Rate. The Euribor (Euro Interbank Offered Rate) is the interest rate used as an indexing parameter for variable-rate mortgage loans. The Euribor has replaced the national indexes since January 1, 1999.

Euribor is calculated daily as a simple average of the quotations recorded by a group of banks representing the European and world credit panorama selected by the European Banking Federation.

The reference rate for variable-rate mortgages is published daily at 11 a.m. (GMT) by a group of banks representing the European credit landscape. There are currently 20 institutions that contribute to the Euribor [62].

Summarizing the main section, regardless of the will of the parties that have signed the contract, the data coming from a third party, the may involve economic changes Should the Euribor, with the flow of data, be capable of modifying, *inaudita altera parte*, with the increase or decrease of the interest rate, the economic conditions, may impose changes on the parties. A similar idea can be applied to insurance smart contracts against natural hazards. The flow of data entered into the digital blockchain platform is capable of modifying the parameters, such as risk and insurance premium, regardless of the parties' will [63].

2.4.3. Implementation of the Multi-Period Smart Contract: Potential Drawbacks for the Smart Insurance Contract against Natural Hazards

In this first methodological phase, the authors, by background and by connection with local insurance companies, have focused attention on the study of the normative dimension within the Italian panorama.

It is necessary to define the standard insurance contract within the Italian civil code which, moreover, in substance, does not differ absolutely from that of other major European countries. Article 1882 of the civil code states that insurance is the contract with which the insurer, following the payment of a fee, defined as a premium, is obliged to compensate the insured, within the agreed limits, for the damage that the latter suffered from a claim, or to pay a sum or an annuity upon the occurrence of an event related to human life.

Therefore, the first characteristic outlined, namely the fact that the contract is onerous, is absolutely transferable to the new agreement as an essential element and inherent to the definition.

Regarding the *alea*, as a determining element of the insurance contract, the risk is attributable to the abstract possibility that a damaging and detrimental event of a certain interest of the subject occurs. It is easy to understand how it can remain in a "latent" shape, more properly potential or materialize, when that possibility mentioned in abstract terms becomes real. The risk must therefore be possible (albeit with a greater or lesser likelihood of verification that affects only the amount of the premium), but objectively uncertain (i.e. caused by external causal factors and not by the parties, unaware of the possibility of occurrence and when), while, as mentioned, harmful and detrimental to the protected interest. The state of objective and absolute uncertainty that characterizes its essential features with the probabilistic forecast of the fact, human or natural, which is detrimental to the protected interest must already exist effectively at the time of adherence to the policy, since its lack *ab origine* determines the invalidity *ex tunc* of the contract due to absence of cause (art. 1895), while the termination of the contract results in the termination of the relationship, again for lack of a causal justification. And, therefore, even this single characteristic has no impediment to its inclusion in the new contract.

The next three characteristics, i.e. IT, blockchain and real-time data flow, can be analysed together. In particular, since these characteristics are extremely distant from the determinations referred to in the 1942 civil code, it is possible to make a comparison in relation to the contractual experiences that have developed in recent years. As mentioned above, it is precisely the AXA contract, to give an example, among the particular implementations of blockchain technology in the insurance sector that provides a methodological answer. In fact, the AXA contract perfectly encompasses the three characteristics *de quibus*.

Without going into detail already explained in the previous section, the smart insurance contract against flight delay, integrates IT consistency, being completely digital, able to be stipulated by using an app on a smartphone.

It also uses blockchain technology, and by reconnecting to the third profile, it uses the aforementioned technology to: 1) verify the flow of data, in particular the possible communication of the delay or arrival on flight time, 2) certify the information received, and 3) pay the agreed sum in the case of delay.

For the purposes of drafting this paper, it is worth highlighting that almost all the features, some of which are inherent *ex se*, such as compensation and the *alea*, others for subsequent implementation, such as IT, the flow of data and blockchain, are adaptable to our contract implementation project.

In regards to the dynamics of the renewal of the consensus to change the initial parameters of a contract, it seems appropriate to briefly outline a double scenario. *Prima facie*, the dynamics of the variable rate inherent to the loans, by structure and contractual framework do not seem to coincide with the insurance dynamics, and therefore, and this is the *trait d'union* with the section of engineering mitigation risk, [64] it appears extremely prudent to operate a contract in which a high premium insurance is envisaged, above the real initial risk. In particular, when the initial conditions change *in peius*, the premium in any case continues to be suitable from the point of view of the insurance company for the continuation of the activity, and when, with determined time scans, reconnecting to the theme of the multi-period, the risk conditions reduce the difference between the bonus paid and the premium that, ideally, would be corrected from a mathematical point of view, could be used to create risk mitigation structures. [65]

With regard to possible implementation and the combination of purely legal aspect, i.e. civil insurance and smart contract *latu sensu*, it is worthwhile to add that Italy has proved to be a precursor of the times and has promulgated a specific regulation, D.L. 135/2018 modified in L. 12/2019, currently in the implementation definition phase.

As far as European regulations are concerned, the supranational legislator, within the smart contract discipline, including cryptocurrencies and blockchains, has moved along two lines. On one hand, through the introduction of binding regulations, such as, Regulation 910/2014 (which repeals Directive 1999/93/EC) 1127/201; and on the other, through mere resolutions, notably 2018/2185 of 13.12. 2018, addressed to specific bodies within the Parliament, urging the Commission to develop a draft of technical standards at the level of the relevant international organizations, such as ISO, ITU and CEN-CELENEC and to promote an analysis of the existing regulatory framework in the various Member States in order to verify the overlap and applicability of smart contracts, strengthening, if possible, their validity through legal coordination or mutual recognition among Member States.

2.4.4. Other Aspects in Insurance Smart Contract: Link with a Bayesian-Quantitative and Engineering Context

The closure of the aforementioned section and the simultaneous and relative apparent impossibility of operating an analogue implementation between insurance and loans, determines a mandatory and natural involvement of two distinct scientific areas. The first is actuarial science, the application of which, prodromal to the implementation of the contract, consists of the draft of a Bayesian model and engineering science to determine possible risk mitigation structures in relation to the income of difference between insurance premium and the actual risk borne [66].

Considering the current instruments for an economic mitigation of cat-risks due to natural hazards, traditional reinsurance, cat-bonds and resilience bonds, our Bayesian approach concerns a similar approach to the resilience bonds scheme that is not only compensation coverage of eventual damages, but also the chance of financing infrastructures for mitigating risks. Our methodological proposal is based on the calculation of an insurance premium at issue date and at every updating time, based on information collected at each time in a classic Bayesian adaptive scheme, such that the premium level may automatically change over time. Furthermore, at each renewal scan time, part of the eventual surplus of the premium paid in respect to the payments procured for damages shall be (automatically, settled in contractual conditions) used for financing mitigative infrastructure. Blockchain technology has the role of certifying reliable new information and also the state of mitigative infrastructure, which can vary according to the use of the surplus as mentioned before [67].

3. Results and Discussion

From the proposed literature review, it is highlighted that a blockchain technology applied to smart contracts in the insurance sector against natural hazards has an important role and, as of yet, unexplored potential.

In fact, the blockchain and smart contracts could have a tremendous impact on the use insurance in disaster risk reduction (DRR) strategies, in turn strengthening resilience to natural disasters. In this way, the implementation of a blockchain platform would speed up claims processing, reduce operating costs, and have the possibility to develop a more up-to-date policy premium in real time. In this scenario, a smart contract could facilitate reimbursements based on data collected from various available sources including a connection with cloud-stored 'Big-data'.

With this in mind, this paper proposes a methodological approach using the blockchain as supporting platform technology involving four distinct scientific areas which are interconnected inextricably: engineering, insurance-actuarial, legal, and IT (Fig. 1).

This represents an innovative multidisciplinary platform towards an optimized interaction of the regulatory, insurance, and engineering dimensions in order to move towards the development of a tool capable of implementing the potential data processing of different types of information: the use of the blockchain technology within risk reduction strategy to natural hazards can support this transition.

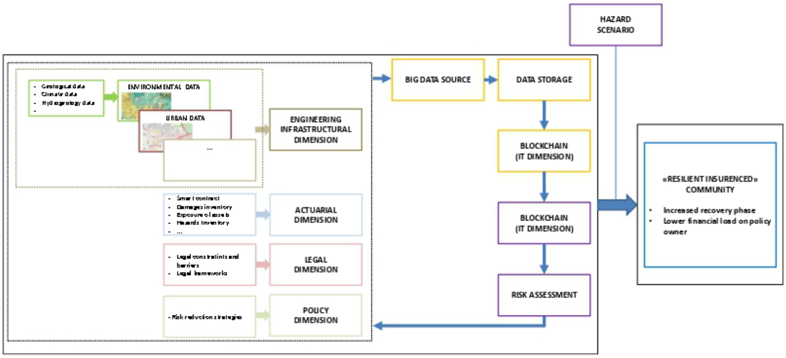

Fig. 1. Novel multi-disciplinary approach for blockchain implementation.

In this specific definition, a blockchain platform customized for the insurance market on "community" risks could be applied for an environmental risk in a certain geographical area, the potential damages of which are borne by both individual citizens and the public administration of the entire community.

Disciplines involved:

- Engineering: estimate of the probability of an accident due to environmental risk (i.e. floods), design and evaluation of risk mitigation tools, estimate of potential damage;
- Legal: legislation for the possibility of public-private synergies, both for investments in risk mitigation tools, and for implementing "community" forms of insurance, and for supervising the digital platform;
- Actuarial: quantification of the bonus for the transfer of the coverage of the potential damage (also in terms of reinsurance layers);
- IT: setting up a digital platform (blockchain) in which the subjects that take charge of the risk (public administration, private, insurance already in place), offer parts of the risk coverage to potential investors, with "prices" (premiums) already agreed according to actuarial valuation principles.

Merging the information coming from different data sources and disciplines in the proposed methodological approach, the role of blockchain technology is the certification of the collected information and the automation with which the contractual terms (i.e. the premium level and the sharing of the surplus) should change at each updating time. Such automation is the core of the concept of smart contracting, that is an update of the contract without a new bargain between the two parties. The legal aspects such that smart contracting is really admissible for this kind of insurance contract, have been analysed in the paragraph above.

The first step of the proposed methodological approach will be oriented towards the creation of an inventory of local hazards, the assessment of their occurrence, and the overall potential impact on the asset at risk based on patrimonial and non-material damages [68]. Finally, the definition of potential specific mitigation strategies applicable in a local context should be mapped and included within an overall inventory. Through this process, the assessment of the potential benefits of mitigation strategies addressed within the infrastructural dimension should be carefully explored.

The proposed innovative platform based on the developed approach could give an opportunity to use open source data and "Big data" in a certified and validated way. In the context of defining the premium via a computation/risk assessment, the blockchain would play the role of a shared ledger recording a history of persons (both physical & legal in terms of previous claims, committed infractions, health history, damages, etc.) and immovable assets. Insurance companies could trust the data use for the policy definition and automatically (and up-to-date) determine the premium. In this perspective, blockchain and smart contracts could be used in a flexible way even activating or deactivating certain policies and coverage, based on data collected and validated by the platform itself.

Within this view, blockchain technology represents a good platform to mitigate risk [69] and vulnerability towards the collection and analysis of different data sources [70] (i.e. Big data related to GIS systems, Environmental variables, Exposure data, Social media data, legal constraints, etc.). In this way, a real time risk assessment and thus a better definition of a risk-based pricing of insurance policies faced with potential disaster losses will be possible.

This would thus represent a more advanced system to use insurance as a more adaptive risk reduction tool aiming to increase the overall resilience and to better allocate financial resources towards more vulnerable areas.

The application of such an approach could also play a relevant role for urban disasters for which disaster management is still an issue that needs innovative approaches to build urban resilience strategies. Moreover, this perspective becomes even more relevant towards sustainable development plans and strategies according to the framework of the so-called Sustainable Energy and Climate Action Plans (SECAPs) for Municipalities [71].

Nevertheless, there are several concerns about the adaptation of a blockchain-based platform for smart contracts even including those for natural disasters. As mentioned by Gatteschi et al. [72], one limitation is scalability. This implementation limit is related to the fact that, although the transactions in a given system are relatively low, the possibility of flow congestion of the connected servers is high, and in a contractual context, this aspect certainly represents a limitation. This also increases the risk that accidents could occur during the transaction. Furthermore, the same study highlights that there is a criticality on the integration of different application developed by different blockchain platforms. Finally, there is an intrinsic complexity of the platform itself when experienced by "average users". This could lead to scepticism of fraud associated with blockchain products like Bitcoin.

After having explained the section dedicated to the actuarial part [73], it is necessary to explain the multidisciplinary connection. In fact, the latter is fundamental for innovative technological implementations [74] and shall pay attention to a new possible contractual implementation in the insurance field [75].

Specifically, the proposed approach proposed is a Bayesian calculation method.

Regarding the last methodological part – IT – the authors, stating that for logical consequence they preferred to focus on the areas mentioned above, the IT sphere has been addressed through a specific method on the study of the various blockchain platforms and on the empirical evidence of a stipulation of a smart contract.

4. Conclusions

Insurance dynamics against natural disasters have been evolving for several years. The theoretical and practical aspects involve several fields of expertise in a multifaceted interaction among environmental, engineering and insurance dimensions.

This paper proposes a basis for a quantitative framework to strengthen the role of risk insurance for risk reduction strategies towards a potential blockchain platform merging actuarial, legal, and engineering dimensions.

The novelty of this paper is two-fold: first, the paper identifies the potential of using already existing mechanisms, like the periodic premium renewal in smart contracts, applicable to natural disaster insurance; second, the paper highlights the need for a more quantitative approach including a multi- and inter-disciplinary framework interfacing on a blockchain platform.

Within this paper, the possible benefits of the implementation of blockchain technology from an insurance perspective in terms of assets at risk, has been proposed.

The methodological perspective that the authors have chosen is relevant for reducing risk from several perspectives. In particular, in the first place, it allows an analytical study of the immovable asset insured and, for this reason, the above determinations involve a greater knowledge of the area involved and a lower risk of an unexpected disaster. As explained below, the final insurance agreement allows an investment of a variable amount to be allocated exclusively toward risk mitigation.

The authors point out a first result, in the sense of highlighting an evident regulatory gap within the insurance scenario, also outlining the numerous advantages that would derive from the implementation of blockchain technology under a Bayesian quantitative method.

Moreover, it is worth highlighting that in Italy and, more broadly, in Europe there is regulatory framework capable of welcoming the proposed smart contract, and the clear proof is the example set out in the Fizzy Axa contract. There are no impediments to the implementation of the insurance contractual framework through blockchain technology, with real-time data flow.

The aforementioned flow, due to the substantial and regulatory differences highlighted between the insurance contract and the variable rate mortgage is an example of a contract capable of changing economic conditions to outline the time and the risk and the relative "correct" insurance premium.

It is precisely from the apparent impossibility mentioned above that the engineering risk mitigation profile originates. If it does not seem possible to change the economic conditions for the weak party *in peius*, there are no impediments for both parties to decide for an insurance premium higher than the initial risk. This can be based on the establishment, at each scan time period, the any surplus between actual damage coverage and paid premium insurance is intended for the implementation and construction of risk mitigation measures.

The output of this scientific paper can be divided into three sections: the first concerns the creation of a methodological basis through which to outline all or part of the implementation research project as set out above. Therefore, the first output concerns the explanation of "how" possibly reaching a normative, engineering and actuarial implementation and improvement. Secondly, the paper seeks to highlight the regulatory provisions, especially in Italy, within which insurance companies can move in the field of smart contracts, in particular by connecting these to a dimension against natural hazards.

The main outcomes of the present study are thus oriented towards the proposal of a novel multidisciplinary approach considering legislative, engineering and actuarial dimensions. The aim is to create an assessment tool for the insurance sector in order to quantify the benefit of mitigative risk reduction measures coping against natural hazards.

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REFERENCES

[1] Serre D., Heinzlef C. Assessing and mapping urban resilience to floods with respect to cascading effects through critical infrastructure networks. *International Journal of Disaster Risk Reduction* 2018:30(B):235–243. doi:10.1016/j.ijdrr.2018.02.018
[2] Paleari S. Disaster risk insurance: A comparison of national schemes in the EU-28. *International Journal of Disaster Risk Reduction* 2019:35:101059. doi:10.1016/j.ijdrr.2018.12.021
[3] UN General Assembly. Resolution 69/283 of 23 June 2015. Sendai framework for disaster risk reduction 2015–2030.
[4] Flood Hazards in Central Europe. USA: World Bank, 2012.
[5] Porrini D., Schwarze R. Insurance models and European climate change policies: an assessment. *European Journal of Law and Economics* 2014:38(1):7–28. doi:10.1007/s10657-012-9376-6
[6] Freeman P. K., Scott K. Comparative analysis of large-scale catastrophe compensation schemes. Catastrophic Risks and Insurance – Policy Issues in Insurance. Paris: OECD, 2005:187–234.
[7] Quesne F., Tollman J. Risk transfer and insurance for disaster risk management: evidence and lessons learned. *Proceedings of the 5th Global Platform for Disaster Risk Reduction*. Germany: GIZ, 2017.
[8] OECD. Financial Management of Flood Risk. Paris: OECD, 2016.
[9] Rumson A., Hallet S. Innovations in the use of data facilitating insurance as a resilience mechanism for coastal flood risk. *Science of the Total Environment* 2019:661:597–612. doi:10.1016/j.scitotenv.2019.01.114
[10] Cervantes-Godoy S., Kimura D., Antón J. Smallholder Risk Management in Developing Countries. *OECD Food, Agriculture and Fisheries Papers* 2013:61.
[11] Dahlen S., Peter G. Natural Catastrophes and Global Reinsurance – Exploring the Linkages. *BIS Quarterly Review* 2012.
[12] Abdullayev K. Global Reinsurance Market, 2013.
[13] Kunreuther H., et al. Insurance, Economic Incentives and Other Policy Tools for Strengthening Critical Infrastructure Resilience: 20 Proposals for Action. USA: Wharton University of Pennsylvania, 2016.
[14] Actuaries Institute. The Impact of Big Data on the Future of Insurance. Green Paper. Sydney: Actuaries Institute, 2016.
[15] Bin O., et al. Flood Hazards, Insurance Rates, and Amenities: Evidence from the Coastal Housing Market. *Journal of Risk and* Insurance 2008:75(1):63–82. doi:10.1111/j.1539-6975.2007.00248.x
[16] Hudson P., et al. Incentivising flood risk adaptation through risk based insurance premiums: Trade-offs between affordability and risk reduction. *Ecological Economics* 2016:125:1–13. doi:10.1016/j.ecolecon.2016.01.015
[17] Surminski S., Oramas-Dorta D. Flood insurance schemes and climate adaptation in developing countries. *International Journal of Disaster Risk Reduction* 2014:7:154–164. doi:10.1016/j.ijdrr.2013.10.005
[18] Choi T.-M., Lambert J. Advances in Risk Analysis with Big Data. *Risk Analysis* 2017:37(8):1435–1442. doi:10.1111/risa.12859
[19] Rumson A., Stephen H. Opening up the coast. *Ocean and Coastal Management* 2018:160:133–145. doi:10.1016/j.ocecoaman.2018.04.015
[20] Stoeckli E., Dremel C., Uebernickel F. Exploring characteristics and transformational capabilities of InsurTech innovations to understand insurance value creation in a digital world. *Electronic Markets* 2018:28(3):287–305. doi:10.1007/s12525-018-0304-7
[21] Nakamoto S. Bitcoin: A Peer-to-Peer Electronic Cash System; 2008 [Online]. [Accessed 19.02.2018]. Available: https://bitcoin.org/bitcoin.pdf
[22] Higgins S. Insurance Giant Allianz France Exploring Blockchain Potential [Online]. [Accessed 30.06.2016]. Available: http://www.coindesk.com/allianz-france-exploring-use-cases-with-blockchain-startup/
[23] Insurance Times Newsdesk. AXA leads 55m investment in blockchain [Online]. [Accessed 29.06.2016]. Available: http://www.insurancetimes.co.uk/axa-leads-55m-investment-in-blockchain/1417270.article
[24] Ramada M. For insurers blockchain is the new black [Online]. [Accessed 29.12.2017]. Available: http://blog.willis.com/2016/12/for- insurers-blockchain-is-the-new-black
[25] Shelkovnikov A. Blockchain Applications in Insurance. London: Deloitte LLP, 2016.
[26] Lorenz J.-T., et al. Blockchain in Insurance-Opportunity or Threat? USA: McKinsey Company, 2016:19.
[27] McKinsey Company. Blockchain Technology in the Insurance Sector. Proceedings of the Quarterly Meeting of the Federal Advisory Committee on Insurance (FACI). USA: McKinsey Company, 2017.
[28] Higgins S. European Insurance Firms Launch New Blockchain Consortium [Online]. [Accessed 29.12.2017]. Available: http://www.coindesk.com/europe-insurance-blockchain-consortium
[29] de Broglie L., et al. insPeer [Online]. [Accessed 29.12.2017]. Available: http://www.inspeer.me/

[30] Kunde T., et al. Friendsurance: The P2P Insurance Concept [Online]. [Accessed 29.12.2017]. Available: http://www.friendsurance.com/

[31] Davis J. Peer to Peer Insurance on an Ethereum Blockchain [Online]. [Accessed 29.12.2017]. Available: http://www.dynamisapp.com/whitepaper.pdf

[32] Young E. Voice of the Customer. Time for Insurers to Rethink Their Relationships. London: EY, 2012.

[33] Sawada Y., Takasaki Y. Natural Disaster, Poverty, and Development: An Introduction. *World Development* 2017:94:2–15. doi:10.1016/j.worlddev.2016.12.035

[34] Botzen W. J. W., van den Bergh J. C. J. M., Bouwer L. M. Climate change and increased risk for the insurance sector: a global perspective and an assessment for the Netherlands. *Natural Hazards* 2010:52(3):577–598. doi:10.1007/s11069-009-9404-1

[35] Lu Y. The blockchain: State-of-the-art and research challenges. *Journal of Industrial Information Integration* 2019:15:80–90. doi:10.1016/j.jii.2019.04.002

[36] de Ruig L. T., et al. A micro-scale cost-benefit analysis of building-level flood risk adaptation measures in Los Angeles. *Water Resources and Economics* 2019:100147. doi:10.1016/j.wre.2019.100147

[37] Szabo N. The Idea of Smart Contracts, 1997. [Online]. [Accessed 18.11.2018]. Available: http://szabo.best.vwh.net/idea.html

[38] Szabo N. Read related articles on Internet economics and Security. *Peer-Reviewed Journal of the Internet* 1997:2(9):1–24.

[39] Perugini M. L., Checco P. D. Introduzione agli Smart Contracts. *SSRN Electronic Journal* 2015. doi:10.2139/ssrn.2729545

[40] Ecosystem of existing crypto-currencies. Available: http://coinmarketcap.com

[41] Khan M. A., Salah K. IoT security: Review, blockchain solutions, and open challenges. *Future Generation Computer Systems* 2018:82:395–411. doi:10.1016/j.future.2017.11.022

[42] Buterin V. A Next-Generation Smart Contract and Decentralized Application Platform. Ethereum White Paper, 2014.

[43] Grasso A. Smart Contracts: Adoption Value for Enterprises and General Use Case, 2018.

[44] Istituto per la Vigilanza sulle Assicurazioni. Relazione sull'attività svolta dall'Istituto nell'anno 2016. (Report on the activity carried out by the Institute in 2016.) Istituto per la Vigilanza sulle Assicurazioni, 2016.

[45] Greenspan G. Beware of the Impossible Smart Contract [Online]. [Accessed 12.04.2016]. Available: http://www.theblockchain.com/2016/04/12/beware-of the-impossible-smart-contract

[46] Wright A., de Filippi P. Decentralized Blockchain technology and the rise of Lex Cryptographia. *SSRN Electronic Journal* 2015. doi:10.2139/ssrn.2580664

[47] Bellini M. Cos'è, come funziona e gli ambiti applicativi in Italia. (What it is, how it works and the application fields in Italy.) [Online]. [Accessed 26.09.2019]. Available: https://www.blockchain4innovation.it/esperti/blockchain-perche-e-cosi-importante (in Italian)

[48] Vranken H. Sustainability of bitcoin and blockchains. *Current Opinion in Environmental Sustainability* 2017:28:1–9. doi:10.1016/j.cosust.2017.04.011

[49] Boucher P., Nascimiento S., Kritikos M. Come la tecnologia blockchain può cambiarci la vita. (How blockchain technology can change our life.) Brussels: Parlamento Europeo, 2017. doi:10.2861/13366

[50] García-Valls M., Dubey A., Botti V. Introducing the new paradigm of Social Dispersed Computing: Applications, Technologies and Challenges. *Journal of Systems Architecture* 2018:91:83–102. doi:10.1016/j.sysarc.2018.05.007

[51] AXA – Comunicato Stampa. AXA fa decollare in Italia Fizzy, la prima assicurazione viaggio al mondo basata su tecnologia blockchain che rivoluziona l'esperienza cliente. [Online] [Accessed 11.06.2018] Available: https://corporate.axa.it/-/axa-italia-premiata-ai-le-fonti-awards-2018

[52] AXA Is Using Ethereum's Blockchain for a New Flight Insurance Product. [Online] [Accessed 13.09.2017] Available: https://www.coindesk.com/axa-using-ethereums-blockchain-new-flight-insurance-product

[53] Assicurazione dei Rischi Calamità Naturali. Insuring Natural Catastrophe Risks. [Online] [Accessed 03.11.2000] 7th R.I.B. Convention, 2000. Available: http://www.ribgroup.com/pdf/RIB_Conv_2000.pdf

[54] Viriyasitavat W., Hoonsopon D. Blockchain characteristics and consensus in modern business processes. *Journal of Industrial Information Integration* 2019:13:32–39. doi:10.1016/j.jii.2018.07.004

[55] Forum W. E. Rischi dei cambiamenti climatici: il ruolo delle assicurazioni. (Risks of climate change: the role of insurance.) 2013. (in Italian)

[56] Campobasso G. Manuale di diritto commerciale. (Commercial law manual.) Torino: Utet Giuridica, 2015. (in Italian)

[57] Makhdoom I., et al. Blockchain's adoption in IoT: The challenges, and a way forward. *Journal of Network and Computer Applications* 2019:125:251–279. doi:10.1016/j.jnca.2018.10.019

[58] Andoni M., et al. Blockchain technology in the energy sector: A systematic review of challenges and opportunities. *Renewable and Sustainable Energy Reviews* 2019:100:143–174. doi:10.1016/j.rser.2018.10.014

[59] Min H. Blockchain technology for enhancing supply chain resilience. *Business Horizons* 2019:62(1):35–45. doi:10.1016/j.bushor.2018.08.012

[60] Abirascid E. Banche, la sfida più grande è la blockchain. (Banks, the biggest challenge is the blockchain.) [Online]. [Accessed 11.06.2016]. Available: https://www.startupbusiness.it/banche-la-sfida-della-blockchain/86184 (in Italian)
[61] Sayegh K. Blockchain Application in Insurance and Reinsurance. France: Skema Business School, 2019.
[62] Banca d'Italia. Tassi di interesse. Analisi E Approfondimenti. (Bank of Italy. Interest rates. Analysis and deepenings) 2019. (in Italian)
[63] Jobst A. What is Securitization? *Finance & Development* 2008:48–49.
[64] Breckner M., et al. Resilience to natural disasters — Insurance penetration, institutions, and disaster types. *Economic Letters* 2016:148:106–110. doi:10.1016/j.econlet.2016.09.023
[65] McAneney J., et al. Government-sponsored natural disaster insurance pools: A view from down-under. *International Journal of Disaster Risk Reduction* 2016:15:1–9. doi:10.1016/j.ijdrr.2015.11.004
[66] Leung M., et al. A comparative study of pricing approaches for longevity instruments. *Insurance: Mathematics and Economics* 2018:82:95–116. doi:10.1016/j.insmatheco.2018.06.010
[67] Wang L., et al. Cryptographic primitives in blockchains. *Journal of Network and Computer Applications* 2019:127:43–58. doi:10.1016/j.jnca.2018.11.003
[68] Oraee-Mirzamani B., Cockerill T., Makuch Z. Risk assessment and management associated with CCS. *Energy Procedia* 2013:37:4757–4764. doi:10.1016/j.egypro.2013.06.385
[69] Albatayneh A., Alterman D., Page A., Moghtaderi B. The Significance of Building Design for the Climate. *Environmental and Climate Technologies* 2018:22(1):165–178. doi:10.2478/rtuect-2018-0011
[70] Miezis M., Zvaigznitis K., Stancioff N., Soeftestad L. Climate change and buildings energy efficiency – The key role of residents. *Environmental and Climate Technologies* 2016:17(1):30–43. doi:10.1515/rtuect-2016-0004
[71] Bertoldi P., et al. Guidebook: How to develop a Sustainable Energy and Climate Action Plan (SECAP)? Publication Office of the European Union, 2018. doi:10.2760/68327
[72] Lamberti V., et al. Blockchain or not blockchain, that is the question of the insurance and other sectors. *IT Professional* 2017:99:1. doi:10.1109/MITP.2017.265110355
[73] Bølviken E., Guillen M. Risk aggregation in Solvency II through recursive log-normals. *Insurance: Mathematics and Economics* 2017:73:20–26. doi:10.1016/j.insmatheco.2016.12.006
[74] Bajcinovci B., Jerliu F. Achieving energy efficiency in accordance with bioclimatic architecture principles. *Environmental and Climate Technologies* 2016:18(1):54–63. doi:10.1515/rtuect-2016-0013
[75] Surminski S., Bouwer L. M., Linnerooth-Bayer J. How insurance can support climate resilience. *Nature Climate Change* 2016:6(4):333–334. doi:10.1038/nclimate2979

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The relationship between insurance companies and natural disaster risk reduction: overview of the key characteristics and mechanisms dealing with climate change

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The relationship between insurance companies and natural disaster risk reduction: overview of the key characteristics and mechanisms dealing with climate change.

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Abstract

The analysis proposed in this study concerns literature reviews among the ways in which insurance companies cope with climate change, natural disasters and climate risk management. The paper aims to explore the several adaptation measures against climate change adopted by insurance companies for the development of models able developing an acceptable risk forecast. The importance of the paper is substantiated in a structural analytical study of the most important literature on the adaptation of insurance companies to climate change, highlighting the methodologies and specific cases. The conclusions of the paper highlight the natural relevance and relationship between insurance companies, the mandatory interface that year after year the insurance companies have to face and especially the numerous tools that have been developed by the latter in the insurance and reinsurance field for the natural hazards

Keywords: Natural hazards; insurance companies; risk management; climate change

1. Introduction

At EU and world level there is an evident need to face with challenges related to the occurring of natural disasters. In the light of constant increase of the global population and thus of the infrastructures interfacing with any

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community there is a growing exposure to disaster related hazards. Moreover, the effects of a climate change are contributing to increasing the likelihood of disruptive occurrence of natural disaster. Even if the effects of the Hyogo framework [1] have been relevant in terms of important benefit on decreasing the number of live lost, the effects of the disasters still greatly affect the social-economic capacity of the community prone to the disaster. Swiss Re's report of year 2013[2] evaluated a total amount of 308 disaster events (150 were natural catastrophes and 158 technological) with almost 26 000 lost lives at EU level. Specifically, Europe has experienced a total amount of $ 33 billion of economic losses with about 50% of insurance payments [3].

Based on the abovementioned background insurance represents a key tool within Disaster Risk Reduction (DRR) strategies in line with the Sendai Framework priorities [4]. Recently the use of an integrated approach involving whole insurance industry, local/national governments together with the experiences offered by donors, NGOs and academia has significantly developed [5].

Specifically, this paper focuses on an overview about the relationship and role played by\insurance companies within the disaster and climate change risk management and how they can bring benefit during prevention, preparedness and adaption phases of disaster management. The overview will try to explore the connection with macro-economic dimension as well as policy levels.

The paper clarifies the way of insurance companies' schemes to interface with natural disasters [3, 6], risk prevention and mitigation techniques and financing or payment of the price following the event. In particular, the literature review wants to assess the role of subjects involved in the difficult relationship mentioned above, the main related issues and possible development of risk reduction approaches in synergy with the private and public market.

2. Literature review on insurance companies in disaster risk reduction and management

2.1. Insurance companies facing with adaptation measures to climate change

First of all, it seems preliminary to clarify whether, actually, especially in recent years, at least on the date of the second industrial revolution, it would be possible to speak tout court of disasters (totally natural). A dramatic response was provided by Yeb Sano, head of the Philippines delegation at UN climate talks in Poland (November 2013). It should be remembered that shortly before the emotional speech made by Mr. Sano, Philippines were badly hit by a typhoon that caused countless human and economic losses and that still continue to have repercussions *latu sensu*.

He told he would refuse to eat until progress was made. In a nutshell, he linked the "staggering" devastation caused by Typhoon Haiyan to a changing climate. "*In solidarity with my countrymen who are struggling to find food back home, I will now commence a voluntary fasting for the climate, this means I will voluntarily refrain from eating food during this Cop, until a meaningful outcome is in sight ... What my country is going through as a result of this extreme climate event is madness, the climate crisis is madness. We can stop this madness right here in Warsaw*" [7].

And it is precisely from the climate change that the paper originates with a first reflection about the interface between it and the insurance companies [8] or the stakeholders *latu sensu*. It is a fact that climate change is a factor that involves changes and countermeasures for any company [9]. Indeed, as stated by several authors [10], climate change should be one of the areas of greatest interest for companies to place on their agenda. Insurance companies are absolutely not exempt from this obligation [11] of confrontation to climate change. Indeed, far from it, insurance companies are, certainly among the subjects most affected by climate change. Indeed, they must be understood "*on the frontlines of climate change* [12].

Before highlighting the various strategies of adaptation of the insurance companies [11] according to the most important literature in this study field, it is worth remembering that most of the studies have had as their centre of research a specific case. In particular, the authors that referring to specific case study approach [13] have helped to highlight important issues. Nevertheless, the proposed studies highlight lacks on proposing a more extended and general approach applicable to all insurance companies and different situation facing with natural disaster.

Resuming the first part of the paper on the fact that climate change affects most companies in the market [14], the role of insurance companies on adaptation strategies to climate changes is becoming starting from the second half of the twentieth century. A prerequisite for understanding the various types of adaptation mechanisms proposed by the most influential literature concerns the impact (direct or indirect) [15] of climate change on insurance companies in connection to the evaluation of financial consequences. In short, the direct impacts are the "*cause effect*" relationship between the natural hazard and the structure of the company, i.e. the real and immediate effect of the disaster on any part involved in the company. On the other hand, the indirect effects affect the residual consequences of the disaster, from economic to social effects [16].

Although there is lack of interest on the direct impact assessment there are several evidences on the effect of climate change in the daily activity of a company, not necessarily insurance [17], and how this aspect is relevant for companies tout court [18]. For example are reported cases that required the change of the company operative place as a result of temperature or water raising, occurred of a flood or even a structural damage connected to typhoon or earthquake.

On the contrary, as said before, indirect impacts concern social, regulatory, economic and cultural changes, without forgetting the possible consequences on the role or the decisions of the stakeholders [19]. In the following, according to the major literature, all the adaptation measures concern indirect impacts.

After making the necessary premises and framing the scope of adaptation measures, entirely related to indirect impacts, it is now necessary to examine the financial consequences. In particular, the two main financial consequences are decreasing revenues and increasing claims expenses [20]. As Maynard stated, both sides of the balance sheet are affected [21].

In this part is proposed a classification of adaptation measures in the insurance companies to climate change impact based on the collected references.

Two of the most important authors who have undertaken to draw up a possible classification in the sense are definitely Dlugolecki [22] and Mills [23]. The first of the two has developed a classification divided into four categories risk reduction, damage control, product price adaptation and risk transfer. Mills, has obtained greater feedback from the public and from the market. In particular, Mills proposes a classification divided into ten categories of adaptation measures, based on economy, financial technic and policy [24]. Among the ten adaptation categories, the following next six categories are those related to climate change.

For the first group of categories, Mills points out that insurance companies promote and encourage any activity for *understanding the climate change problem*, because data collection, catastrophe modelling and risk analysis are prodromal for evaluating climate change risks. In practice, in order to gain greater knowledge of the dynamics of climate change, insurance companies, in addition to the standard work referred to the civil code and the insurance code of any legal system, invest in their own research, [25] creating research teams or assigning external research institutes for specific tasks [26]. Mills also points out that for the second category insurance companies are "*building awareness and participating in public policy*". In order to stimulate the protection of private property against disaster, policyholders must be acquainted and aware about climate change impacts, possibilities of long-term physical risk reduction and related adaptation. The third category group, "*aligning terms and conditions with risk reducing behaviour*", aims to make policyholders aware of the impact, or even better, to push them to consciously and actively reduce the risk associated with it through specific implementation measures. The next category related to the adaptation measure refers to "*new insurance products and services*". Specifically, these new economic tools are necessarily and closely linked to already existing insurance products offered by the insurance companies. For example, one of the innovations in this field is the so-called adjusted gross revenue (AGR), a new USA insurance tool that ensures the harvest through the provision of a quantum in cash proportionate to the average income of previous years. The last two categories referred to in the Mills classification are respectively related to "*investment in climate change solutions*" and "*financing customer improvements*" [27]. The author, in order to the investments above, points out that rebalancing their asset portfolios, insurers participate in investment opportunities due to climate change, meanwhile in order to the last category he sets out that such operation should be promoted by both insurance and bank sectors, but he admits only minimal efforts in this field has been showed by all the subjects involved.

2.2. Insurance companies' different approaches to natural disaster

In this section the paper has an emphasis on the next steps of various adaptation measures to climate change for insurance company, i.e. the possible financial and economic mechanism to be performed in relation to a natural hazard. The possible insurance operations in relation to a natural hazard vary a lot depending on the country where the insurance has its registered office and where it stipulates the contract [28]. The differences are notable, and to conclude this literature review, it seems necessary to draw up the most important.

A first distinction concerns the relationship between private insurance and public interventions that can be modulated on a range of different systems ranging from exclusive dependence on the market to complete public monopoly. Meantime interesting forms of cooperation between the public and private sectors through reinsurance through public bodies or *addressing* the risk to the financial markets can also be relevant [29].

A second difference relates to the type of risks covered which can essentially provide for three different types of coverage: the mono-linear one (coverage of a single type of risk, such as hurricanes or earthquakes, etc.), the one protecting a list of specific events; the open one that covers any natural catastrophe [30].

The cost of covering risk is preeminent. The cost of the policies may vary depending on the amount of the capital insured, based on the type of risk, the lower or greater exposure of a certain territory to the risk considered or the incentives that the public body makes available to the insurance companies [31].

It is also necessary to take into account the damages covered: most of the systems cover only direct material damage (some systems only consider buildings and others include goods contained in homes). However, there are cases in which coverage also extends to the loss of income due to the calamitous event. The Spanish system also considers personal injuries [32]. Another difference concerns the limit of the insurance claim [33]. Despite the fact there are few systems that, thanks to the state guarantee, offer unlimited damage coverage, generally a maximum limit is set for the compensation for each type of damage or for each type of event. In addition, there are almost always specific deductibles that are designed to discourage customers claiming compensation for irrelevant or unproven demonstrable damages.

Moreover, the bureaucratic part linked to the issuing of an official natural disaster declaration should not be de minimized. Generally, this declaration is issued by a specific public body specifically appointed and is the necessary condition to open a claim. However, in the case of Spain, this official declaration is not necessary and covering risk is not subject by the extent and amount of damage [34].

The last characteristic of different insurance companies' approach to natural hazards concerns the financial reserves of guarantee: due to the need to maintain a considerable tied-up capital to guarantee interventions to natural disasters, some countries stimulate the accumulation of funds of guarantee through favourable fiscal arrangements, other countries, on the other hand, implement other measures, more inherent to the financial market such as those related to the contingent capital [35].

2.3. How insurance can be beneficial in disaster and climate risk management

Given the natural correlation between natural risks and insurance companies, the latter, over the years, have developed some tools to interface in a productive and suitable manner for the needs of a problem as serious as that of an earthquake or a flood [36, 37]. In particular, insurance companies, without distinction, have been able to develop insurance and reinsurance tools in order to completely reduce the risk of a possible insolvency on their part whether the risk actually would take place [38].

Given the impossibility of a complete structural analysis of each single tool, perhaps it is the case of a drafting of a table with the analytical description, the social and economic function, the advantages and the challenges that the greatest of these are addressed [39].

Table 1. insurance and risk transfer tools to natural disaster, adapted from [39].

Name of tool – systematic framework	Description	Advantages	Challenges
Natural Catastrophe Bonds - Alternative risk transfer tools/ insurance- linked securities (ILS)	Type of insurance in which securities are involved (derivative bonds) that transfer natural catastrophe (re)insurance risks to the capital market	For investors: relatively high payback and low correlation involvement with other asset classes mean promise of diversification. For sponsors: CAT bonds allow access to a quite large pool of capital and guarantees long coverage periods. More convenient in these terms than conventional re-insurance.	The most complicated challenge concerns the diffusion and disclosure of bonds in relation to the population less accustomed to the financial and reinsurance world. Furthermore, it would be useful to reduce the total cost of the operation and simplify the legal and economic documentation.

Indemnity insurance: (a) Single Peril (b) Multiple Peril - Traditional insurance	Type of insurance by which the claim is calculated on the basis of the degree of damage from the event immediately following the moment in which the event takes place	The amount and emoluments payable by the insurance company are based on actual damage and the project and the methods of distribution are established on a contractual basis.	In particular, this type concerns moral hazard, adverse selection and a particularly high cost for the conclusion of the operation.
Weather Derivatives - Alternative risk transfer tools (ILS)	Type of insurance in which intermediation takes place that provide options on weather indices (i.e. a rainfall index) for specific sectors.	It can indifferently be used on a sector or on a company basis (level) and allows access to the financial market, by reducing the risk on the part of the insurance company, just like the CAT bonds tool, which is one of the cardinal principles of the so-called reinsurance.	Dissemination of a weather index accessible to the entire population to prevent the most vulnerable people from being excluded. Moreover, the costs and the diffusion due to its purely financial conception have always hindered the evolution of this tool

3. Conclusions and discussion

The conclusions, in agreement with the aim of the paper, move towards three foundational guidelines. The first concerns the importance of the established relationship between natural hazards and insurance companies. The relationship established over the years has become increasingly important both in a private and public dimension and involves public and private citizens as also mentioned the study of Kolk et al. [40]. The second conclusion concerns the studies and adaptation classifications presented by different researcher and insurance companies in particular to interface in the best possible way to the natural hazards. Given a general approach often aimed at the study of the specific case, it seems desirable that the next theoretical and practical studies will turn towards a more general approach applicable to all the companies involve, an item already similarly addressed in the study of Weinhofer et al. [41]. The third conclusion, in accordance with description of the most widespread tools in insurance and insurance, concerns a criticism of the lacks that the companies have not yet been able to fill. In particular, it seems necessary to highlight that the totality of the tools, [42] subject to high costs, general disinformation and a propensity to the financial world, which although theoretically positive, involves the exclusion of large part of the population, unrelated to the above financial dynamics [43, 44].

References

[1] UN-ISDR. (2005) Hyogo Declaration, in World Conference on Disaster Reduction. Kobe; 2005

[2] Swiss Re-Sigma. (2014). Natural catastrophes and man-made disasters in 2013: large losses from floods and hail; Haiyan hits the Philippines. https://reliefweb.int/sites/reliefweb.int/files/resources/SwisRe_2014_Natural_Catastrophes_sigma1_2014_en.pdf

[3] Toseroni, Romagnoli, Marincioni. Adapting and reacting to measure an extreme event: a methodology to measure disaster community resilience. Energy Procedia 95, 2016, pp. 491 – 498

[4] UNISDR (The United Nations International Strategy for Disaster Reduction), "Sendai Framework for Disaster Risk Reduction 2015 - 2030," p. 36, 2015.

[5] Surminski, S., Bouwer, L. M., & Linnerooth-Bayer, J. (2016). How insurance can support climate resilience. *Nature Climate Change*. https://doi.org/10.1038/nclimate2979

[6] Herweijer, C., Ranger, N. and Ward, R.E.T. (2009) 'Adaptation to climate change: Threats and opportunities for the insurance industry', The Geneva Papers on Risk and Insurance—Issues and Practice 34(3): 360–380.

[7] McGrath, Typhoon prompts 'fast' by Philippines climate, BBC News, http://www.bbc.com/news/science-environment-24899647

[8] Anderson, D.R. (2003) 'Global warming/climate change: Implications for the risk management and insurance industry', CPCU eJournal 56(1): 1–14.

[9] For example, Hawker, M. (2007) 'Climate change and the global insurance industry', The Geneva Papers on Risk and Insurance - Issues and Practice 32(1): 22–28.

[10] Busch and Hoffmann (2009) Ecology-driven real options: An investment framework for incorporating uncertainties in the context of the natural environment', Journal of Business Ethics 90(2): 295–310.

[11] Stechemesser, Endrikat, Grasshoff and Guenther (2014) Insurance Companies' Responses to Climate Change: Adaptation, Dynamic Capabilities and Competitive Advantage - The Geneva Papers, 2015, (1–28) 2015 The International Association for the Study of Insurance Economics 1018-5895/15

[12] Mills, E. (2009) 'A global review of insurance industry responses to climate change', The Geneva Papers on Risk and Insurance—Issues and Practice 34(3): 323–359

[13] Lin, Y. and Wu, L.-Y. (2014) 'Exploring the role of dynamic capabilities in firm performance under the resource - based view framework',

Journal of Business Research 67(3): 407–413.
[14] Hoffmann et al. (2009). Charpentier, A., 2007. Insurability of climate risks. Geneva Pap. Risk Insur. Issues Pract. 33, 91–107
[15] Li and Liu (2014) 'Dynamic capabilities, environmental dynamism, and competitive advantage: Evidence from China', Journal of Business Research 67(1): 2793–2799.
[16] Zahra, S.A. and George, G. (2002) 'Absorptive capacity: A review, reconceptualization and extension', The Academy of Management Review 27(2): 185–203.
[17] Hecht, S.B. (2008) 'Climate change and the transformation of risk: Insurance matters', UCLA Law Review 55(6): 1559–1620.
[18] Beermann (2011). Linking corporate climate adaptation strategies with resilience thinking', Journal of Cleaner Production 19(8): 836–842
[19] Keskitalo E.C.H, Vulturius, G., Scholten, P. (2014), Adaptation to climate change in the insurance sector: examples from the UK, Germany and the Netherlands - Nat Hazards 71:315–334.
[20] Cilinskis, E., Vesere, R., Blumberga, A., Blumberga, D. (2017). Sustainable National Policy Planning with Conflicting Goals. *Energy Procedia*, *113*, 259–264. https://doi.org/10.1016/j.egypro.2017.04.063
[21] Berkhout, F., Hertin, J. and Gann, D.M. (2006) 'Learning to adapt: Organisational adaptation to climate change impacts' Climatic Change 78(1): 135–156
[22] Dlugolecki (2008) Climate change and the insurance sector. Geneva Pap Risk Insur Issues Pract 33(1):71–90
[23] Mills (2003). Climate change, insurance and the buildings sector: Technological synergisms between adaptation and mitigation', Building Research & Information 31(3–4): 257–277
[24] Ambrosini, V. and Bowman, C. (2009) 'What are dynamic capabilities and are they a useful construct in strategic management?', International Journal of Management Reviews 11(1): 29–49.
[25] Wilkins (2010). The need for a multi-level approach to climate change—An Australian insurance perspective', The Geneva Papers on Risk and Insurance—Issues and Practice 35(2): 336–348
[26] Maynard, T. (2008) 'Climate change: Impacts on insurers and how they can help with adaptation and mitigation', The Geneva Papers on Risk and Insurance—Issues and Practice 33(1): 140–146
[27] Mills, Roth, R.J. and Lecomte, E. (2005) Availability and Affordability of Insurance under Climate Change. A Growing Challenge for the U.S, Boston: CERES, from www.c2es.org/docUploads/Ceres%20–%20Insurance %20&%20Climate%20Change%202005.pdf, accessed 8 July 2014.
[28] Pollner, J., Kryspin-Watson, J., Niewwejaar, (2010). S.2010.Disaster Risk Management and Climate Change Adaptation in Europe and Central Asia, The World Bank, http://www.preventionweb.net/files/15518_gfdrrdrmandccaeca1.pdf
[29] Busch T. (2011) 'Organizational adaptation to disruptions in the natural environment: The case of climate change', Scandinavian Journal of Management 27(4): 389–404
[30] Surminski S (2009) Adapting to the extreme weather impacts of climate change—how can the insurance industry help? A Climate Wise study report for those interested in reducing risk. Climate Wise, London
[31] Schwarze R, Wagner GG (2007) The political economy of natural disaster insurance: lessons from the failure of a proposed compulsory insurance scheme in Germany. Eur Environ 17(6):403–415
[32] McAneney, J., McAneney, D., Musulin, R., Walker, G., & Crompton, R. (2016). Government-sponsored natural disaster insurance pools: A view from down-under. *International Journal of Disaster Risk Reduction*. https://doi.org/10.1016/j.ijdrr.2015.11.004
[33] Biener, C., and M. Eling.(2012) Insurability in Microinsurance Markets: An Analysis of Problems and Potential Solutions. The Geneva Papers on Risk and Insurance – Issues and Practice, vol. 37, No. 1, pp. 77-107. Available from https://link. springer.com/article/10.1057/gpp.2011.29
[34] Bof M. (2012) Terremoti: Generali, costi non possono piu' gravare su collettivita', Il Sole 24 Ore, giovedi' 29 novembre 2012, URL http://archivio-radiocor.ilsole24ore.com/articolo-1134153/terremotigenerali- costi-possono
[35] Di Trapani G., Profili e principali approcci alle coperture dei rischi catastrofali – in Calamità Naturali e coperture assicurative, D. Flaccovio editor (2013).
[36] Anderson, D.R. (2003) 'Global warming/climate change: Implications for the risk management and insurance industry', CPCU eJournal 56(1): 1–14.
[37] Botzen, W.J.W. and van den Bergh, J.C.J.M. (2008) 'Insurance against climate change and flooding in the Netherlands: Present, future, and comparison with other countries', Risk Analysis 28(2): 413–426.
[38] Buzzacchi L., Turati G. (2010), Rischi catastrofali e intervento pubblico, Consumatori Diritto e Mercato, n 2/2010
[39] Le Quesne, F., Tollman, J., Ranage, M., Balogun, K., Zissener, M., Bohl, D., … Kreft, S. (2017). The Role of Insurance in Integrated Disaster and Climate Risk Management: Evidence and Lessons Learned, (22), 68.
[40] Kolk, A. and Pinkse, J. (2007) 'Towards strategic stakeholder management? Integrating perspectives on sustainability challenges such as corporate responses to climate change', Corporate Governance 7(4): 370–378.
[41] Weinhofer, G. and Hoffmann, V.H. (2010) 'Mitigating climate change—How do corporate strategies differ?', Business Strategy and the Environment 19(2): 77–89.
[42] Zahra, S.A. and George, G. (2002) 'Absorptive capacity: A review, reconceptualization and extension', The Academy of Management Review 27(2): 185–203.
[43] Wilkins, M. (2010) 'The need for a multi-level approach to climate change—An Australian insurance perspective', The Geneva Papers on Risk and Insurance—Issues and Practice 35(2): 336–34.
[44] Hecht, S.B. (2008) 'Climate change and the transformation of risk: Insurance matters', UCLA Law Review 55(6): 1559–1620.

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