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BRIDGING KNOWLEDGE, PROTECTION AND DEVELOPMENT GAPS THROUGH AN INTERDISCIPLINARY MULTI-STAKEHOLDER APPROACH TO NATURAL HAZARDS RISK MANAGEMENT

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Abstract

The escalation of climate-induced disasters underscores how climatic variability has become a main question in designing risk-sensitive policies in advanced and developing countries. The macroeconomic implications of Natural Hazards (NHs) are extremely significant as they can compromise financial stability and long-term prosperity. To mitigate risks and close the knowledge, protection and development gaps can free resources speeding up reconstruction of infrastructures, recovering from disruption of supply chains, returning to pre-disaster levels of activities. This is not a simple task involving different steps of a "ladder approach" sharing the burden of cost and responsibilities across the relevant stakeholders and reducing moral hazard. This approach rests on Public-Private-Partnerships (PPP) and technological R&D public investments able to crowd private ones in and establish useful Public-Private-Insurance-Schemes enhancing the disaster risk managing role of the State. The paper proposes leveraging innovation technology both to enhance risk assessment and reduce uncertainty for climate-related NHs such as landslides. It is an important interdisciplinary question, in fact, despite the unequivocal acknowledgment of the warming global climate system, the precise ramifications of global warming and associated climatic shifts on NHs like landslides remain still elusive. The advanced modelling technique implemented by our interdisciplinary PPP contributes to geographically circumscribe the areas eventually subjected to landslides and constantly monitor the vulnerability of their structures, infrastructures, economic activities and hence population. The reliable data that we can produce through remote sensing acquisition systems are necessary inputs to contain risk exposure both physically and financially.

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1. Introduction

Engagement in Public-Private-Partnerships (PPPs) addresses the largest and most complex risks modern societies are facing. As evidenced by the Geneva Association (2023), this approach can tackle even the Changing Risk Landscape due to tangible risks as climate-induced Natural Hazards (NHs). Technological advancements such as richer datasets and sophisticated modeling may improve the insurability of risk.

Our interdisciplinary multi-stakeholder approach precisely fits this evidence focusing its attention on climate-induced NHs, specifically landslides and floods, leveraging new advanced physical modeling and reliable data that will be obtained through new generation of remote sensing monitoring systems.

Among climate-induced NHs, Lin et al. (2020), showed that despite the unequivocal acknowledgment by the Fifth Assessment of the Intergovernmental Panel on Climate Change (IPCC) of the warming global climate system, the precise ramifications of global warming and associated climatic shifts on landslides are still elusive.

Defining risk management in the case of hydrogeological hazards linked to climate change such as floods and landslides requires a dynamic susceptibility assessment to circumscribe, from time to time, subjected areas, structures and infrastructures and hence populations and their environmental and economic exposure. Moreover, if these hydrogeological hazards occur in seismic and volcanic areas the continuous happening of events produces a progressive negative impact on structures and infrastructures increasing the vulnerability and catastrophic impact of each following event. This problem is very complex in the Eurozone because of its crumbling structures and infrastructures result of decades of austerity and underinvestment, in an era of extremely severe emergencies as the climate change and aggressive global competition. This is even far more engaging in Italy as it involves cultural and historical sites very difficult to protect from NHs while maintaining their priceless values.

In the case of the Eurozone the opportunity of a new financial strategy to increase resilience of society from NHs is suggested by the coexistence of the private savings glut of the rich and the strict fiscal rules.

In the following the paper refers to the role of financial institution and technological innovation in Natural Hazard Risk Management. (§ 2). The discussion highlights the role of interdisciplinary research and the need for cooperation between public and private sectors through Public-Private Partnerships (PPPs) (§ 2.1). In section 3 it is presented the Italian smart climate risk protection policy evidencing European comparisons and concluding about how it is possible to improve insurance affordability and the behavior towards risk. Section 4 summarizes the risk assessment methodology. Section 5 explains how to refine risk assessment to increase resilience. The advantages of refining risk assessment and future perspectives are evidenced in section 6.

2. The Role of Financial Institution and Technological Innovation in Natural Hazard Risk Management.

In Macroeconomics and Finance literature the de-risking approach is everything but new. The de-risking role of financial institutions as the Central Bank is well described in making efficient financial markets and safe assets to satisfy "Liquidity Preference as Behavior Towards Risk" (Tobin, 1958), and the need for money capital in the firm (Vickers, 1987). Different components of risk can then be managed, not only financial risk but even operative and technical ones (Ross, 2013).

In a speech at Lloyd's of London given by Carney (2015), the former Chairman of the Financial Stability Board and Governor of the Bank of England, on September 29, 2015, the UK insurance industry was invited to reflect on how urgent was to take into much more serious account the threat of climate change posed to the financial stability and hence long-term prosperity. Since the 1980s the number of registered weather-related loss events had tripled and NatCatSERVICE of Munich Re evidenced the extraordinary increase of inflation-adjusted insurance losses from these events.

More recently "the soft budget constraint syndrome has penetrated capitalism" (Kornai, 2012) and "de-risking" regimes involving PPPs have become hegemonic (Gabor & Braun, 2023) with respect to State-led planning that, as well evidenced by Kornai, may suffer from inconsistency and be less reliable especially in a context of the very high uncertainty of the NHs.

2.1 A Path to Sustainable Financial Protection

In de-risking regimes, multiple stakeholders must be effectively involved through Public-Private Partnerships (PPPs) and Public-Private Insurance Programs (PPIPs). As evidenced in "High-Level Framework for Public-Private Insurance Programs" presented in May, at G7 Italia (2024), global financial markets and particularly insurance markets can accomplish the extremely important role to absorb damages and losses from NHs.

According to OECD (2023a) "Recommendation on Building Financial Resilience to Disaster Risks", for a sustainable development to be guaranteed it is necessary to prevent new disaster risks, reduce the existing and manage the residual ones. All this must be done even "Leveraging technology in insurance to enhance risk assessment and policyholders risk reduction" and "Enhancing Financial Protection Against Catastrophe Risks" through "the Role of Catastrophe Risk Insurance Programs" (OECD, 2023b). The International Association of Insurance Supervisors, then, underlies in its Report "A call to action", "the role of insurance supervisors in addressing natural catastrophe protection gaps" (IAIS, 2023). It's evident in this context the extremely effective role of technology and innovation to measure the effects and reduce uncertainty for whatever NH and degree of climate change. This is to some extent what it is done by Aladdin (BlackRock), to cite the biggest example in the new era of investment management tech. Our PPP, a networking cooperation between universities and enterprises, fits precisely into this area to create spill-over effects as catalyst for economic and social development at local level, strengthen universities' entrepreneurial capacity supporting innovation and even research commercialization.

3 The Italian Smart Climate Risk Protection Policy and European Comparisons

Draghi et al. (2024a, b) evidenced the opportunity to issue guidelines for EU Pension Plans and fix capital adequacy rules for insurance companies established in the Eurozone as the existing fragmented regulatory framework can compromise European economic growth. In fact, EIOPA (2021) reports, for example, that in France the coverage of NHs was already compulsory in 1982; policies are mandatory and due to a principle of solidarity among citizens insurers charge an extra premium for the NHs coverage which is set by the law as a fixed percentage on the Property and Causality insurance premiums of the underlying contracts.

As far as the Italian approach to the regulation of insurance industry, on 31 December 2024 it is going to start a new Smart Climate Risk Protection policy specifically implemented for catastrophic damages characterized by a compulsory scheme, circumscribed, by now, to a limited target of policyholders made of enterprises and households. We will refer to the last Italian Budget Law 2024 (https://www.gazzettaufficiale.it)) to describe its perimeter and the role of each stakeholder involved in it; namely the Italian government, insurance industry and its Supervisory Authority (IVASS), the Italian insurance-financial group directly controlled by the Ministry of Economy and Finance (SACE), and the national reference price comparison site for the insurance sector (Facile.it). In the paper the Italian approach will be briefly compared to a Lloyd's catastrophe insurance policy in the Netherlands (§ 3.2.4) as referred into the EIOPA's Report (2021).

3.1 Bridging protection gaps

Climate change and NHs can rapidly and severely hit the financial stability of economies. Due to scarce information and awareness on their impact on the economies and lack of financial literacy, the effective demand for insurance may be scarce and public and private finance may end up being extremely exposed. Thus financial "protection gaps", happening whenever those who may be directly or indirectly injured by the NHs cannot rapidly recover from a disaster due to the absence of insurance coverage and other financial protection, can be very far to be closed. This can justify the choice of the Italian de-risking government to adopt a compulsory coverage as that introduced by the last Italian Budget Law 2024 (https://www.gazzettaufficiale.it).

3.2 Regulation and Re-insurance.

3.2.1 Businesses

With reference to the hazards to be covered, pending the detailed indications that the Ministers of Economy and Finance and of Enterprise and Made in Italy, in agreement with the Institute for Insurance Supervision, IVASS, the current list (i.e. earthquakes, floods, landslides, inundations and overflows) is merely exemplary.

Similarly to civil liability arising from the circulation of vehicles and vessels, insurance companies will not be able to avoid the obligation to contract, under penalty of applying an administrative pecuniary sanction ranging between €100,000 and €500,000.

Acting as a public reinsurer, then, SACE, an Italian insurance-financial group directly controlled by the Ministry of Economy and Finance, will ensure that the obligations undertaken by the insurance companies are fulfilled, indemnifying the private insurance and reinsurance companies up to 50% of the compensation paid by the latter, for an amount not exceeding 5000 million Euro for the year 2024 and, for each of the years 2025 and 2026, not exceeding the greater amount between 5000 million Euro and the free resources at December 31 of the immediately preceding year, not used for the payment of compensation in the reference year.

To further ensure the overall solvency of the system, it is expected that the obligations assumed by SACE will be guaranteed on first demand and without the possibility of recourse by the State as insurer of last resort. The State guarantee is explicit, unconditional and irrevocable (parag. 109 of art. 1 of the Budget Law 2024; https://www.gazzettaufficiale.it).

3.2.2 Real Estate Sector

With specific reference to the real estate sector, the legislator also intended to extend the range of subjected to the mandatory insurance to those who have benefited from the tax benefits under the so-called "superbonus" (see art. 119, paragraph 8-ter, Italian Leg. Decree 34/2020; https://www.gazzettaufficiale.it), in relation to expenses for interventions started after 30 December 2023. The beneficiaries of the "superbonus", therefore, could find themselves in a delicate position: while, on the one hand, they are entitled to the enjoyment of specific tax breaks, on the other they will now be required to take out additional insurance policies, representing a further financial burden for them.

3.2.3 Online platforms

On the 4th of July 2024 SACE (SACE, 2024), in partnership with Facile.it, launched the Smart Climate Risk Protection a catastrophic damage policy for micro-enterprises. The partnership between SACE and Facile.it marks an important point in the world of insurance and, for the first time, two leading companies join to allow micro-enterprises to obtain maximum benefits with the best technology available on the market. The aim of the agreement is to make Climate Risk Protection smart, accessible in a simple and fast way, with a direct link to MySACE.it, the Facile.it platform.

With this initiative, SACE extends its commitment to serve micro-enterprises, providing them with tailor-made products and digital promotion channels, while Facile.it confirms its desire to become a point of reference in savings not only for end consumers, but also for the B2B sector.

3.2.4 Improving insurance affordability and the behavior towards risk

It was the European Insurance and Occupational Pensions Authority (EIOPA), a European Union financial regulatory institution, that introduced the concept of "Impact Underwriting" that is "the development of new insurance products and the engagement with public authorities, without disregard for actuarial risk-based principles of risk selection and pricing" (EIOPA, 2019, 2021).

The compulsory regime chosen by de-risking Italian government can be mitigated by big data and technologies, useful to better adapt the insurance products or services to customers' needs, but even to prevent NHs and their consequences. Reflecting actual risk a policyholder is exposed, risk-based pricing as premiums and deductibles can produce safer behavior helping climate change adaptation and mitigation of the risks. This then reflects on a reduction in risk, less money to afford losses and decreasing premiums.

For example, a Lloyd's catastrophe insurance policy in the Netherlands, allowed purchasing coverage for flood damage, earthquake and terrorism risks. As far as flood risk, policyholders received premium discounts if they take measure to "floodproof" their home. They found flood risk information on the insurer's website on which they could enter their zip code to extract information about flood probabilities, potential water levels, quality of flood protections and the risk-based insurance premium. Four different measures allow each a 5% premium discount: 1) installing electrical equipment, 2) the central heating installation above the ground floor level, 3) having flood shields available, 4) having a water-proof floor on the ground floor level, such as tiles.

Similar approaches have already been adopted even in Italy through the DERRIS (Disaster Risk Reduction InSurance) Pilot Project (Climate, 2020) by UNIPOLSAI (a multi-line insurance company belonging to the Unipol group, which is a leader in the Italian non-life sector). DERRIS is a project (2015-2018) co-funded by the European LIFE program. The project aims to test and implement an innovative form of PPP between insurance companies, municipalities, and businesses to enhance the resilience of Italian SMEs to climate change. It provides them with a simple and free tool linked to their zip code (the CRAM tool; https://cram.derris.eu/) for the assessment, prevention, and management of risks related to NHs considering five hazards: Flood, Lightning, Rain, Hail, Landslide, Wind, and Temperature. The approach is essentially empirical, using reference scenarios found in the IPCC (Intergovernmental Panel on Climate Change) climate reports (IPCC AR5, 2014) and ISPRA (ISPRA 58, 2015). It starts with a simplified assessment of the effects of NHs without analyzing the causes and physical mechanisms of natural phenomena, but directly evaluating qualitatively the consequences on the territory. For example, regarding the risk of landslides, a simplified methodology has been referenced, based on the National Geological Map (ISPRA) (www.isprambiente.gov.it/Media/carg/index.html) and the Italian Landslide Inventory (IFFI) (www.progettoiffi.isprambiente.it/). The assessment of the hazard considers simply that the increase in precipitation associated with climate change may trigger only shallow landslides among the documented landslides. The assessment of vulnerability is based on the CRAM tool for self-assessment by companies, with the construction of a risk class matrix.

The definition and pricing the policy will be linked to the eventually adoption of a series of intervention strategies.

The examples cited above of the Lloyd's catastrophe insurance policy in the Netherlands and the Italian Derris pilot project offer us the occasion to stress the importance of our contribution. Firstly, the climate change effect may produce dynamic extreme tail events that very simplified and static systems of evaluation are not able to detect. Secondly, the risk assessment based on a zip-code identification rests on an extremely simplified territorial schematization (§ 4). Finally, a contest of changing climate, expectedly growing climate-related losses and increasing premiums, justify the intervention of public re-insurances and PPIPs to contain the "protection gap". The unaffordability for the policyholders on one hand and a crowding of the private insurances and re-insurances out of the market due to their incapability to remain profitable were, in fact, other sources of long-term financial instability to economies.

4. Risk assessment methodology

Our working methodology is based on a critical analysis of the weaknesses dis-cussed earlier for Derris Pilot Project in Turin (Italy). Indeed, as highlighted in Gariano & Guzzetti (2016), there is no universally accepted methodology to define the landslide risk assessment in a changing climate.

The data sources of the Italian pilot project to define the landslide risk assessment are the Geological Maps of ISPRA and the Inventory of Landslides in Italy.

The methodology they use to calculate risk, and its evolution induced by climate change is based on the estimation of hazard (IFFI landslide inventory) and vulnerability (CRAMTool and zip code).

It is a very reliable starting point of analysis but assuming the estimation of vulnerability valid, even if based on a self-assessment, the technical weak point, where our PPP can in-tervene to improve the methodology is the assessment of hazard at more detailed scale.

In fact, the IFFI inventory on Landslides suffers from a series of problems inherent in the methodology used for mapping landslides:

- The national territory is described by collecting heterogeneous data obtained with different mapping and interpretation techniques.
- the scale adopted for mapping of landslides (1:10,000 or 1:25,000) is too broad to allow for a correct assessment.
- although the inventory contains 635.003 landslides (based on 1.009 landslide events), the coverage of the national territory is still partial.
- The periodic updating of the maps is carried out in a heterogeneous manner across the national territory.

Considering all that has been discussed, and intending to apply the same working methodology, the next paragraphs outline actions to be taken to enhance the risk assessment.

5 Refining risk assessment to increase resilience.

The probability of a catastrophic event is related to the system's ability to counteract it, depending on the mechanical and geometric characteristics of the natural and built system in question. Therefore, the calculation of the probability of occurrence is more accurate the more precise is the definition of the models capable of following the underlying physical phenomenon and the related physical parameters. Hence, the probability of occurrence is closely tied to the uncertainties inherent the definition of behavioral models and the related physical parameters. The techniques available in the engineering field for handling uncertainties have been discussed in Ferrero et al. (2004), Baecher & Cristian (2003) and Hudson (2013). Each source of uncertainty must be adequately considered and addressed. Epistemic uncertainty can be overcome as it is linked to a lack of knowledge that can be refined through in-depth investigations. As discussed earlier one of the main sources of epistemic and aleatory uncertainty in risk assessment for landslides lies in the quality of the data and the scale to which they refer. For example, in modeling landslide phenomena, a scale of analysis with insufficient level of detail induces not only epistemic errors with serious repercussions on the geological and geotechnical models used, but also errors with high aleatory uncertainties due to greater data dispersion resulting from an excessively broad scale of analysis. Thus, having a detailed analysis of the geotechnical model through a combination of conventional monitoring systems and innovative instruments, along with continuous data acquisition, results in a significant reduction of both epistemic uncertainty (allowing previously unavailable information to be obtained) and aleatory uncertainty (availability of a large quantity of high-quality data) (Dubois & Guynnet, 2011)

Our PPP therefore works in the direction of producing information for accurate calculation of the probability of occurrence of catastrophic events and managing the related uncertainties to reduce risk and improve resilience. Moreover, as previously discussed, the huge quantity and quality of data that will be disposable can be useful to train AI algorithms to refine the precision of the forecasts with further significant implications even for the insurance and reinsurance industries by providing more accurate risk calculations. Clearly, the distribution of the population, strategic and non-strategic civil and military structures and infrastructures, as well as productive activities across the territory, can provide guidance on the priority scale to adopt and the level of detail to reduce uncertainty.

In the following, the attention is devoted exclusively on NHs related to climate-induced landslides. In fact, the landslide risk assessment can be effectively supported by our PPP as it includes even the expertise to develop advanced models to simulate the effects of climate change and, on the other hand, the creation of innovative investigation and monitoring systems.

6. Advantages of refining risk assessment and future perspectives.

The application of the refining assessment just described is presented for three cases where the Derris approach would have been un-reliable due to the extreme complexity of hydrological, geological and geotechnical characteristics of the sites as generally found throughout the Italian territory. Different approaches have been developed depending on the characteristics of soil deposits and the type of landslide.

In the case of rainfall-induced landslides in shallow pyroclastic deposits of the Campania Region (Figure 1), Netti et al. (2012) proposed a multidisciplinary approach that involves the expertise of hydrologists, meteorologists, computational mechanics experts, economists, and geotechnical engineers for landslide risk management, which significantly impacts the epistemic component of uncertainty. In the territories under consideration, a supplementary investigation program was developed, which included the redaction of thematic maps at detailed scales (1:1000 and 1:2000) and the execution of in-situ and laboratory tests for the mechanical characterization of soils. Furthermore, complex monitoring systems with continuous data acquisition and remote management were installed in the study areas. A framework (Figure 2) was proposed for the assessment of landslide evolution under a simplified hypothesis, which can be used to create a Decision Support System (Damiano et al., 2012) for stakeholders involved in land management and the protection of areas at risk.

This also led to the creation of a soil database for hydro-geotechnical models for volcanic soil deposits (Damiano et al. 2023). The database contains all the data needed to define advanced constitutive relationships to be implemented in a physically based model to capture landslide failure under weather rainfall forecasts (such as those caused by climate change). The data contained in the soil database represent an essential input for initializing AI algorithms, while the monitoring data serve to train the AI.

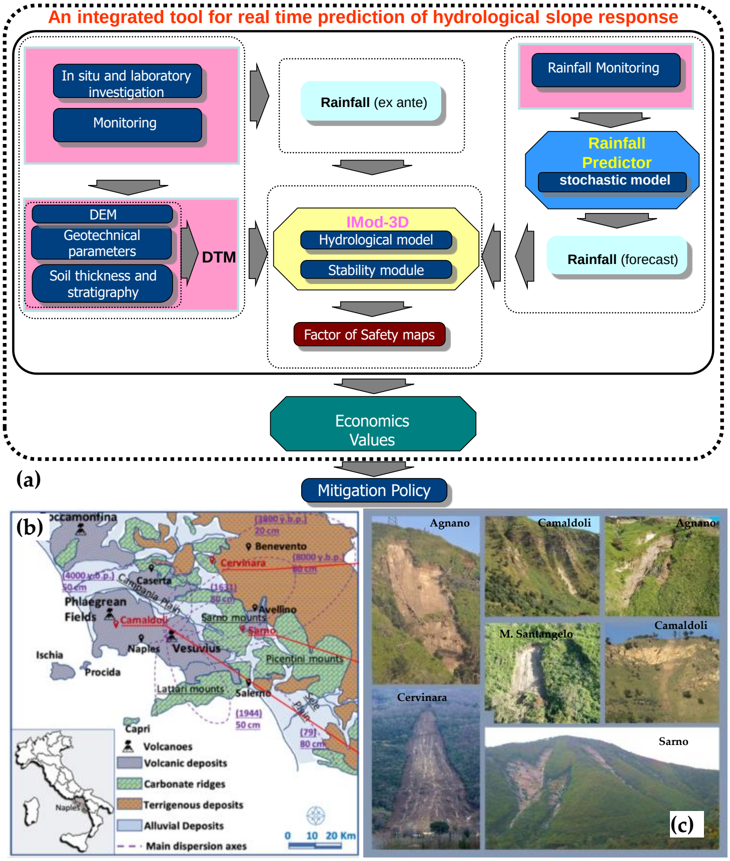


Figure 1. a) Flow chart of the Decision Support System (DSS); b) Geomorphological contexts of the pyroclastic deposits in Campania, Italy c) Landslides case history.

Moreover, since 2019, the research has been implementing technological innovation and advanced expertise in defining advance monitoring systems both for the study of the effects of landslides and earthquakes and for Structural Health Monitoring and Reinforcement (SHMR) (Di Gennaro et al 2022). This research activity led to the realization of the New Smart Hybrid Transducer (NSHT) (Figure3) and the registration of industrial property patents (EP-3948167-A1, 2022). In the Figure 3a there is a schematic representation of an application of NSHT as a landslide Early Warning System (EWS) and as SHMR system by a single acquisition system (Figure 3c). The proposed monitoring system is constituted by distributed strain and temperature NSHT transducers based on optical fiber sensing technology. NSHT transducer (Figure. 3 b) is constituted by a mono-mode optical fiber for communication embedded in a composite support material connected to an interrogation system (Figure 3c).

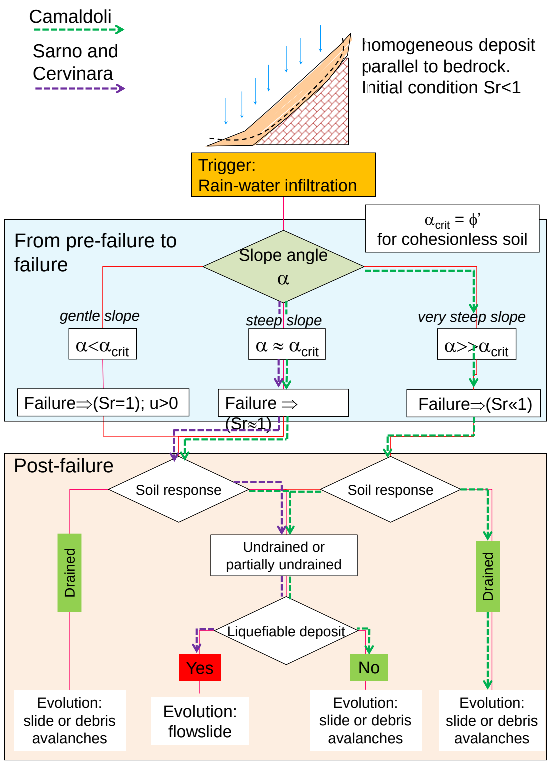
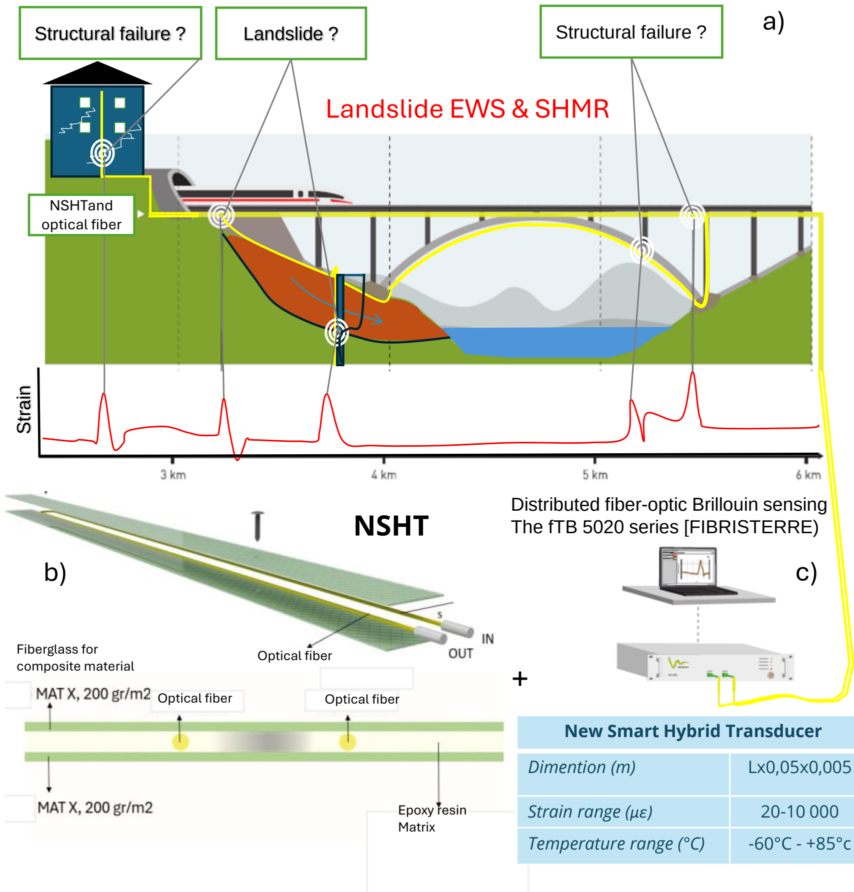


Figure 2. Flow chart for simplified assessment of the post failure evolution of landslide.

This NSHT transducer can be remotely interrogated with different techniques (Brillouin scattering and Rayleigh backscattering) and each part of fiber act as sensor. In static acquisition, a monitoring system including the NSHT, is capable of continuously monitoring strains and temperatures along the transducer covering 1 km up to 50 km with a spatial resolution of up to 20 cm and spatial sampling of 5 cm. In dynamic acquisition, it can monitor sections from 20 m to 100 m with a sampling frequency of 20 to 50 Hz and subcentimeter spatial resolution and sampling. Applying NSHT transducers (described by yellow line in figure 3a) in adherence to the structures of buildings, tunnels, viaducts, and in landslides (as a Smart Estenso Inclinometer), it is possible to continuously remotely monitor the strains induced and highlight in real time the occurrence of a failure (the strain peaks detected by the red curve in Figure 3a).



New Smart Hybrid Transducer	
Dimention (m)	Lx0,05x0,005
Strain range (με)	20-10 000
Temperature range (°C)	-60°C - +85°c

Figure 3. a) Schematic representation of Landslide EWS and SHMR; b) implementing the NSHT as strain and temperature distributed transducer; and c) the interrogation system of FIBRISTERRE for optical fiber sensor.

As a final example, NSHT has been implemented by CUGRI (inter-University Consortium, named the Research Center for prevision prediction and prevention of the Great RIsks) and Centola Municipality in the case of deep clay shales landslides as a smart estenso-inclinometer, with the complex monitoring system installed in Cilento Geopark (Southern Italy) (Damiano et al., 2024). This complex monitoring system has been providing practically continuous information on weather and subsoil variable, since 2021. This enables to identify the link between rainfall, pore water pressure, the underground strain profiles of deposits and the reactivation of landslides (Figure 4).

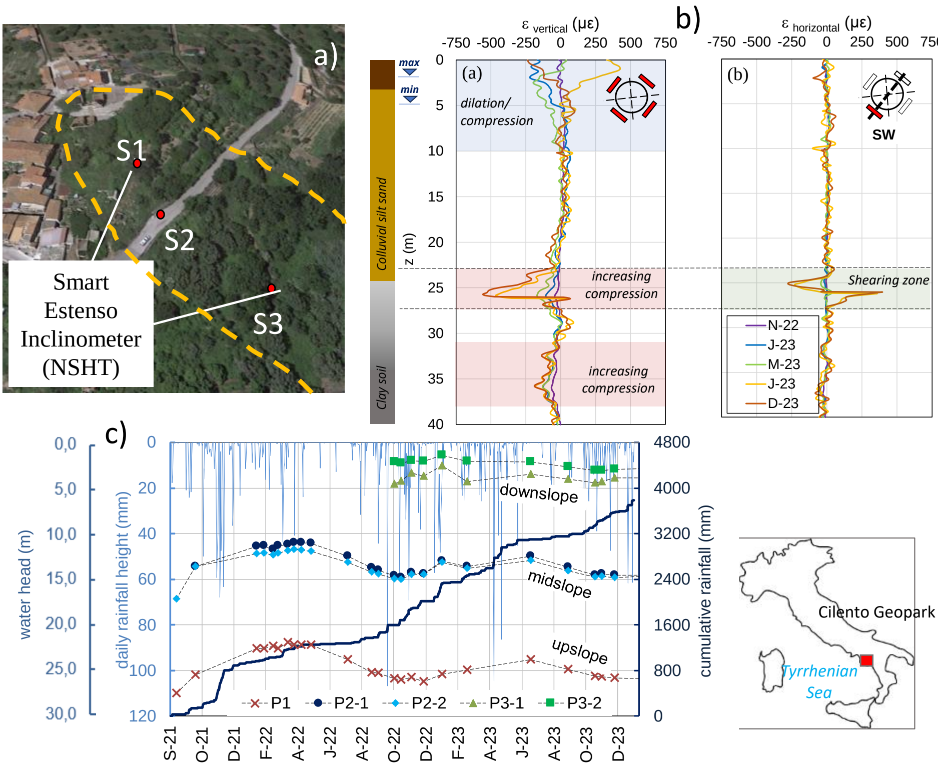


Figure 4. a) San Nicola experimental field: location of the three monitored sites (S1, S2, S3); b) daily and cumulative rainfall and groundwater fluctuations at the three sites ; c) identification of land-slide activation by smart estenso inclinometer strain profiles..

Applications on pile foundations and bridge piers are ongoing. For further research we suggest that NSHT might be used even to constantly monitor the strain of underground along very long distances (up to 50km) (e.g. the monitoring of the effects of bradyseism such as that recently seen in Campi Flegrei, in the Southern Italy).

7. Conclusions

In the paper it has been presented an interdisciplinary multi-stakeholder approach to NH risk management that exploits the expertise of meteorologists, geologists, engineers, economists of public institutions such as Universities, Knowledge Transfer Management, Interuniversity Centers for the Prediction and Prevention, Municipalities, Academic Spinoffs, Enterprises.

The approach has proposed to leverage innovation technology both to enhance risk assessment and reduce uncertainty for landslides. The advanced modelling technique presented contributes to geographically circumscribe the areas eventually subjected to landslides and constantly monitor the vulnerability of their structures, infrastructures, economic activities and hence population.

This helps bridging protection gaps, encouraging behaviour towards risk, increasing the affordability of the policies and the capability of businesses to stay on the market hence boosting the socioeconomic resilience, financial stability and long-term prosperity.

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