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Integrating Insurance and Risk Management into Climate Change Governance: A Social-Ecological System Framework for Enhancing Resilience

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ABSTRACT

BACKGROUND AND OBJECTIVES: Climate change increasingly manifests through systemic extreme weather events—such as heatwaves, floods, storms, and wildfires—that pose complex challenges to interconnected social, economic, and biophysical systems. While the insurance sector is highly exposed to these perils through property, infrastructure, and agricultural liabilities, it is simultaneously pressured by transition risks from emerging low-carbon development policies. Nonetheless, insurance mechanisms hold significant potential to enhance social resilience, mobilize adaptation finance, and incentivize risk-reducing behaviors. Existing literature, however, frequently treats climate change adaptation, mitigation, and disaster risk management (DRM) in isolation, rarely exploring their integration within comprehensive insurance and financing frameworks. To address this gap, this study conceptualizes insurance within a holistic climate governance structure based on Elinor Ostrom's Social-Ecological System (SES) framework. By reframing insurance from a reactive, corrective mechanism to a proactive agent within multi-level governance, this study extends the applicability of the SES framework from conventional common-pool natural resources to the governance of climate finance, using global best practices and expert insights from the specific context of Iran.

METHODS: A three-level analytical approach was employed to investigate the integration of insurance into climate governance. First, Ostrom's SES framework was adapted to construct a conceptual model consisting of a governance core and six interacting subsystems: economy-wide, public, finance, rural, urban, and social development. Within this model, insurance serves as a critical conduit in the finance subsystem, facilitating risk transfer, resource allocation, and adaptation, while capturing institutional linkages and feedback loops between climate impacts, regulatory frameworks, and financial decision-making. Second, an international comparative analysis was conducted using case studies and policy data from the Climate Change Laws of the World (CCLW) database—comprising 931 policies, 499 laws, and 1,520 targets in developed countries, and 1,321 policies, 429 laws, and 1,015 targets in developing countries. This analysis identified global trends in regulatory design, compulsory pooling, agricultural schemes, disclosure requirements, and parametric solutions. Third, empirical validation was gathered through a semi-structured survey of 181 experts. Qualitative data from open-ended responses were analyzed inductively using manual line-by-line coding and iterative thematic consensus, while quantitative subsystem rankings were analyzed using variance and bootstrap 95% BCa confidence intervals.

FINDINGS: The proposed SES framework positions insurance as a crucial systemic connector that operationalizes risk transfer and adaptation. International evidence demonstrates that insurance acts as an active policy instrument rather than a passive buffer: Norway's Natural Damage Insurance Act mandates post-disaster risk pooling; the UK's Flood Re program ensures flood insurance affordability; France and Spain integrate risk transfer with agricultural and forestry policies; and Turkey and Kyrgyzstan leverage insurance platforms to meet national resilience targets. In evaluating the transferability of these models to Iran, public-private pooling and parametric solutions emerged as viable pathways, though constrained by international sanctions, restricted reinsurance access, and data infrastructure deficits. While experts prioritized immediate interventions in urban and rural subsystems, the finance subsystem remained a critical long-term strategic anchor. Key implementation barriers included fragmented institutional coordination, deficient hazard and climate-risk modeling, and weak integration between environmental monitoring and insurance underwriting. Addressing these barriers requires expanding satellite-based parametric products for drought, enhancing spatial risk mapping, and improving access to innovative financing.

CONCLUSION: Under changing climate regimes, insurance serves as a vital strategic tool for integrating adaptation, mitigation, and DRM. By shifting the paradigm from reactive risk transfer to proactive, multi-sectoral coordination, the adapted SES framework addresses a critical gap in climate finance literature. Operationalizing this framework requires bridging risk-information deficits, developing localized and sector-specific products, and embedding insurance mechanisms within broader governance subsystems. Ultimately, implementing targeted, short-term regional interventions alongside long-term structural finance and insurance reforms will allow policymakers to align environmental objectives, financial stability, and social equity, fostering climate-resilient development pathways.

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INTRODUCTION

Climate change increasingly drives extreme weather events—including heatwaves, floods, wildfires, and storms—that impose estimated annual financial costs of US$143 billion (Cologna et al., 2025; Seneviratne et al., 2021). These events inflict profound damage upon environmental, social, and economic systems. While the insurance sector provides critical coverage against climate-related hazards, it faces significant operational challenges alongside transition-related financial risks that affect both insurers and broader capital markets. Conversely, insurance can facilitate the transition to a low-carbon economy by mitigating financial losses for corporations and promoting climate-resilient investments (IAIS & SIF, 2018; Yang et al., 2025).

Three primary strategies characterize climate change response: adaptation, mitigation, and Disaster Risk Management (DRM) (Cardenas, 2024; Farzaneh & Banimostafaarab, 2023; Patel et al., 2021). These strategies, while distinct, are deeply interconnected. Adaptation involves adjusting to actual or expected climate impacts to reduce harm or exploit potential benefits; mitigation refers to actions that reduce greenhouse gas emissions or enhance carbon sinks (IPCC, 2022); and DRM focuses on risk reduction and the management of residual risks to strengthen overall resilience (UNDRR, 2017). Insurance serves as a vital, albeit non-structural, instrument across all three domains[1]:

Adaptation: Insurance promotes resilience by facilitating risk spreading, providing liquidity, and incentivizing risk reduction through underwriting, pricing, and product development. In developed countries, this encompasses storm and flood coverage, agricultural insurance, national disaster funds, and green finance initiatives (Hamzeh et al., 2024a). Developing countries frequently employ microinsurance, index-based products, and weather derivatives, often supported by international aid (Hamzeh et al., 2023a). In Iran, rising awareness of climate impacts has generated demand for advanced instruments—including risk-based pricing, parametric techniques, and ecosystem restoration—though technical capacity and training gaps persist (Hamzeh et al., 2023-b; Hamzeh et al., 2024-b; Mendoza & Dai, 2023; Scholer & Schuermans, 2022).

Mitigation: Insurance can incentivize emission reductions by modulating premiums and coverage limits. For instance, in the U.S. residential market, escalating hurricane damages have prompted premium adjustments that facilitate emission offsets proportional to exposure (Nabriski et al., 2025). While short-term insurance is effective for known, high-severity risks compared to localized physical self-protection measures (e.g., irrigation), its efficacy under uncertainty remains limited, underscoring the necessity for improved climate forecasting (Traore, 2024).

Disaster Risk Management (DRM): DRM leverages risk pooling to reduce impacts and enhance recovery. In the EU-28, high coverage is achieved through government-led compulsory or hybrid models. Furthermore, emerging technologies—including satellite imagery, AI, blockchain, and GIS—are enhancing transparency, facilitating parametric transfers, and enabling ex-ante protections (Paleari, 2019; Sheehan et al., 2023).

Despite the growing literature on the role of insurance in adaptation, mitigation, and DRM, existing studies frequently treat these dimensions in isolation and lack a comprehensive model that positions insurance within Iran's climate governance framework. This research addresses this gap by developing a holistic model that integrates insurance across economy-wide, public, rural, urban, and social subsystems using the Social-Ecological System (SES) framework. Theoretically, this study contributes to the SES literature by extending its application from common-pool natural resources to the governance of climate finance. It reframes insurance from a reactive tool for risk transfer into a proactive agent that sustains governance processes within the finance subsystem. In the Iranian context, this integration is challenged by international sanctions, restricted reinsurance access, low insurance penetration, and systemic deficits in hazard data and modeling capabilities. Furthermore, the finance subsystem is often perceived as a lower priority compared to urgent urban and rural issues, such as water scarcity and drought.

This study is guided by the following research questions:

Primary research question

How can insurance be effectively integrated into Iran's climate governance to enhance resilience across sectors?

Secondary research questions

Level I: How can the SES framework be adapted to develop a conceptual model for the role of insurance in multi-sectoral climate governance?

Level II: What lessons can be drawn from international laws, policies, and targets regarding the contribution of insurance to climate adaptation, mitigation, and DRM?

Level III: What are the key priorities, challenges, and recommendations for insurance integration in Iran's climate governance subsystems, based on expert consensus?

To address these questions, this study employs a three-level analytical framework, which is detailed in the following section.

1 Non-structural measures are measures not involving physical construction which use knowledge, practice or agreement to reduce disaster risks and impacts, in particular through policies and laws, public awareness raising, training and education (UNDRR, 2017).

MATERIALS AND METHODS

This study adopted a mixed-method approach combining conceptual modeling, international comparative analysis, and expert consultation to address the identified research gap.

Level I: Conceptual Model Development

The conceptual model positions insurance as a mechanism for strengthening financial systems in support of climate adaptation and mitigation. It builds on Ostrom's Social-Ecological System (SES) framework, which captures governance–policy interactions within socio-ecological systems (Palomo & Hernández-Flores, 2019).

The framework comprises first-tier components, including social and ecological factors, external influences, interactions, and outcomes, as well as second-tier variables (Nagel & Partelow, 2022). Its core subsystems include resource units, resource systems, governance systems, and actors (Ostrom, 2009).

Adapted from international climate policy frameworks (Climate Change Laws of the World, 2025; Del Mar Delgado-Serrano & Ramos, 2015), the model focuses on the governance system and examines mitigation-related decision-making across six subsystems: economy-wide, public sector, finance, rural, urban, and social development. Within this structure, insurance is conceptualized as a bridging mechanism linking financial instruments to climate action.

Data were drawn from the Climate Change Laws of the World (CCLW, 2025) database, including 931 policies and 1,520 targets in developed countries, 1,321 policies and 1,015 targets in developing countries, and 499 and 429 laws, respectively.

Level II: International Comparative Analysis

At this level, the conceptual model was applied to selected international cases. The analysis examined how insurance, as positioned within the finance subsystem, interacts with other subsystems to support adaptation, mitigation, and resilience. It identified insurance-related laws, policies, and targets, as well as recurring patterns, cross-sectoral synergies, and implementation gaps.

Level III: Expert Analysis of Iran's Context

This level examined Iran's context through expert perspectives, informed by the Level I conceptual model. A semi-structured questionnaire was used to assess priorities and challenges across the six subsystems. Responses were obtained from 183 professionals in academia, government, and industry, of which 181 were complete and suitable for analysis.

Data Analysis

The questionnaire required respondents to rank the six governance subsystems according to priority, with a lower rank indicating higher priority. The Friedman test was used to assess differences in the rankings across the six subsystems, and mean ranks and variances were calculated for each subsystem. To assess the uncertainty of the mean rankings, 95% bias-corrected and accelerated (BCa) bootstrap confidence intervals were estimated using 2,000 bootstrap samples. Qualitative responses to the open-ended questions were analyzed inductively through repeated reading for familiarization, manual line-by-line coding, and iterative clustering into themes and subthemes through author consensus.

This three-level analytical design generated both a robust conceptual framework and empirically grounded insights.

RESULTS AND DISCUSSION

Conceptual Model of Insurance in Climate Governance

In this study, we adapt Ostrom's Social-Ecological System (SES) framework to analyze climate change governance (Fig. 1), focusing specifically on the governance system (GS) variable. We decompose the GS into six primary subsystems: economy-wide, public sector, finance, rural, urban, and social development. These subsystems collectively shape the decision-making processes and policy implementation pathways for climate change mitigation and adaptation. Within this structural arrangement, the finance subsystem operates as a critical locus; the insurance sector serves as an institutional bridge that transfers risk, fosters resilience, and mobilizes financial resources across all other subsystems.

This adapted framework establishes the conceptual basis for evaluating the empirical application of insurance mechanisms within global climate governance, as detailed in the following subsection.

Empirical Insights from Insurance-Related Instruments in Global Climate Governance

Guided by this conceptual model, we analyzed empirical cases to evaluate the operational role of insurance in climate governance. We retrieved insurance-related laws, policies, and targets from the Climate Change Laws of the World (CCLW) database, mapping these instruments to the finance subsystem while documenting cross-sectoral linkages to agriculture, the economy-wide domain, and the building sector. Table 1 summarizes these instruments, followed by targeted analyses demonstrating how insurance mechanisms facilitate adaptation, mitigation, and resilience building in practice.

The regulatory and policy instruments cataloged in Table 1 demonstrate that insurance is a core instrument of climate governance. Rather than leaving the financial consequences of floods, storms, or agricultural failures

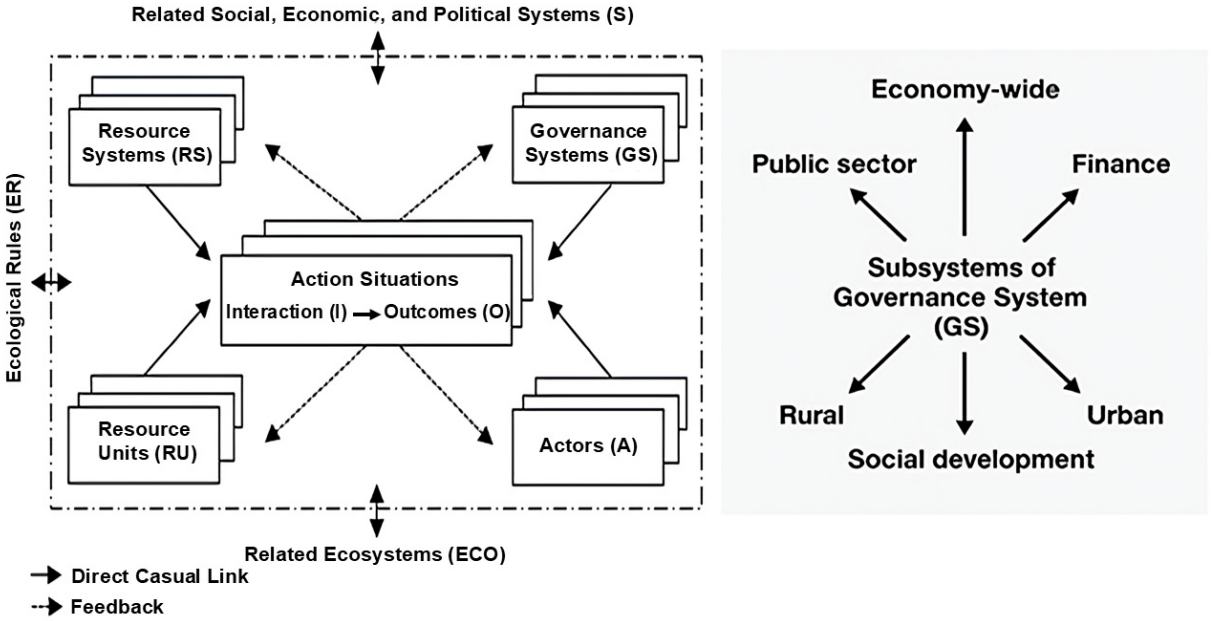


Fig. 1. Ostrom SES framework (left) (Vogt et al., 2015) with integrated with the author-developed governance subsystems (right).

Table 1. Selected insurance-related laws, policies, and targets in global climate governance*

Type	Country	Name/Description	Year	Related Subsystems
Law	Norway	Natural Damage Insurance Act	1989	Finance
Law	UK	Water Act 2014 (creation of Flood Re scheme)	2014	Finance, Building
Law	South Korea	Storm and Flood Insurance Act	2014	Finance
Policy	France	Law no. 2022-298 from 2 March 2022 relating to a better allocation of crop insurance in agriculture and reforming the tools for managing climate risks in agriculture	2022	Finance, Agriculture
Policy	Spain	Royal Decree No. 425/2016 - Regulatory basis for the granting of subsidies from the General State Administration to Agrarian Insurance	2016	Finance, Agriculture
Policy	Brazil	SUSEP Regulation 666/2022	2022	Finance
Target	Turkey	Increase compulsory earthquake insurance coverage; disaster reduction plans in all provinces	2023	Finance, Agriculture, Buildings, etc.
Target	Kyrgyzstan	Mitigate climate risks for agricultural producers via agricultural insurance system	2023	Finance, Agriculture, Economy-wide, etc.

Source: Climate change Laws of the World (2025)

* Selected insurance-related laws, policies, and targets are shown in Table 1; Full lists are available in appendix tables A1–A3.

to be borne solely by individual actors or public balance sheets, these instruments systematically distribute risk across society.

For instance, *Norway's Natural Damage Insurance Act* (1989) mandates natural hazard coverage for all properties holding fire insurance. This public-private pooling mechanism accelerates post-disaster recovery while generating critical actuarial data for spatial planning. Similarly, the UK's Flood Re scheme (established under the Water Act 2014) pools premiums to ensure flood insurance affordability in high-risk areas. This scheme directly couples financial risk transfer with adaptation strategies and building standards, thereby stabilizing property values and incentivizing resilient construction methods (UK Government, 2016). South Korea's *Storm and Flood Insurance Act* (2014) adopts a broader governance scope by integrating government premium subsidies, mandatory coverage requirements, and hazard mapping.

In the agricultural sector, France's Law No. 2022-298 (République Française, 2022) establishes a universal agricultural risk-management framework for the 2023–2030 period, supported by substantial state funding. This framework distributes financial liability among farmers, insurers, and the state, transitioning agricultural insurance from a reactive safety net into a proactive resilience-building instrument. In a similar vein, Spain's Royal Decree 425/2016 subsidizes agrarian insurance to enhance market penetration and lower capital barriers for producers (Legislación Consolidada

de España, 2016). Beyond direct risk transfer, regulatory frameworks also target financial transparency; Brazil's SUSEP Regulation 666/2022 mandates climate-related risk disclosures for insurers and pension funds, thereby enhancing market transparency and aligning domestic financial practices with international sustainability standards (SUSEP, 2022).

Furthermore, national development plans increasingly integrate insurance targets. Turkey's Eleventh Development Plan (2019–2023) sets a target of extending earthquake insurance to 12.1 million households, linking coverage expansion with disaster risk reduction initiatives and digital infrastructure deployment (Turkish National Assembly, 2019). Similarly, Kyrgyzstan's Program for the Development of a Green Economy (2019–2023) utilizes agricultural insurance to assist smallholders in managing climate-induced risks, securing domestic food supplies, and promoting low-emission agricultural practices (Government of the Kyrgyz Republic, 2019).

Cumulatively, these empirical cases indicate that insurance serves functions far beyond simple post-loss compensation. It functions as a policy instrument that drives behavioral change, supports evidence-based risk assessment, and aligns short-term financial security with long-term adaptation goals. These regulatory tools foster risk pooling, incentivize risk-mitigating behaviors, and establish quantifiable metrics for resilience progress, while simultaneously creating pathways for mitigation co-benefits—such as premium discounting for low-carbon technologies and the deployment of parametric insurance products.

The subsequent section applies these global governance insights to the specific institutional and socio-ecological context of Iran.

Applicability of International Insurance Instruments to Iran's Climate Governance

The instruments listed in Table 1 offer important lessons for climate governance in Iran. However, these mechanisms must be adapted to Iran's specific institutional, financial, and environmental conditions.

The public-private risk pool model, as implemented in Norway and the UK, is highly relevant to Iran given its seismic exposure and frequent flooding. This approach could help distribute reconstruction costs more effectively after catastrophic events. At the same time, sanctions constrain Iran's access to reinsurance markets, which complicates the adoption of this model.

Agricultural subsidy schemes from France, Spain, and Kyrgyzstan are also aligned with Iran's rural priorities. These instruments can help address drought risk, support farmers, and promote equity for low-income groups. However, Iran's underdeveloped financial infrastructure may limit the effectiveness of such subsidy-based mechanisms.

Disclosure requirements, as seen in Brazil, together with multisectoral targets, as in Turkey and Kyrgyzstan, may help address Iran's data and modeling gaps, particularly for slow-onset risks and index-based insurance. To close these gaps, Iran will need to invest in stronger data collection and monitoring systems.

Iran faces distinct constraints, including sanctions and limited financial infrastructure, that hinder the implementation of more advanced insurance models. A hybrid strategy may therefore be most appropriate, combining compulsory disaster risk pooling, agricultural subsidies, and parametric insurance[2] for drought relief.

Accordingly, Iran should prioritize insurance-based climate policies that are feasible under fiscal constraints while also supporting broader institutional integration. Lessons from Norway, the UK, and Turkey underscore the value of compulsory pooling for managing catastrophic disasters. France, Spain, and Kyrgyzstan illustrate how agricultural subsidies can strengthen support for climate-vulnerable farming communities. Brazil's disclosure regime shows how regulatory tools can reduce data and modeling gaps.

Recommended actions include:

- Assessing satellite-based parametric insurance for drought relief and improved monitoring.
- Reviewing crop subsidy mechanisms within existing budgets to support the rural economy.
- Requiring insurer disclosures to strengthen regulatory transparency.

Taken together, compulsory disaster pooling, rural subsidies, and parametric innovations appear well aligned with Iran's SES framework. Iranian expert insights further complement these global lessons by identifying subsystem priorities and clarifying the opportunities and constraints surrounding insurance integration.

Prioritizing Governance Subsystems and Thematic Insights from Expert Opinions on Iran's Climate Adaptation

The expert questionnaire identifies key governance weaknesses in Iran based on feedback from practitioners and scholars. The ranking results indicate the most urgent areas of concern, while the open-ended responses clarify their relevance and their connections to finance and insurance.

The Friedman test indicates significant differences in how experts prioritize the governance subsystems ($p < 0.001$). As shown in Table 2, the urban and rural subsystems receive the highest rankings, whereas

2 Parametric insurance provides rapid payouts triggered by predefined, measurable parameters of Natural Catastrophe (NatCat) events, offering alternative or supplementary coverage for losses that are often excluded from traditional indemnity insurance due to excluded risks, limited (re)insurance capacity or situations of widespread damage (Ocampo & Moreira, 2024).

Table 2. Ranked priorities of governance subsystems

Subsystem	Mean Rank (Friedman test)	Variance	95% BCa Confidence Interval for Mean
Urban	2.16	1.735	1.98 – 2.35
Rural	2.45	1.416	2.29 – 2.62
Economy-Wide	3.03	2.210	2.83 – 3.25
Public Sector	3.93	1.278	3.78 – 4.09
Finance	4.68	1.808	4.48 – 4.87
Social Development	4.75	2.888	4.51 – 4.99

Source: Authors' analysis of expert questionnaire responses (n = 181).

Table 3. Dominant thematic issues within each governance subsystems

Subsystem	Top recurring items / dominant phrases (ordered roughly by frequency)
Urban	Air pollution; Waste management; Transportation; Urban water crisis; Aging infrastructure
Rural	Drought; Water scarcity; Agricultural losses; Migration; Rangeland degradation
Economy- Wide	Impact on labor markets; Reduced investment; Rising operational costs; Fragile businesses
Public Sector	Lack of coordination; Fragmented mandates; Insufficient climate budget; Weak laws
Social Development	Education/Awareness gaps; Inequality; Mental health effects; Gendered vulnerability
Finance	Insurance gaps (Low penetration); Reconstruction costs; Limited risk-transfer instruments; Lack of green financial instruments; Insufficient data for pricing

Source: Authors' analysis of expert questionnaire responses (n = 181).

finance receives the lowest. However, the open-ended responses suggest that finance is still viewed as essential. Experts identified several constraints, including limited data, inadequate risk modeling, reinsurance gaps, outdated regulations, and the absence of climate-smart insurance (ECO-insurance[3]) products. Although these issues may appear less immediate than urban and rural challenges such as water scarcity, heat stress, and infrastructure deficits, the variance (1.808) and bootstrap 95% BCa confidence interval (4.48–4.87, based on 2,000 resamples) indicate strong expert consensus regarding the relatively low priority assigned to finance as a barrier to insurance development. This low ranking reflects a readiness gap rather than a lack of importance. Many experts believe that finance will play a more prominent role in climate adaptation once data systems and infrastructure improve. Accordingly, the primary emphasis should remain on immediate, on-the-ground adaptation while financial resilience is strengthened over time.

Table 3 summarizes recurring problems across the governance subsystems and shows how funding arrangements may shape climate adaptation.

Within the urban and rural subsystems, experts emphasized issues such as air pollution, waste management, transport, water scarcity, drought, and agricultural losses. One expert noted, “Reduced agricultural production and increased food prices due to pest proliferation.” Another proposed solutions such as “preventing water waste in agriculture through advanced irrigation and low-water crops.” These concrete challenges underscore the importance of insurance and finance in addressing immediate climate risks.

Although mentioned less frequently, finance-related issues revealed important gaps. These included inadequate insurance coverage, high reconstruction costs, limited risk-transfer instruments, weak green finance, and insufficient information for premium setting. Experts pointed to barriers such as “increased financial risk in the insurance sector due to rising natural damages” and the “lack of data for systemic risk management.” These constraints limit insurance’s capacity to support adaptation, but they do not diminish its role in stabilizing income, supporting prevention, and enhancing resilience.

Slow-onset risks, such as drought, are particularly difficult to insure through conventional mechanisms because of measurement and timing challenges. Experts therefore advocated parametric or index-based insurance using satellite-derived data such as rainfall and vegetation indices. One expert also suggested the “development of early warning systems for floods and storms.” Better databases for building losses, hazard mapping, and weather monitoring are essential for improving underwriting and pricing.

Experts also recommended innovative financing instruments, including public-private disaster bonds, crop and city risk pools, and subsidized green insurance. One respondent referred to “banking and insurance facilities from international aid mechanisms.” These options could expand access to coverage, improve equity, and connect adaptation with financial protection.

3 The Enhanced Coverage Option (ECO) is an endorsement to select crop insurance policies that provides additional area-based coverage for a portion of the underlying policy deductible, offering trigger levels of 90% or 95% (USDA RMA, 2024).

Social programs could also help make insurance more affordable for vulnerable groups.

Other subsystems, including the economy-wide, public sector, and social development domains, provide the broader context for financial interventions. Poor coordination, unclear mandates, and budget constraints make it difficult to scale insurance solutions. Experts frequently referred to "rising costs, such as increased healthcare and insurance expenses." These social pressures illustrate how risk transfer can help alleviate wider development challenges.

Overall, the thematic analysis shows that insurance and finance instruments can do more than provide a safety net. They can function as adaptation tools by enabling targeted responses, encouraging preventive behavior, and supporting long-term resilience, provided that appropriate data systems and policy frameworks are in place.

CONCLUSION AND SUGGESTIONS

This study demonstrates that insurance functions far beyond a simple mechanism for post-event financial compensation. When systematically integrated into broader governance frameworks, it serves as a critical enabler of climate security.

By adapting Ostrom's Social-Ecological System (SES) framework, we mapped the interactions between insurance instruments and climate-sensitive governance subsystems within Iran's specific socio-ecological context. This application addresses a key theoretical gap by extending the SES framework to financial instruments and multi-sectoral climate finance governance, thereby positioning the insurance sector as a proactive institutional bridge across subsystems.

Furthermore, international regulatory frameworks, policies, and targets offer valuable practical lessons for Iran. Our comparative analysis of selected global instruments underscores how insurance can be structured to support adaptation, mitigation, and disaster risk reduction. Despite institutional challenges, such as international sanctions and significant data deficits, we recommend domestic adaptations of these instruments, including satellite-based parametric insurance for drought and public-private risk pooling mechanisms.

Although currently assigned a lower urgency rating by experts, the financial subsystem acts as a crucial catalyst for climate adaptation. Parametric insurance schemes, index-based products, and innovative disaster risk instruments present viable pathways for systemic advancement. The inductive thematic analysis, expert testimonies, and statistical evaluations presented herein identify persistent barriers—specifically, underdeveloped risk modeling and reinsurance limitations—yet confirm the long-term strategic potential of financial mechanisms. Consequently, near-term policy interventions should focus on aligning insurance instruments with local-scale adaptation projects while strengthening the capacity of supporting financial institutions.

Ultimately, embedding insurance within an SES-based governance framework can reduce environmental vulnerabilities and incentivize pro-nature behaviors. Based on our conceptual model, the international comparative analysis, and the synthesis of expert opinions, we propose the following key recommendations to enhance insurance integration within Iran's climate governance:

- **Enhance Data Infrastructure and Risk Modeling**

Sustained investment in advanced climate and risk data infrastructure, including satellite-derived monitoring technologies, is required to address the analytical gaps identified within the domestic insurance sector. Enhancing data availability is critical to improving actuarial risk pricing, particularly for slow-onset events such as drought, where historical data remain insufficient. Developing these databases will facilitate the design and scaling of parametric insurance products, directly addressing the concerns raised by experts within the finance and rural subsystems.

- **Develop Sector-Specific Parametric Insurance Products**

Future policy designs should prioritize the expansion of satellite-based parametric insurance for agricultural drought relief, alongside index-based risk products tailored for both urban and rural areas. These instruments should be linked to objective, verifiable triggers such as rainfall thresholds or vegetation index anomalies.

- **Provide Targeted Premium Subsidies**

To improve the accessibility of risk transfer mechanisms for vulnerable smallholders in rural areas and exposed populations in urban centers, targeted government premium subsidies should be introduced. Even modest public subsidization can significantly increase insurance penetration, particularly if coupled with green loans or eco-friendly financial products to promote equity.

- **Improving transparency and coordination between regulations**

Regulatory frameworks should be updated to mandate climate risk disclosures by insurance companies, thereby improving market transparency. Furthermore, insurance-based risk transfer plans should be closely integrated with national spatial planning and public budget allocations to minimize jurisdictional fragmentation and administrative overlap among relevant public agencies.

AUTHORS' CONTRIBUTION

Mohammad Reza Farzaneh: Conceptualization, Acquisition of data, Analysis and interpretation of data, Drafting of the manuscript, Supervision. Faezeh Banimostafaarab: Conceptualization, Statistical analysis, Critical revision of the manuscript for important intellectual content, Review and refinement of methodology, Synthesis and interpretation of results.

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CONFLICT OF INTEREST

The author(s) declares that there is no conflict of interest regarding the publication of the registered research. Furthermore, ethical considerations including plagiarism, informed consent, misconduct, fabrication and/or falsification of data, duplicate publication, and also Journal Policy on Artificial Intelligence Use have been fully observed by the authors.

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