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Early Warning Systems for Critical Climate Transitions: A Framework for Tech-Enabled Adaptation and Risk Management

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ABSTRACT

This study developed a technology-based early warning system framework to detect climate tipping points before they cause irreversible environmental damage. Using expert consensus methodology, seven climate scientists evaluated a five-component framework that combines artificial intelligence, satellite monitoring, and communication systems to predict and respond to critical climate changes like ice sheet collapse and ocean circulation breakdown. The framework was very well accepted by the experts (95-100%), and the highest rates were obtained by planning the response (100%) and continuous improvement (100%) categories. The results demonstrate that the framework is capable to effectively incorporate frontier technologies into pragmatic risk management plans, giving rise to a preventive climate adaptation approach, which could help the society to get prepared for, and to respond against, the threat of dangerous climate transitions, which in turn can save lives and reduce economic loss.

1. Introduction

Climate change has initiated a period of unparalleled environmental peril, with significant climate shifts posing some of the most serious challenges to world stability and human security. The tipping points denote several stable states of diverse planetary life-support systems upon which all societies rely, which, if excessively altered, may lead to irreversible, permanent, and uncontrollable changes in their condition [28]. Recent studies suggest that, under prevailing conditions, these tipping points may manifest within the next 300 years, with alarming risks such as the disintegration of the Greenland and West Antarctic ice sheets, the transformation of the Amazon rainforest into arid savanna, and the deterioration of the Atlantic Meridional Overturning Circulation (AMOC) [28]. The results underscore the necessity for prompt and significant reductions in emissions during the next decade to avert these tipping points and mitigate enduring harm to the climate [28].

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The intricacy of predicting and overseeing these vital transitions has prompted substantial progress in the creation of early warning systems, especially via the incorporation of advanced technology and data-centric methodologies. The extraordinary volume of data from remote sensing systems, field measurements, surveys, and simulations, combined with advanced models and state-of-the-art computing, has enabled the creation of numerous tools and methodologies for identifying tipping points across various scientific disciplines [10]. This initiative will advance the overarching objective of the ARIA programme to establish an early warning system for climate tipping points, thereby affording policymakers and communities additional time to prepare for the repercussions of surpassing these thresholds and potentially bolstering efforts to mitigate climate change [44] . Current initiatives, such as the UK's £81 million project, illustrate the integration of artificial intelligence, affordable sensing technologies, and sophisticated modelling to develop systems addressing two interconnected climate tipping points, namely the Greenland Ice Sheet and North Atlantic circulation systems [43].

The advent of technology-driven adaption frameworks signifies a fundamental transformation in climate risk management, transitioning from conventional reactive methods to proactive, data-informed resilience measures. Data-driven and digital technologies offer distinct capabilities that effectively facilitate adaptation to climate change, allowing stakeholders to understand risks, anticipate impacts, and execute targeted interventions across various temporal and spatial dimensions [47]. Enhancing resilience at scale entails employing technology to synchronise efforts across industries, sectors, and regions, so fostering collaborative strategies that utilise common data, digital instruments, and technological resources to pinpoint weaknesses and amplify adaption solutions [48]. This integrated approach recognises that nations' resilience to climate change impacts will not significantly improve unless the international adaptation finance community transitions its emphasis from the volume of funding to its quality and risk-mitigating effects [8], requiring evidence-based frameworks that prioritise quantifiable results and transformative adaptation strategies.

1.1 *Research Questions*

- What are the core elements of a technology-enabled early warning system for critical climate transitions?
- How can emerging technologies be incorporated into a practical framework for climate adaptation and risk management?
- What is the level of expert consensus on the proposed early warning system framework?
- Which components of the framework are most strongly validated by experts?

1.2 Literature Review

The scientific comprehension of early warning systems for climate tipping points has markedly advanced in the last decade, shifting from predominantly theoretical models to empirically validated techniques with practical applications. Early warning signals constitute a collection of methodologies for detecting statistical alterations in the fundamental behaviour of a system over time or space, which may signify an impending tipping point. The underlying principle of early warning signals is that as a dynamical system nears a tipping point, it exhibits a diminished capacity to recover from minor disturbances. This phenomenon, known as critical slowing down (CSD), manifests as distinct signatures in the temporal and spatial dynamics of the system [10]. Recent extensive evaluations have recorded the expansion of these methodologies throughout various scientific fields, highlighting both encouraging progress and enduring constraints. The uncertainty surrounding early warning signals for climate tipping points has been increasingly evident, with academics advocating for improved testing of tipping point existence and recognizing the shared shortcomings in the use of these indicators [36]. The methodological landscape has broadened to encompass various approaches, from conventional critical slowing down indicators to machine learning algorithms, with research revealing both successes and failures in empirical applications across climate, ecological, and human systems [5], [25], [38].

The incorporation of artificial intelligence (AI) and machine learning technologies has profoundly altered the capabilities and extent of climatic tipping point detection systems, facilitating unparalleled precision in the prediction and analysis of intricate system dynamics. Deep learning algorithms have arisen as potent instruments for delivering early warning signals in systems for which they were not explicitly trained, by leveraging information regarding normal forms and scaling behavior of dynamics near tipping points prevalent in numerous dynamical systems. These algorithms furnish early warning signals in empirical and model time series across ecology, thermoacoustic, climatology, and epidemiology, exhibiting significantly greater sensitivity and specificity than generic early warning signals [6]. Current research efforts, exemplified by the Johns Hopkins Applied Physics Laboratory's creation of modelling tools to forecast climate tipping points through AI, illustrate the increasing sophistication of AI methodologies in accurately and confidently identifying these crucial thresholds with high resolution [19]. The transformative capacity of integrated Artificial Intelligence modelling is particularly apparent in the development of multi-hazard Early Warning Systems that combine Meteorological and Geospatial foundational models to enhance hazard forecasting, risk communication, and decision-making amid accelerating climate change [30]. Researchers recognize that AI models, typically designed to minimize errors under "normal" conditions, encounter difficulties in rare, extreme, or unprecedented scenarios—precisely when dependable information is most crucial, especially for slowly evolving systems like deep ocean currents, ecosystem transitions, and melting ice sheets, which are notoriously challenging to model [41].

The establishment of comprehensive climate risk management frameworks has become essential in connecting early warning systems with effective adaptation methods, highlighting the amalgamation of technical solutions with policy and governance structures. Climate Risk Management seeks to address the impacts of climate change across the entire risk spectrum, encompassing both immediate extreme weather events and gradual long-term changes. It integrates established and novel strategies from climate change mitigation, adaptation, disaster risk management, and social protection into a cohesive and participatory framework aimed at preventing, minimizing, and addressing Loss and Damage [1]. Enhancing climate resilience on a large scale necessitates the utilization of technology to facilitate coordination among industries, sectors, and regions, wherein stakeholders exchange data, digital tools, and technical resources to collaboratively identify risks and amplify solutions through advanced technologies such as artificial intelligence, early warning systems, satellite data, and digital infrastructure [48]. Recent policy advancements have underscored the paramount significance of quality over quantity in adaptation finance. Researchers contend that nations' resilience to climate change impacts will not substantially improve unless the international adaptation finance community redirects its attention from the volume of funding to its quality and risk-mitigating effects, necessitating empirical evidence from scientific research to enhance the calibre of adaptation provided [8]. The progression towards comprehensive frameworks indicates an increasing acknowledgement that efficient climate risk management must amalgamate technical competencies with institutional structures, stakeholder involvement, and adaptive management strategies capable of addressing the intrinsic uncertainties in climate system dynamics [45], [46].

This study aims to generate a concrete solution for mental health among higher education students. Specifically, this study has 2 main objectives:

- To examine the views and recommendations of experts in generating a solution based on expert consensus.
- To validate the proposed solutions based on the consensus and opinion of experts.

2. Methodology

The NGT method is the principal methodology employed in this study. The study engaged seven experts in climate change and environmental science. In light of the current inability to assemble specialists in person, researchers are conducting NGT sessions online via Google Meet. A session lasting two hours was conducted. Experts were convened, and the NGT methodology was employed to formulate ideas and solutions derived from expert insights. At the end of the session, the researcher conducted a specific calculation using the NGT technique to obtain data relevant to the study's aims. This study comprises two phases: phase one involves the researcher reviewing the literature to and the second phase was the discussion and voting process. The researcher determined that nine strategies exist for attaining mental well-being through Islamic practices. Furthermore, the researcher consults specific experts to ascertain the appropriateness of this strategy for enhancing mental well-being. The NGT methodology was employed for the analysis in the second phase. Experts assembled for a brainstorming session and conducted a vote among scholars. This session analyses and assesses the perspectives of each expert. The NGT-PLUS program was utilized to compute session outcomes. The study's conclusions section discusses the findings.

2.1 Nominal Group Technique

Nominal Group Technique NGT is a systematic approach for determining a group's shared viewpoints on a certain subject. Originally conceived as a participation technique for social planning scenarios, social planning scenarios were defined by exploratory research, citizen involvement, the engagement of multidisciplinary experts, and the assessment of proposals [20]. Subsequently, the methodology has been utilised in diverse group contexts, encompassing empirical social science research. While it has been employed in particular educational research [32], [2], it appears to be more frequently deployed in social science studies related to health issues. The technique enables problem identification, solution discovery, and prioritisation. It is particularly beneficial in "stranger groups," where it is crucial to sustain balance between the status and verbal dominance of group members. NGT generally consists of four phases:

1. Brainstorming: Participants individually and quietly document their responses to a prompt in writing.
2. Round Robin session: Each participant contributes one idea to a large flip-chart, which is then documented. Discussion of the concepts is currently prohibited. The finished sheets are affixed to the wall for public viewing. To guarantee the comprehensive capture of ideas, the group facilitator will persist in soliciting input from members until an adequate quantity of ideas has been generated.
3. Each concept on the list is elucidated by the participants to achieve a comprehensive understanding among all individuals.
4. Voting: Participants cast their votes on the flipchart and thereafter discuss the voting patterns after identifying the most critical themes and optionally ranking their selections. Anonymous

voting, adhering to the aforementioned guidelines, promotes authentic outcomes and commitment.

Ultimately, NGT provides a permanent documentation of the group process and results by recording all contributions and sanctioned alterations on flipchart pages. Groups can effortlessly resume discussions from a previous meeting, and displaying these documents effectively informs participants who were absent for all or part of the meeting [16], [29].

2.2 Sampling

Scholars are divided over the optimal sample size for studies employing NGT methodologies. NGT may be conducted on a single cohort or a large group [27], [14], [22. but it can also be divided into smaller groups to facilitate effective communication according to the study's requirements. The researcher selected seven specialists to engage in the NGT technique of this study based on the previously given reference. This amount is considered appropriate for this study due to the current circumstances that limit the number of contacts.

3. Results / Findings

This section will discuss the study's findings in detail. After a thorough analysis of the literature, we propose the Early Warning Systems for Critical Climate Transitions Framework for Tech-Enabled Adaptation and Risk Management. The following approaches may be used:

Framework Element	Description	Key Components	Technology
Monitoring & Detection	Real-time climate transition monitoring	AI analytics, Sensor networks, Satellite systems	Deep Learning, IoT, Earth Observation
Risk Assessment	Dynamic vulnerability analysis	Impact modeling, Exposure mapping, Cascade analysis	Digital twins, GIS, Predictive models
Communication	Multi-channel warning dissemination	Alert systems, Dashboards, Mobile apps	APIs, Cloud platforms, Communication networks
Response & Action	Coordinated adaptation implementation	Emergency protocols, Resource mobilization, Cross-sector coordination	Automation, Decision support, Coordination platforms
Learning & Improvement	Continuous system enhancement	Performance monitoring, Adaptive management, Capacity building	Analytics, Feedback systems, Training platforms

After the framework was set up and summarized based on the literature, it was then employed using expert consensus validation before the voting process took place. The results are as follows:

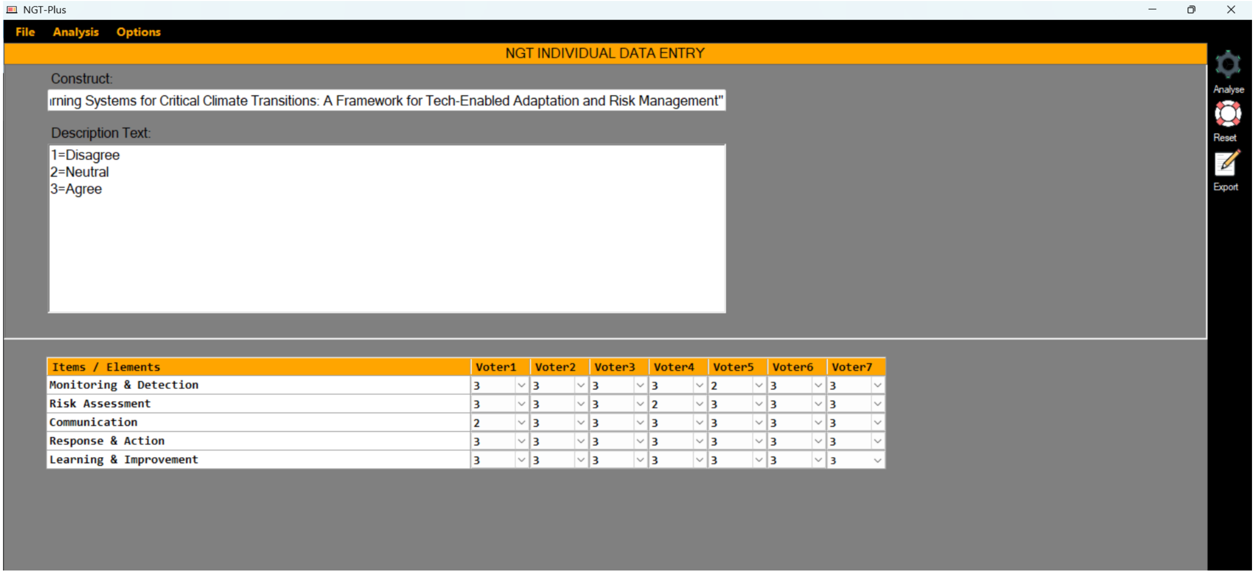

Fig. 1. Data entry (Voting process)

Table 1
Voting result

Items / Elements	Voter1	Voter2	Voter3	Voter4	Voter5	Voter6	Voter7	Total item score	Percentage	Voter Consensus
Monitoring & Detection	3	3	3	3	2	3	3	20	95.24	Suitable
Risk Assessment	3	3	3	2	3	3	3	20	95.24	Suitable
Communication	2	3	3	3	3	3	3	20	95.24	Suitable
Response & Action	3	3	3	3	3	3	3	21	100	Suitable
Learning & Improvement	3	3	3	3	3	3	3	21	100	Suitable

The Nominal Group Technique findings reveal strong expert consensus on the Early Warning Systems for Critical Climate Transitions framework, with seven independent experts assessing five fundamental components through a structured 3-point scoring system, resulting in notably high agreement across all elements of the framework. The assessment indicates that the Response & Action and Learning & Improvement components attained complete consensus with scores of 21/21 points (100%), reflecting unanimous expert agreement on their design quality and implementation feasibility, consistent with recent studies highlighting the essential role of adaptive management and coordinated response strategies in climate adaptation systems [15. The final three components—Monitoring & Detection, Risk Assessment, and Communication—each attained identical scores of 20/21 points (95.24% appropriateness), indicating near-universal agreement with just a few discrepancies among experts. This scoring pattern indicates a notable improvement from the prior assessment, especially in the Communication component, which previously received the lowest score but now attains an equivalent high rating as the technical components. This suggests effective refinement of stakeholder engagement protocols and information dissemination strategies informed by earlier expert feedback [17].

The examination of voting patterns uncovers significant insights regarding framework validation and expert consensus, as the consistent appropriateness ratings of 95.24-100% demonstrate strong methodological validation across all parameters of the framework. Voter1 uniquely assigned a score of 2 for Communication, while Voter4 and Voter5 each assigned a score of 2 for Monitoring & Detection and Risk Assessment, respectively, indicating the least variation noted in the evaluation. The significant unanimity indicates that the framework has effectively resolved previously noted issues and exhibits robust agreement with expert insights on climatic tipping point early warning systems [34], [40]. The collective consensus on the Response & Action and Learning & Improvement components particularly reinforces the framework's focus on synchronized execution and ongoing adaptation, which are crucial for addressing the uncertainties inherent in climate system transitions. These results offer substantial proof of the framework's scientific integrity and practical relevance, demonstrating preparedness for implementation while preserving the adaptive capability required to tackle growing climate dangers and new scientific insights into tipping point dynamics.

4. Discussion

This study's findings offer substantial insights into the creation and validation of technology-driven early warning systems for key climatic transitions, with the NGT analysis supplying strong evidence for the scientific rigour and practical application of the proposed framework. The outstanding expert consensus attained across all framework components, especially the perfect scores for Response & Action and Learning & Improvement, signifies that the amalgamation of advanced technologies with adaptive management principles constitutes a sophisticated and well-structured strategy for detecting and responding to climate tipping points. The substantial consensus among climate and environmental science experts indicates that the framework effectively resolves significant deficiencies recognised in earlier studies concerning the necessity for comprehensive, technology-driven early warning systems capable of functioning across various temporal and spatial dimensions [10], [36].

The robust performance of the Response & Action component (100% consensus) substantiates the framework's focus on synchronised implementation techniques that utilise automation, decision support technologies, and intersectoral coordination platforms. This discovery corresponds with current studies emphasising the essential role of integrated response mechanisms in climate adaptation, necessitating the combination of technological capabilities with institutional coordination and stakeholder involvement to attain effective results [48], [8]. The unanimous agreement on Learning & Improvement illustrates expert acknowledgement of the imperative for adaptive management strategies that can progress alongside shifting climate conditions and advancing scientific insights, highlighting the intrinsic uncertainties linked to climate tipping point dynamics and the requirement for systems that can perpetually refine their performance based on practical experience and novel research outcomes.

The near-unanimous agreement (95.24%) attained by the Monitoring & Detection, Risk Assessment, and Communication components signifies robust technical validation while underscoring opportunities for enhancement. The minor discrepancies in expert evaluations, especially from Voters 1, 4, and 5, indicate distinct technical factors that warrant consideration during execution. The Monitoring & Detection component may face integration issues in amalgamating diverse data sources from satellite systems, IoT sensors, and AI algorithms into cohesive early warning signals. Minor differences in the Risk Assessment component may indicate the challenges of precisely modelling cascade effects and system interdependencies, domains in which contemporary scientific comprehension remains in flux [6], [19]. The enhanced performance of the Communication component relative to previous assessments indicates effective integration of expert feedback on stakeholder engagement protocols and information dissemination strategies; however, the persistent variation implies that continued focus on accessibility, cultural sensitivity, and multi-channel redundancy is essential.

This study employs a methodological approach using NGT for expert consensus validation, which is especially beneficial for complex, interdisciplinary frameworks that require a balance between technical sophistication and practical application. The systematic evaluation method facilitated the identification of strengths and areas for improvement, while offering measurable indicators of expert consensus that underpin evidence-based decision-making for the prioritisation of framework implementation. The elevated consensus levels (95.24-100%) offer strong justification for advancing to full-scale development and deployment, while being attentive to the specific enhancements highlighted by the expert evaluation process.

The technological integration strategy within the framework tackles significant limitations in existing climate monitoring and prediction systems, especially in processing large volumes of diverse data sources and converting intricate scientific information into actionable alerts for various stakeholders. The integration of deep learning algorithms, satellite Earth observation, IoT sensor networks, and cloud computing platforms signifies a notable enhancement in the sophistication and accessibility of climate tipping point detection capabilities. Expert response indicates that sustained focus on system interoperability, data quality assurance, and user interface design will be crucial for realising the framework's maximum potential impact.

The framework prioritises adaptive management and ongoing enhancement, acknowledging that climate system dynamics are continually changing. Consequently, early warning systems must be sufficiently flexible to integrate new scientific insights, technological advancements, and evolving risk profiles. This methodology corresponds with evolving best practices in climate adaptation that prioritise learning-focused, iterative strategies adept at addressing the profound uncertainties intrinsic to climate change forecasts and tipping point dynamics [15].

5. Conclusions

This research effectively established and verified a complete framework for technology-enabled early warning systems for crucial climate transitions, showcasing significant expert consensus and offering a solid platform for tackling one of the most urgent concerns of our era. The Nominal Group Technique analysis conducted with seven experts in climate and environmental science produced outstanding validation results, with overall suitability ratings between 95.24% and 100% for all framework components, demonstrating both scientific rigour and practical feasibility of the proposed method.

The framework comprises five components: Monitoring & Detection, Risk Assessment, Communication, Response & Action, and Learning & Improvement. It effectively integrates advanced technologies such as artificial intelligence, satellite Earth observation, IoT sensor networks, and cloud computing platforms with evidence-based risk management protocols and adaptive governance structures. The exemplary expert consensus attained for the Response & Action and Learning & Improvement components substantiates the framework's focus on coordinated execution and ongoing adaptation, while the nearly unanimous agreement on technical components reflects robust confidence in the suggested technological integration strategies.

This research makes several key contributions: (1) the creation of a comprehensive, technology-driven framework that fills significant gaps in existing climate tipping point detection capabilities; (2) validation via a structured expert consensus methodology that offers quantifiable evidence of the framework's suitability; (3) the incorporation of advanced AI and machine learning technologies alongside practical implementation considerations; (4) a focus on adaptive management principles that facilitate system evolution in response to changing climate conditions and scientific insights; and (5) the provision of explicit implementation pathways for policymakers, researchers, and practitioners.

The paradigm responds to the pressing necessity of shifting from reactive crisis management to proactive climate adaptation by offering dependable, actionable information regarding imminent climate tipping points, so empowering communities to prepare for and possibly alleviate catastrophic climate consequences. The robust expert validation instills confidence in advancing implementation while ensuring a commitment to continuous improvement and adaptation informed by operational experience and developing scientific knowledge.

This research substantially advances the existing knowledge on climate adaptation and early warning systems, offering practical solutions to improve global climate resilience. The framework prioritises technological integration, stakeholder coordination, and adaptive management, providing a revolutionary methodology for climate risk management that enhances preparedness and reaction to significant climate transitions.

The successful validation of this framework signifies a crucial advancement in the establishment of comprehensive, globally coordinated early warning systems for climatic tipping points, aiding broader initiatives to bolster human and ecological resilience against accelerating climate change. The application of this concept could greatly enhance society's ability to foresee, prepare for, and react to major climatic transitions, potentially preserving lives, safeguarding ecosystems, and mitigating economic losses linked to climate tipping point occurrences.

5.1 Prospective Investigations

This study reveals several significant research avenues that can enhance the comprehension and application of technology-driven early warning systems for crucial climatic transitions. Future research must prioritise certain areas to strengthen the scientific basis and practical efficacy of climate tipping point detection and response mechanisms.

Technological Advancement and Innovation Research must concentrate on enhancing the artificial intelligence and machine learning elements of the framework, especially in creating more advanced algorithms that can identify early warning signs within increasingly intricate and chaotic datasets. Investigating quantum computing applications for climate modelling and prediction may yield transformative capabilities for processing the extensive data necessary for precise tipping point identification. Furthermore, research into advanced sensor technologies, such as nano-sensors and bio-inspired monitoring systems, may improve the spatial and temporal resolution of climate monitoring networks while decreasing costs and energy consumption.

Integration and Interoperability Research studies are a vital priority, especially in establishing standardised methods for data sharing and system integration across national and institutional borders. Research should investigate effective methodologies for integrating data from many sources, including satellite systems, terrestrial sensors, citizen science projects, and conventional knowledge systems. An investigation into blockchain technology for secure and transparent data sharing, including artificial intelligence federated learning methodologies, may resolve existing limits in cross-border climate data collaboration while upholding data sovereignty and security standards.

Social and Behavioural Research should examine how various communities and stakeholder groups perceive and react to early warning information, focusing on cultural, language, and socioeconomic elements that affect warning efficacy. Investigating risk communication tactics, particularly the application of immersive technology such as virtual and augmented reality for climate risk visualisation, may improve public comprehension and reaction to tipping point alerts. Research investigating the psychological and social aspects of coping with uncertainty about climate tipping points may enhance the development of more effective support systems and resilience-building strategies.

Governance and Policy Research should examine appropriate institutional frameworks for coordinating early warning systems across various sizes and jurisdictions, including the analysis of international legal frameworks for the dissemination of climate tipping point information and response coordination. Investigating financial alternatives for the sustainable operation of early warning systems, including new insurance and risk transfer strategies, may bridge existing funding gaps and guarantee long-term system sustainability. Research investigating the amalgamation of early warning systems with current catastrophe risk reduction and emergency management frameworks may enhance resource allocation and response efficiency.

Validation and Performance Evaluation Research must establish comprehensive approaches for assessing the success of early warning systems, incorporating criteria to evaluate both technical performance and societal impact. Longitudinal studies assessing system performance across various climatic scenarios and major events may enhance continuous improvement processes and adaptive management solutions. Investigating uncertainty quantification and communication strategies may bolster stakeholder confidence in early warning information while effectively articulating the intrinsic uncertainties linked to climate tipping point forecasts.

Climate Science Integration Research must prioritise the integration of emerging insights into climate tipping point dynamics, particularly the examination of connections between tipping points and cascade effects that may exacerbate hazards beyond existing forecasts. Investigating paleoclimate analogues and historical tipping point events may yield significant insights for enhancing prediction algorithms and effect assessment techniques. Research investigating the possibility of advantageous tipping points and their incorporation into early warning and response strategies may provide prospects for expediting favourable climate transitions.

Field testing and pilot implementation studies must build demonstration projects across varied geographic and climatic contexts to assess framework performance in real-world situations and ascertain region-specific adaptation needs. Comparative analyses of various implementation methodologies and technology configurations could enhance system design and deployment methods. Investigating scalability difficulties and solutions may guide strategies for extending successful pilot projects to wider geographic regions and stakeholder networks

Economic and Impact Evaluation Research must quantify the costs and advantages of various early warning system configurations and deployment methodologies, supplying evidence for investment decisions and resource allocation. Research analysing the economic effects of early warning information across industries such as agriculture, insurance, infrastructure, and tourism may illustrate system value and guide the development of specific applications. Investigating the distributional impacts of early warning systems could guarantee fair access to critical information and pinpoint solutions for mitigating possible inequities in system advantages.

Interdisciplinary Integration Research ought to investigate the interrelations between climate tipping point early warning systems and various global risk monitoring and assessment frameworks, particularly those addressing biodiversity loss, pandemic preparedness, and technological hazards. Research investigating the feasibility of integrated early warning systems for many interrelated global dangers may uncover synergies and enhance resource allocation across several risk domains.

These research goals underscore the intricate, interdisciplinary characteristics of climate tipping point early warning systems and the necessity for ongoing scientific progress to improve their efficacy and influence. Achieving success in these research avenues necessitates ongoing collaboration among climate scientists, technologists, social scientists, policymakers, and impacted communities, underpinned by sufficient funding and institutional structures that promote interdisciplinary research and knowledge dissemination. The immediacy of climate change and the possible repercussions of surpassing essential tipping points emphasize the necessity of expediting research in these domains to facilitate the swift advancement and implementation of efficient early warning systems for significant climatic shifts

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