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Integrating insurance design and resilience metrics for climate-disrupted infrastructure delivery: A conceptual framework

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Abstract

This paper is based on the argument that insurance and surety mechanisms can be more actively involved in funding and motivating resilience in the context of disrupted infrastructure delivery in climate disruptions. Instead of serving merely as tool of risk dispersion, insurance and surety design can be designed in a strategic manner with quantifiable resilience measures to facilitate reduction of risks, enhance incentive, and contribute to increased project continuity outcomes. To combine these functions, a well-structured framework is needed which links measures of resilience with insurance and surety terms in a manner which is transparent and operational.

In this respect, this paper proposes a conceptual framework of insurance-based resilience financing in construction and infrastructure projects disrupted by climate. The framework particularly identifies the exposure to hazards, vital infrastructure and the mitigation measures to insurance policy coverage, deductibles, and sureties. By ensuring that the financial protection measures and the resilience actions that are displayed are aligned, the framework will reduce the magnitude of losses, accelerate the claims processes, reduce confrontations, and improve the rapid restoration of the vital infrastructure services in case of a climate inference.

This paper has threefold input. It begins by providing an analytical assessment of the existing interaction between infrastructure programmes and hazard information with insurance coverage underwriting practices on areas of greatest misfit, and how these work against the creation of resilience. Second, it presents a new conceptual scheme that combines risk transfer and reduction that incorporates quantifiable risk reduction and reduction machineries that are contractually entrenched. Third, it demonstrates the relevance of the framework in practice by providing real-life scenarios of disruption and advice on future contracts and governance implementation. Therefore, concerns of relevance in the paper are directly linked to enhance demand on policy-based and financially grounded resilience in infrastructure delivery among climate-exposed infrastructures.

Keywords: Climate; Design; Insurance; Integrating

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1. Introduction

Natural hazards that relate to climate are proving to be a major disruption in the implementation of construction and infrastructure projects all over the world. According to Barnett and Bouw (2022), Flooding, hurricanes, wildfire smoke, and extreme heat events have ceased to be an episodic shock to the project but have become habitual characteristics of the project risk environment. During the construction stages, infrastructure assets are frequently left unguarded, partially finished, temporary, and lack of redundancy. This causes the disruptions caused by climate to often result in schedule slips, work-in-progress damages, cost increases, insurance damages, and long-term disruption of the provision of necessary services.

The financial and contractual arrangements that apply to the delivery of construction have not kept pace with this increasing realization of climate risk in the framework of the infrastructure planning process (Aduwa et al., 2025). Specifically, insurance and surety instruments remain formulated mainly as post-incident risk transfer solutions, which are triggered when damage or inconvenience has taken place. In comparison, Nahid et al (2024) states that the measures of resilience, i.e., hazard mitigation, design adaptation, and operational preparedness, is considered as risk mitigation strategies that are frequently tackled by the engineering standards or project management practices. These two areas are usually developed and regulated independently with little coordination between resilience planning and insurance or surety design.

This division brings about a structural inefficiency in climate risk management to deliver infrastructure. Absence of explicit recognition of resilience investments in insurance and surety provision frameworks means that project participants have quite limited financial incentives to take quantifiable risk-reducing measures that go beyond the minimum regulatory or contractual requirements (Pallaria, 2023). On the other hand, insurers and sureties face the increasing losses that are driven by climate-related disruptions without any systematic mechanisms to incentivize or compensate proactive resilience efforts. The outcome is a vicious circle of increasing premiums, rising deductibles, often stalled claims settlement, and increased disagreements and delays in resumption of the essential services after the occurrence of hazards, all of which hamper continuity of the project and the speed with which essential services are restored after such disruptions.

Chirisa and Nel (2022) posit that both current policy initiatives and infrastructure investment programmes are focusing more on the role of resilience and climate adaptation. Nevertheless, the aim of such efforts tends to be at the asset level design or long-term operating performance and not at the stage of delivery of infrastructure projects. The construction period is a critical weak spot, which is marked by disaggregated and short-term contractual incentives, and distribution of risks that are not aligned. Current insurance coverage typically lacks explicit connections among the exposure to hazards, critical infrastructure and responses to mitigate against hazards and the form of coverage trigger, deductible or surety bonding (Majka, 2024).

2. Fragmented Treatment of Climate Risk in Infrastructure Delivery

2.1. Climate disruption and the construction phase vulnerability

The construction and delivery of infrastructure projects is associated with unique and exaggerated risks that are related to climate. Construction infrastructure is necessarily exposed, as compared to operational assets: structural systems can be unfinished, protective measures are temporary and contingency capacity is restricted. Flooding may destroy foundations and earthworks, excessive heat may stop labor-intensive processes and material degradation, and wildfire smoke and hurricanes may halt operations and supply chains (Mukke et al., 2025). These effects often drive into schedule slip, rework, and loss of more money.

Fragmented risk ownership is also typical of the construction stage. The roles are shared among the owners, contractors, subcontractors, designers, insurers, and sureties with each having various contractual horizons and incentive schemes. According to Aamir et al (2025), climate disturbances do not merely cause physical losses but also enhance coordination breakdowns, claims conflicts and decision delays. This renders the delivery stage a more crucial but underserved aspect of the infrastructure resilience.

2.2. Risk transfer mechanisms: Insurance and surety.

Construction insurances and sureties are mostly structured to help in shifting financial risks once they have been incurred (Bunni, 2025). Builders risk insurance, delay-in-startup insurance and performance bonds are designed on the basis of predetermined coverage triggers, deductibles and exclusions responding to physical damage or contractual default. Underwriting is usually grounded on the available past losses data, zoning of hazard areas, and characteristics of the project, like size, location and nature of contract.

2.3. Risk reduction domain of resilience.

Simultaneously, resilience is usually tackled in terms of engineering design criteria, building methods, and project management approaches (Naderpajouh et al., 2023). There are measures like high foundations, temporary flood defences, heat-adapted work schedules, and smoke management guidelines which will minimise the vulnerability and cause minimal disruption. These measures are, however, usually determined on technical or regulatory basis as opposed to being directly associated with financial risk allocation mechanisms.

Consequently, the resilience investments that may be undertaken in the course of construction are usually understood as the cost centres as opposed to the value-creating behaviours. In the absence of financial incentives to reduce risk reflected in the costs of insurance, deductibles, or surety requirements, project participants are not motivated to go beyond the minimum standards.

3. Conceptual Framework for Insurance-Enabled Resilience Financing

3.1. Rationale for integrating insurance and resilience

The increased rate of and severity of disruptions related to climate indicates the necessity to transcend insurance and resilience as two separate platforms of infrastructure delivery. Only insurance systems that are created to offer post-loss compensation schemes do not go much to offset underlying vulnerability and resilience mechanisms that are not captured in the financial recognition are struggling to make ends meet in overcoming minimum requirements (Roper et al., 2025). There is therefore a need to have a combined approach with insurance and surety design actively involved in encouraging risk-reducing behaviours during the construction stage.

The current paper proposes resilience financing structure based on insurance, which will even the financial risks transfer process and quantifiable resilience controls. The major assumption is that the resilience activities which are undertaken in the construction must have a direct impact on the construction and operation of insurance and surety instruments.

3.2. Framework overview and structure.

The framework proposed will be made of three interconnected blocks resilience metrics, insurance and surety mechanisms, and project continuity outcomes. The metrics of resilience record the exposure and preparedness of the project in relation to climate hazards. These metrics are converted into contractual and financial terms by insurance and surety mechanisms. The end products of project continuity are the impact on the level of losses, claims settlement, and recovery rate.

The framework works based on a systematic mapping. To measure the resilience properties of a project, first, pre-defined and measurable indicators are used. Second, these indicators are associated with certain design features of insurances and sureties. Third, the altered financial conditions establish an incentive in the proactive reduction of risks and help to achieve better continuity messages after a disruption.

3.3. Resilience metrics

The framework sets the definition of resilience based on the three central dimensions which are measurable, observable and pertinent to the risk in the construction phase.

The former is the exposure to hazards. This describes the nature, occurrence, and severity of climatic risks in the project site within the construction time. Exposure assessment is not just about the geographic zoning of exposure, but also includes time using seasonal flood risk, hurricane windows, or temporal extreme heat periods or times of heavy wildfire smoke (Koman & French, 2023). The increased exposure levels imply the increased possibilities of disruption and loss.

The second one is infrastructure criticality. This is a mirror of the society and functional significance of the asset under delivery and the impact of construction delay or failure. High criticality is considered to be projects that support the provision of vital services like transport corridors, energy supply, water infrastructure, or emergency response infrastructure. The criticality affects the levels of intolerance of downtime and the focus on quick recovery.

The third is mitigation and preparedness measures. It also involves physical and operational controls used in the construction process, e.g. temporary flood protection, high storage of materials, climate-adjusted work sequencing, backup supply set-ups and emergency response procedures. These measures are evaluated on the basis of the effectiveness, the quality of their implementation and their correspondence to hazards identified.

3.4. Mapping resilience metrics to insurance and surety design

The core idea of the framework is to map the resilience measures to certain insurance and surety conditions. This mapping forms clear financial acknowledgment of risk lowering measures and integrates resilience performance in the terms and conditions of contracts.

Insurance covers and deductibles are associated with hazard exposure and mitigation measures. High exposure projects that have been shown to have mitigation controls can be adjusted to trigger earlier in the disruption event or less deductibles based on a lower likelihood of the expected severity of loss. On the other hand, high exposure, low mitigation projects can have an increased deductible, or restrictive triggers, indicating a degree of risk.

Coverage scope and claims handling provisions are themed to infrastructure criticality. In assets of high criticality, insurance constructions can focus on quick and liquidated provision of the assets by parametric or hybrid trigger, so that they can effectively respond and stabilize immediately upon disruption. The terms of sureties can also be modified to include continuity terms as opposed to just financial completion terms.

The surety bond terms and performance incentives are also connected with mitigation and preparedness measures (Patel, 2025). Contractors who have converted to known resilience controls could enjoy less bonding, performance flexibility, or convoluted profits. Avoidance of observed resilience standards agreed upon can lead to contractual remedies or higher requirements of financial security.

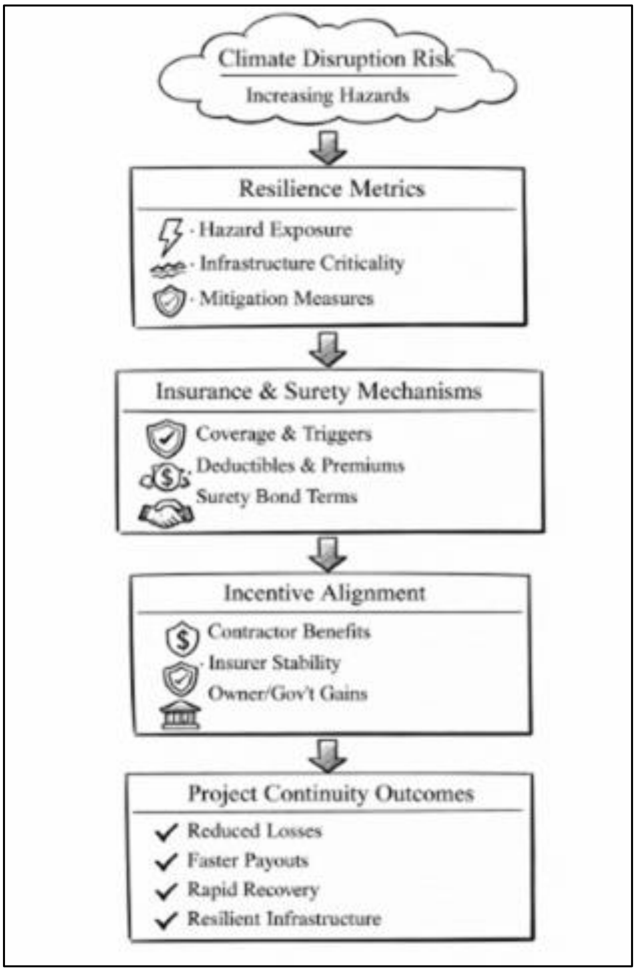
3.5. Incentive alignment and effects of behaviour.

The framework transforms the incentives according to the project stakeholders by incorporating resilience metrics into the design of insurance and surety. Resilience is directly financially beneficial to the contractors and developers, including deductibles and coverage conditions, or bonding costs. The insurers and sureties are also enjoying the decreased volatility of losses and unambiguous risk separation. The proprietors and the government agencies increased continuity within the project and expedite recovery of essential services.

3.6. Project continuity expected results.

Insurance and resilience integration should have a number of benefits in terms of continuity. Mitigation is the most effective in regard to reducing the severity of losses and the early-triggering coverage facilitates quick stabilisation and response (Saidy et al., 2025). The predetermined connections between resilience measurements and coverage conditions make claims processing faster. Conflicts are minimized because the expectations regarding the contract and the financial implications are well expressed beforehand.

The framework operates at a system level, facilitates more robust infrastructure delivery through harmonization of financial mechanisms with climate adaptation goals. It allows insurance and surety instruments to not only be used as a form of compensation, but facilitate positive resilience in construction sites disrupted by climate. The structure of the proposed insurance-enabled resilience financing system is shown in Figure 1 below, which shows how project continuity in the situation of climate risk is formally organized into insurance and surety instruments through an integrated approach to resilience metrics.



Source: (Researcher, 2026)

Figure 1 Conceptual Framework for Insurance-Enabled Resilience Financing

4. Methodology

4.1. Research design and methodological approach

The research design used in this paper is the conceptual and analytical research design, which is suitable in the development and illustration of a new framework in the area of convergence of infrastructure resilience, insurance, and climate risk governance (Ogbuefi et al., 2023). Instead of applying empirical data collection as the methodology, the framework combines policy analysis, review of the market practices, and scenario-based reasoning to build and operationalise the proposed insurance-enabled resilience financing framework. This strategy is aligned with the conceptual research done so far in the field of disaster risk reduction and insurance, where the goal is to develop theory and practice by organizing the integration of the existing systems and mechanisms.

Its methodology is aimed at achieving three goals: first, determining structural incompatibilities between the infrastructure delivery system and its use of hazard-related data and the insurance underwriting system; second, the translation of resilience concepts into measurable and contractually applicable metrics; and third, how the system proposed changes incentives and project outcomes in the event of realistic climate disruptions.

4.2. Policy and market review

The critical review of structures of infrastructure programme, practices of hazard data and the insurance and surety underwriting practices is the first methodological component. The review is analytic and not descriptive by nature, and dwells on the interaction of these systems as they are today and where there are points of failures in integration (Ivanov and Velkova, 2025). The infrastructure programmes are analyzed in terms of procurement models, allocation of risks in contract and governance arrangements at the construction stage. Close focus is given to the way the responsibilities of climate risk are shared out between the owners, contractors, insurers and sureties and how such roles affect decision making in case of disruption.

The usage of hazard data is discussed in the context of incorporation of climate and natural hazards data in project planning and resilience design in comparison to insurance underwriting. The review indicates variations in temporal resolution, performance measures, and decision levels, which frequently do not allow hazard data to be operationally transferred within domains. Surety and insurance underwriting procedures are considered with regards to coverage structure, deductibles, and exclusion, bonding requirements, and claims handling procedures. The analysis shows that the majority of risk assessments are static and little have been done to recognize project-specific resilience actions especially in construction.

4.3. Framework design and operationalisation.

The second methodological element is the conceptualization of structural design and operationalisation. It involves the definition of resilience metrics, their measurability and systematic mapping to insurance and surety mechanisms (Almaleh, 2023). The metrics of resilience are operationalised in the three dimensions as the hazards exposure, criticality of infrastructure and mitigation and preparedness measures. The dimensions are specified on the basis of indicators that can be observed at the construction stage and that can be verified with the help of documentation, inspection, or by third-party evaluation. This priority on quantifiability makes resilience performance plausibly entrenched in the finance and contractual frameworks.

Mapping transforms these resilience metrics to particular features of insurance and surety design. The coverage triggers and deductibles are associated with hazard exposure and mitigation measures, and infrastructure criticality with coverage scope, prioritisation of claims, and continuity-oriented bond conditions. The framework will be flexible so that it can be adapted to different types of hazards, project sizes, and institutional environments, but a similar logic of incentive fit applies.

4.4. Scenario-based demonstration approach

The third methodological element uses scenario-based simulations to explain how the framework works during disruptions related to climate (Orru et al., 2023). These are not empirical case studies but systematic illustrations which are based on plausible hazard events that usually occur during infrastructure construction. Three types of disruptions are chosen to reflect the various hazard dynamics and impact ways including flooding, hurricanes, and wildfire smoke or extreme heat disruption. A comparative logic is used to analyse each situation. To begin with, the anticipated results in the case of the traditional insurance and resilience plans are enumerated, with slowing, loss, and conflict being the key factors. Second, the identical situation is reviewed in the framework proposed where the adjusted insurance triggers, deductibles, and surety conditions are reviewed to show how these conditions affect behaviour, minimise losses, and enhance quicker recovery.

4.5. Governance and implementation analysis.

The last methodological aspect is an implementation feasibility and governance implication. This will entail examining how the framework can be incorporated into the contracts of construction, insurance policies, and programme governance structures (Khan, 2022). The mechanisms that are proposed are resilience-related clauses in the contract, performance verification requirements, claims acceleration, and dispute avoidance arrangements.

The methodology, having a specific focus on implementation and governance, will be making sure that the framework is not just a piece of theory that can be adopted in the current institutional and market framework. This is also a supporting element of policy-oriented journals alignment, as it shows a concern with practitioners, regulators, and sponsors of the infrastructure programme.

5. Scenario Demonstrations: Climate Disruption in Infrastructure Delivery

5.1. Purpose and structure of the scenario demonstrations

The objective of the scenario demonstrations is to show the way the proposed insurance-based resilience financing framework will change the risk outcomes, incentives, and the project continuity in the case of climate-related disruptions. Pagano (2024), states that these situations are not empirical case studies but structured analytical examples on the basis of the typical hazards in infrastructure building. Both situations are comparatively organized, analyzing the results under conventional provisions and then comparing them to the results under the suggested framework. The scenarios revolve around three likely climate disruptions namely flooding, hurricanes, and wildfire smoke or extreme heat. Collectively, they record various classes of hazard dynamics, comprising of sudden-onset, long-term disruptions, and indirect effects on labour and supply chains. This is in all the situations, with the focus on the effect of the resilience measures on the insurance and surety design and the enhancement of the continuity results of this integration.

5.2. Scenario 1

5.2.1. During transport infrastructure construction, flooding occurs.

In a traditional set-up, a transport infrastructure project within a flood-prone environment will normally depend on the physiological damage of constructions to builders risk insurance once the works have been completed or partially finished (Ayorinde et al., 2023). General hazard zoning is used to measure flood exposure, and temporary flood protection measures adopted during construction are hardly incorporated in coverage provisions. In a case of floods, destruction of foundations, excavation and stock leads to the cessation of the work, rework, and insurance claims with a substantial deductible. Handling of claims can be delayed because of the causation, extent of damage and temporary works responsibility.

Using the proposed framework, the exposure to flood risks is determined at the level of the construction phase, and seasonal risk and site-specific conditions are considered. Increased storage of materials, flood barriers that are temporary, and regulated drainage systems are all considered to be resilience metrics. Such measures are mapped to the insurance design using modified deductibles and coverage triggers. Confirmed mitigation results in reduced deductibles and faster activation of the triggers, which allow recovery resources to be mobilized quicker. Surety bond terms are harmonized on the basis of schedule recovery as opposed to penalties on failure to complete on schedule. Consequently, the severity of losses is mitigated and claims are settled within a shorter period and construction starts with a short time lag.

5.3. Scenario 2

5.3.1. Coastal energy infrastructure disruption due to Hurricane

Conventionally, the exposure to hurricanes increases insurance premiums on projects in coastal energy infrastructure, and there has been little distinction by project insurance based on resiliency to construction phases (Lachman et al., 2023). The coverage triggers tend to have some physical damages requirements, whereas extended closures because of safety issues or disruption of the supply chain cannot be covered under the standard. After a hurricane, arguments can be made as to whether the delay is caused by insured damage or operational choices that are outside the insurance cover, which is likely to slow down the claims processes and project resumption.

Using the proposed framework, the exposure to hurricanes is used along with the infrastructure criticality to guide the insurance and surety design. The project is a critical energy asset and it is being put under high continuity. Such measures as reinforced temporary structures, sequence of modular construction, and previously established quick inspection procedures are checked and evaluated. These are mapped on the coverage scope by using hybrid or parametric triggers which are activated by wind intensity or evacuation levels so as to provide immediate liquidity after disruption. The conditions of surety bonds focus on continuity responsibilities and recovery planning. The outcome is increased access to funds faster, less downtime and improved definition of priorities in recovery by the insurers, the contractors and the owners.

5.4. Scenario 3

5.4.1. Wildfire smoke and extreme heat disruption to urban construction

Indirect but already growing risks of construction projects, especially in urban settings, exist in the form of wildfire smoke and extreme heat (Naser & Kodur, 2025). The insurance coverage under the conventional arrangements usually lags behind such disruptions because they might not result in the direct physical damage but can stop work as a result of health and safety issues. Delays are piled without evident financial backup that results in cost escalation, schedule conflicts, and poor relationships between the project members.

In the suggested framework, hazard exposure assessment will involve non-causal, yet obstructing climate conditions e.g. smoke and heat. Adaptive work schedule, protective equipment, on-site cooling infrastructure, and contingency labour arrangements are mitigation and preparedness measures that are determined as resilience metrics. These measures are connected to the insurance coverage that acknowledges disruption-related triggers and less waiting time to delay-related coverage. Surety arrangements provide flexibility of schedule change in which protocols of verification of resilience are adhered to. Consequently, proactive management of disruptions is achieved, and financial uncertainty is minimised as well as responsibility disagreements on the cause of delay being minimised.

5.5. Comparison of scenarios and synthesis of results

In all three cases, the suggested structure proves to be effective in enhancing risk performance and incentive alignment. The framework minimizes insurance and surety design through the explicit connection of the resilience metrics relating to the severity of losses, speeding up claims processing, and project recovery. Notably, it transforms the stakeholder behaviour by rendering resilience investments financially transparent and contractually significant. The scenarios also bring out the flexibility of the framework in regard to the types of hazards and project situations. Regardless of whether one is dealing with a case of sudden physical damage or a longer operational disruption, integration of risk transfer and risk reduction mechanisms helps to have a continuity of the project and minimize the systemic inefficiencies. These findings maintain the thesis that insurance design can serve as a strategic instrument of financing and incentivising the provision of infrastructure delivery in the event of climate disruption.

5.6. Implementation and Governance Implications

The suggested framework is supposed to be installed into existing infrastructure supply, insurance, and surety provisions, and it will not need profound institutional restructuring. Its success is based on specialized contractual, governance, and claims-management adjustments that incorporate resilience metrics within standard project controls. On a contractual level, contractual clauses associated with resilience can be added to construction contracts and insurance policies. These provisions characterize anticipated mitigation and preparedness actions, determine the verification procedures, and determine how the resiliency performance affects insurance deductibles, coverage triggers, or bond conditions. Contracts eliminate uncertainty by transforming resilience expectations into clear and quantifiable numbers and curb post-disruption conflicts.

Governance structures are essential in the realisation of the structure. It is the role of the project owners or programme authorities to determine the resilience metrics, verify independently and to organize information flows between the contractors, insurers as well as the sureties. This controlling action is in place so that the data on hazards and resilience performance are regularly evaluated and openly connected to the financial processes during the construction process. Predefined claims acceleration mechanisms can be applied to handle and recover claims. Insurance triggers based on the established resilience measurements facilitate quicker access to liquidity after disruption, especially of critical infrastructure ventures. Defined pre-established thresholds mitigate delays to do with loss attribution and interpretation of the coverage to enable faster mobilisation of recovery efforts and project re-institution.

6. Discussion

The gap in climate risk management in infrastructure delivery that this paper deals with is that there has been a longstanding division between risk reduction via resilience efforts and risk transfer via insurance and surety measures. As climate-related disconnects are turning into a greater contributor to the construction timeline, project expenses, and service interruption, existing systems are more of a reactionary financial tool that fails to effectively incentivise proactive resilience throughout the delivery stage. Such fragmentation negatively impacts project continuity and it helps to increase losses, conflicts, and delays in recovery.

The main value of the paper lies in the conceptual framework that combines the insurance and surety design and quantifiable resilience controls. The framework revisits the concept of insurance as the active, instead of the passive, instrument of governance by connecting the exposure to hazards, the importance of infrastructures, and mitigation measures to coverage triggers, deductibles, and bond terms. This harmonization of incentives amongst the project participants and integration of climate adaptation into the financial and contractual frameworks is done.

The scenario demonstrations show the way this alignment enhances the results of various hazard types. In both scenarios, the framework will mitigate the level of losses, enhance speed in claims, and enable recovery to be faster since resilience performance will be recognised and rewarded. Notably, the mentioned improvements can be made without new insurance products or regulatory transformation, which is important to emphasize the feasibility of the approach in the current market and institutional environment.

On a policy and industry level, the results would imply that resilience goals may be furthered in a more efficient manner in case financial mechanisms are set to support risk-reducing behaviour. Making resilience metrics embedded into insurance and surety plans makes them more transparent, less prone to disputes and contributes to the continuity of critical infrastructure services during times of climate pressure. This relates to the governance of infrastructure programmes, practice of underwriting, and government-sponsored strategies of climate adaptation in their public investment.

The paper has flaws that are within its conceptual design. The framework is illustrated with the help of illustrative scenarios, and there are no empirical tests of it; its usage might have different applications in various legal, regulatory, and market settings. Future studies might empirically test the framework with project-level data and help determine the effects that it has on pricing and loss performance as well as how well it can be extended to other infrastructure sectors and geographic scopes.

7. Conclusion

Finally, the paper proves that insurances and surety can be an effective strategic instrument in the financing and incentivisation of resilience in the delivery of business climate-disrupted infrastructure. The proposed framework provides more resilient, efficient, and adaptive infrastructure systems through the combination of risk transfer and risk reduction using measurable and contractually embedded systems in a more uncertain climate environment.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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