BARRIER ANALYSIS AND ENABLING FRAMEWORK OF ADAPTATION TECHNOLOGIES FOR PAPUA NEW GUINEA

TECHNOLOGY NEEDS ASSESSMENT

JUNE 2025

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BARRIER ANALYSIS AND ENABLING FRAMEWORK OF ADAPTATION TECHNOLOGIES FOR PAPUA NEW GUINEA

REPORT 2

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This document is an output of the Technology Needs Assessment (TNA) project of PAPUA NEW GUINEA, funded by the Global Environment Facility (GEF), implemented by the United Nations Environment Program (UNEP), and executed through the UNEP Copenhagen Climate Centre in collaboration with the Asian Institute of Technology (AIT). The present report is the output of a fully country-led process, and the views and information contained herein are a product of the TNA team led by the Climate Change and Development Authority (CCDA), Ministry of Environment, Conservation and Climate Change, Papua New Guinea.

Foreword

Climate change poses one of the most pressing challenges to the sustainable development of Papua New Guinea. As a country whose economy and well-being are deeply rooted in its natural environment, our vulnerability to climate-related shocks is significant. Increasing variability in weather patterns, more frequent extreme events, and the erosion of traditional coping mechanisms are already affecting our communities—especially those in rural, highland, and coastal areas.

In recognition of this urgent reality, the Government of Papua New Guinea, through the Ministry of Environment, Conservation and Climate Change (MECCC), is committed to strengthening national resilience across key development sectors. As part of this effort, the **Barrier Analysis and Enabling Framework (BAEF)** has been developed under the Technology Needs Assessment (TNA) process to identify critical barriers and propose practical solutions for the adoption of high-priority climate adaptation technologies in both the **agriculture** and **infrastructure** sectors.

The agriculture sector, which sustains over 85% of the population, is increasingly at risk from droughts, floods, and shifting agro-climatic zones. Technologies such as **Climate-Smart Agriculture (CSA)** and **Climate Information and Early Warning Systems (CIEWS)** have been prioritized for their potential to safeguard food security and enhance adaptive farming practices. At the same time, the infrastructure sector—vital for connectivity, service delivery, and economic resilience—is severely impacted by landslides, coastal erosion, and extreme weather events. Technologies such as **Climate-Resilient Infrastructure (CRI)** and robust **Early Warning Systems (EWS)** have been identified to help reduce vulnerability and ensure continuity of essential services.

This report reflects the outcome of an inclusive and consultative process involving national and sub-national stakeholders, technical working groups, and development partners. It provides a structured framework to address institutional, financial, technical, and socio-cultural challenges while proposing enabling measures aligned with Papua New Guinea's National Adaptation Plan (NAP) and Nationally Determined Contributions (NDCs).

I wish to acknowledge and commend the collective effort of all contributors—government agencies, civil society organizations, academia, and international partners—whose dedication and insights have made this assessment possible. As we move forward with implementation, let us reaffirm our shared commitment to a resilient and inclusive development pathway for all communities across Papua New Guinea.

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Debra Sungi,
Acting Managing Director General, Climate Change and Development,
Ministry of Environment, Conservation and Climate Change

List of Abbreviations

ACIAR	Australian Centre for International Agricultural Research
ADB	Asian Development Bank
AIT	Asian Institute of Technology
AWS	Automatic Weather Station
BAEF	Barrier Analysis and Enabling Framework
CCAFS	Climate Change, Agriculture and Food Security
CCCDMP	Climate Change and Disaster Management Program
CCDA	Climate Change and Development Authority
CEPA	Conservation and Environment Protection Authority
CFCSP	Climate-Field School for Papua
CGIAR	Consultative Group on International Agricultural Research
CIEWS	Climate Information and Early Warning Systems
CIFOR	Center for International Forestry Research
CRI	Climate-Resilient Infrastructure
CSA	Climate-Smart Agriculture
DAL	Department of Agriculture and Livestock
EWS	Early Warning Systems
EU	European Union
FAO	Food and Agriculture Organization
GCF	Green Climate Fund
GDP	Gross Domestic Product
GFDRR	Global Facility for Disaster Reduction and Recovery
GIS	Geographic Information System
GoPNG	Government of Papua New Guinea
ICIMOD	International Centre for Integrated Mountain Development
ICRAF	World Agroforestry Centre
ICT	Information and Communication Technology
IFAD	International Fund for Agricultural Development
IMF	International Monetary Fund
MECCC	Ministry of Environment, Conservation and Climate Change
MTDP	Medium Term Development Plan
NAP	National Adaptation Plan
NARI	National Agricultural Research Institute
NDC	National Disaster Centre / Nationally Determined Contribution
NICTA	National Information and Communication Technology Authority
NSC	National Steering Committee
NWS	National Weather Service
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
OECD	Organisation for Economic Co-operation and Development
PNG	Papua New Guinea
SMS	Short Message Service
SPREP	Secretariat of the Pacific Regional Environment Programme
TNA	Technology Needs Assessment
TWG	Technical Working Group
UN	United Nations
UNCDF	United Nations Capital Development Fund
UNDP	United Nations Development Programme

UNDRR	United Nations Office for Disaster Risk Reduction
UNEP	United Nations Environment Programme
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNFCCC	United Nations Framework Convention on Climate Change
UNITECH	Papua New Guinea University of Technology
UPNG	University of Papua New Guinea
WMO	World Meteorological Organization

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Executive Summary

Papua New Guinea (PNG) faces growing climate threats that endanger both its agriculture and infrastructure sectors—two pillars critical to the country's livelihoods and development. Over 85% of PNG's population relies on agriculture for food and income, yet the sector is increasingly impacted by erratic weather patterns, prolonged droughts, floods, and pest outbreaks—exacerbating food insecurity and economic vulnerability. Simultaneously, PNG's infrastructure systems—including roads, bridges, buildings, and utilities—are highly exposed to climate risks such as landslides, cyclones, and sea-level rise. Inadequate infrastructure not only disrupts essential services and emergency response but also compounds agricultural losses by limiting access to markets and inputs. To respond to these dual challenges, PNG's Technology Needs Assessment (TNA) has prioritized two climate adaptation technologies for each sector**: Climate-Smart Agriculture (CSA) and Climate Information and Early Warning Systems (CIEWS) for agriculture**; and **Climate-Resilient Infrastructure (CRI) and Early Warning Systems (EWS) for infrastructure**. Through in-depth Barrier Analysis and Enabling Frameworks, the country seeks to address economic, institutional, technical, and social constraints to technology adoption—paving the way for resilient, inclusive, and sustainable development.

Agriculture Sector
Technologies and Targets CSA and CIEWS

1. Climate-Smart Agriculture (CSA): government aims to scale up implementation across climate-vulnerable provinces by 2030, enhancing food security and farm resilience. Supporting actions include establishing agroecological field schools and demonstration plots in at least 50 rural districts by 2027, providing climate-resilient seed varieties to 100,000 farming households by 2028, and integrating CSA training modules into the National Agricultural Research Institute (NARI) and extension curricula by 2026.
2. Climate Information and Early Warning Systems (CIEWS): nationwide dissemination of agro-climate advisories through SMS, radio, and extension services by 2028 to support timely farm-level decision-making. Additionally, 5,000 lead farmers and extension officers will be trained in interpreting and communicating climate advisories by 2027. By 2026, community-based early warning systems will be installed in 100 high-risk rural communities, and localized seasonal forecasting tools will be developed and piloted in at least five major agricultural zones.

Barrier Analysis CSA and CIEWS

The integration and deployment of Climate-Resilient Infrastructure (CRI) and Early Warning Systems (EWS) in Papua New Guinea face multiple overlapping challenges across institutional, financial, technical, and social domains. From an economic and financial perspective, both CRI and EWS suffer from inadequate domestic financing and a lack of long-term funding mechanisms, stemming from high upfront costs, limited budget allocations, and ongoing dependence on donor support. In the policy and regulatory domain, weak governance frameworks and institutional fragmentation—manifested through outdated standards, fragmented mandates, and the absence of integrated land-use or EWS strategies—create planning inefficiencies and reduce policy coherence.

Technically, both systems are constrained by insufficient access to reliable climate and hazard data and weak integration of risk considerations into design and planning tools. Infrastructure-wise, gaps such as poorly maintained roads, energy supply, and communications networks reduce the resilience of physical assets and compromise the operability of EWS platforms.

Institutional challenges are compounded by coordination failures and procedural delays, with limited collaboration between agencies, sluggish procurement, and absent maintenance structures. These are mirrored by human resource constraints, especially at the subnational level, where a lack of trained engineers, planners, and technical operators limits implementation effectiveness.

Social and cultural factors also play a significant role. Low community engagement, preference for low-cost structures, and culturally fragmented communication channels hinder uptake and trust in climate services. Finally, in terms of awareness and information dissemination, both sectors are weakened by poor risk communication, inconsistent messaging, and a general lack of public preparedness and education on climate risks.

Addressing these shared barriers is essential for PNG to build adaptive capacity across infrastructure and early warning systems. It calls for integrated financing, cohesive policy reforms, cross-sectoral institutional collaboration, and community-centered capacity building to deliver resilient outcomes in the face of escalating climate threats.

Measures and Enabling Framework CSA and CIEWS

Level 1 Cross-Cutting (Systemic) Enabling Measures

Papua New Guinea faces several common challenges in implementing Climate-Smart Agriculture (CSA) and Climate Information and Early Warning Systems (CIEWS), such as limited funding, weak policies, low technical capacity, and poor access to climate information. To address these, a range of coordinated enabling measures is proposed. Financial barriers can be tackled by integrating CSA and CIEWS into national climate finance plans like the NAP and NDC, while offering low-interest loans and blended financing options to support farmers and communities. Policy gaps can be addressed by developing a national CSA-CIEWS strategy, embedding climate services into agricultural policies, and enforcing data-sharing regulations across government agencies. Technical constraints require the creation of joint research and extension hubs to co-develop locally tailored forecasts that combine science and traditional knowledge.

To strengthen human resources, extension agents should receive joint training and certification, and CSA-CIEWS content should be included in academic and vocational education. Infrastructure in rural areas should be upgraded through solar-powered weather stations, improved water systems, and digital tools that support both agriculture and early warnings. Institutional coordination can be enhanced through a national CSA-CIEWS committee, which will align efforts across ministries and support local implementation. Social and cultural barriers should be addressed by using trusted local champions, inclusive demo farms, and integrating traditional knowledge into outreach. Lastly, climate advisories must be made more accessible through pictograms, voice alerts, mobile apps, churches, and farmer field schools. These enabling actions will help scale up CSA and CIEWS, making PNG’s agriculture sector more resilient, informed, and inclusive in the face of climate change.

Level 2 focuses on technology-specific alternative measures, offering flexible options tailored to different implementation environments.

Climate-Smart Agriculture (CSA), two measure sets present distinct pathways. Measure Set A emphasizes short-term adoption through public sector leadership—providing input subsidies, performance-based grants, government-led extension training, and integration of CSA into local development budgets. In contrast, Measure Set B promotes long-term sustainability by establishing innovation hubs, leveraging public-private partnerships, deploying mobile learning tools, and empowering local cooperatives to lead CSA implementation. These two strategies provide trade-offs between centralized support and decentralized innovation, allowing adaptability based on resource availability and institutional capacity.

Climate Information and Early Warning Systems (CIEWS), Measure Set A focuses on institutional capacity-building and broad coverage, including upgrading national weather station networks, disseminating forecasts via traditional media, training officials, and linking forecasts to formal early action protocols. Alternatively, Measure Set B prioritizes community ownership and local innovation—through low-cost community sensors, interactive mobile platforms, integration of climate literacy into school curricula, and participatory action planning with civil society.

Together, these measure sets provide **customizable options** for stakeholders to scale CSA and CIEWS based on local needs, funding levels, and strategic goals. This approach strengthens PNG's climate resilience by aligning national frameworks with localized, inclusive, and forward-looking adaptation solutions.

Infrastructure Sector

Technologies and Targets CRI and EWS

Papua New Guinea has set ambitious preliminary targets for the deployment of Climate-Resilient Infrastructure (CRI) and Early Warning Systems (EWS) as part of its national climate adaptation efforts.

1. Climate-Resilient Infrastructure (CRI), the government aims to upgrade 40% of rural and feeder roads in high-risk provinces such as East Sepik, Gulf, and Morobe by 2030 using climate-resilient engineering standards. Additionally, at least 500 public buildings—including health clinics, schools, and district centers—are targeted for retrofitting to meet resilience criteria by 2028. To institutionalize climate risk considerations, mandatory risk screening will be integrated into all publicly funded infrastructure projects by 2026, and sector-specific CRI technical guidelines will be published by 2025.
2. Early Warning Systems (EWS) coverage by achieving multi-hazard early warning system implementation across all 22 provinces by 2029, with priority given to flood-, landslide-, and coastal hazard-prone areas. This will be supported by the installation of 150 new hydro-meteorological monitoring stations in high-risk rural regions by 2027 and the establishment of community-based EWS in 300 vulnerable villages by 2026. Furthermore, EWS concepts will be mainstreamed into disaster preparedness curricula in primary schools and integrated into local government contingency plans by 2025.

Barrier Analysis – CRI and EWS

The deployment of Climate-Resilient Infrastructure (CRI) and Early Warning Systems (EWS) in Papua New Guinea is hindered by a series of deeply interconnected and cross-cutting barriers that span financial, institutional, technical, and socio-cultural domains. These shared constraints reveal that the challenges facing both technologies are not isolated but systemic, requiring integrated and multi-level interventions.

Economically, both CRI and EWS suffer from inadequate domestic financing and an over-reliance on donor support. The lack of sustainable, long-term funding mechanisms continues to undermine efforts to build and maintain resilient infrastructure and functional warning systems. On the policy front, fragmented mandates, outdated regulatory frameworks, and the absence of integrated climate and disaster risk strategies have created institutional overlaps and slowed implementation. These legal and regulatory gaps also reflect the broader issue of institutional fragmentation and inefficiencies in governance structures, procurement processes, and inter-agency coordination.

Technically, the country faces major gaps in access to accurate and localized climate and hazard data, along with weak integration of risk information into infrastructure and EWS design. This is compounded by the inadequate physical infrastructure needed to support both sectors—such as poor communication and energy networks, vulnerable transport systems, and informal settlements that lack resilient design. Institutional and organizational barriers further constrain progress, particularly due to poor data sharing, uncoordinated planning, and the lack of robust maintenance frameworks.

Human resource limitations are also pronounced, with a shortage of climate-literate engineers, planners, and trained EWS operators, especially at subnational levels. These constraints are intensified by social and cultural challenges, including low community participation in planning, language diversity, and traditional beliefs that can hinder the effectiveness of warning systems and infrastructure adaptation. Lastly, insufficient public awareness, fragmented communication channels, and the absence of consistent preparedness campaigns lead to poor risk perception and low adaptive capacity across communities.

Measures and Enabling Framework – CRI and EWS

Level 1 Cross-Cutting (Systemic) Enabling Measures

The successful implementation of Climate-Resilient Infrastructure (CRI) and Early Warning Systems (EWS) in Papua New Guinea hinges on addressing a series of systemic, shared barriers through integrated and synergistic enabling measures. These measures are designed to unlock co-benefits and foster long-term resilience by leveraging cross-sectoral coordination, institutional reform, and community engagement.

To solve funding problems caused by limited national budgets and reliance on donors, blended finance models are suggested. These would mix government start-up funds with support from partners like the Green Climate Fund (GCF) and the Asian Development Bank (ADB) to fund both CRI and EWS projects together. A national CRI-EWS strategy should also be created, along with updates to building and planning laws to include early warning systems in infrastructure planning.

On the technical side, the lack of local tools and data will be addressed by creating national platforms for CRI and EWS data, and using GIS hazard maps adapted to local needs. To fix the shortage of skilled workers, especially in rural areas, mobile technical teams and joint training programs will be introduced to build local expertise.

To improve infrastructure, solar-powered EWS equipment and smart sensors will be included in new resilient building projects. Institutional gaps will be handled by setting up a National CRI-EWS Coordination Unit under the National Disaster Centre (NDC), with clear rules for sharing data and coordinating responses between agencies.

For social and cultural challenges, local CRI-EWS committees will be formed to involve communities, design alerts with their input, and include traditional knowledge. Finally, to raise awareness and preparedness, actions like multilingual alerts, school drills, and adding EWS lessons into school programs will be carried out.

Level 2 focuses on technology-specific alternative measures, offering flexible options tailored to different implementation environments.

Climate-Resilient Infrastructure (CRI), two measure sets provide distinct pathways. Measure Set A supports short-term progress through national-level leadership—offering subsidies or tax incentives for resilient materials, developing technical guidelines, prioritizing retrofitting of essential infrastructure (e.g., schools and clinics), and embedding CRI in national and provincial budgets. In contrast, Measure Set B promotes long-term innovation by piloting subnational CRI innovation hubs, fostering public-private partnerships for retrofitting, integrating smart sensors and modular designs into new infrastructure, and enabling community-led maintenance programs. These options offer trade-offs between centralized efficiency and localized innovation, adaptable to available resources and institutional readiness.

Early Warning Systems (EWS), Measure Set A focuses on strengthening national systems through institutional upgrades—expanding the automated weather station (AWS) network, standardizing alert protocols via SMS and radio, training emergency responders, and establishing centralized data verification processes. On the other hand, Measure Set B enhances grassroots ownership by deploying low-cost community hazard sensors, using gamified mobile platforms for engagement, integrating traditional knowledge into alerts, and conducting localized training and drills through community and faith-based organizations. This approach balances top-down capacity building with bottom-up resilience and inclusiveness.

Together, these measure sets provide adaptable pathways to scale CRI and EWS based on local capacity, funding levels, and implementation contexts. This dual-track strategy enhances Papua New Guinea's climate resilience by aligning national systems with community-driven solutions and long-term adaptation goals.

Chapter 1
Agriculture Sector

Papua New Guinea's agriculture sector is highly vulnerable to the impacts of climate change, with over 85% of the population relying on subsistence farming and smallholder-based production for their livelihoods (FAO, 2024; World Bank, 2021). The sector contributes approximately 25% to the national GDP and provides critical food security for rural communities (GoPNG, 2020a). However, it is severely threatened by climatic variability, including prolonged droughts, erratic rainfall, floods, and frost events—many of which are exacerbated by El Niño cycles (OCHA, 2016; IFAD, 2021).

Climate-induced disruptions have led to declining yields in staple crops like sweet potatoes, taro, and bananas, while intensified rainfall events contribute to erosion and landslides, particularly in highland regions (GoPNG, 2018). Soil degradation is widespread, with topsoil losses estimated at 50–100 tons per hectare per year due to unprotected slopes and intense precipitation (Diao et al., 2024). Rising temperatures and altered precipitation patterns have also expanded the habitat range of pests and diseases, further straining food systems (FAO, 2024).

Infrastructural weaknesses, including limited rural road access and inadequate post-harvest storage, intensify food insecurity and income loss. For instance, heavy rains and landslides often isolate communities from markets, compounding vulnerability (FAO, 2022). Despite efforts, fewer than 15% of farmers have adopted climate-resilient practices such as improved crop varieties, agroforestry, or irrigation technologies (Diao et al., 2024).

Two technologies—**Climate-Smart Agriculture (CSA)** and **Climate Information and Early Warning Systems (CIEWS)**—have emerged as top priorities due to their transformative potential, feasibility, and alignment with national adaptation goals. The next phase of the Technology Needs Assessment (TNA) process is the development of a **Barrier Analysis and Enabling Framework (BAEF)**, which will critically assess the key obstacles hindering the adoption of these two technologies and propose actionable, context-specific measures to overcome them. This step is vital to ensure that adaptation efforts in the agriculture sector are not only technically sound but also socially inclusive, economically viable, and institutionally supported.

The Technology Needs Assessment (TNA) for Papua New Guinea (PNG) followed a TNA Step by Step A guidebook for countries conducting a Technology Needs Assessment and Action Plan (Haselip et al., 2019). The methodology was applied to identify, analyse, and prioritize the barriers hindering the diffusion of climate adaptation technologies in PNG's agriculture sector, particularly those that address food security, resilience to climate extremes, and sustainable livelihoods.

A. Identification of Barriers

A comprehensive barrier identification process was undertaken using a combination of:

1. **Identification of Sectoral Objectives and Technology Priorities**
   Building on the prioritization conducted during the TNA Phase I (Multi-Criteria Analysis), the BAEF process focused on two selected adaptation technologies:
   - **Climate-Smart Agriculture (CSA)**
   - **Climate Information and Early Warning Systems (CIEWS)**

The objective was to identify systemic and specific barriers hindering technology deployment and to propose enabling measures to support widespread adoption.

2. **Desktop Literature Review**
   A comprehensive review of national reports, regional assessments, and international publications was undertaken to identify technical, economic, institutional, and policy-related challenges associated with CSA and CIEWS technologies in PNG

3. **Stakeholder Mapping and Engagement**
   A list of key stakeholders was developed based on Phase I stakeholder mapping. This included government agencies, and NGOs. A total of six stakeholders participated in the validation workshop, representing agencies such as:
   - Climate Change and Development Authority (CCDA)
   - Department of Agriculture and Livestock (DAL)
   - Climate Finance Capacity Support Programme (CFCSP)

   The full participant list is included in **Annex 5**, and agencies were referenced in the main text during analysis of institutional and capacity-related barriers.

B. Screening of Barriers

Following the initial identification of a broad set of barriers through literature reviews, stakeholder consultations, and workshop brainstorming, a structured screening and prioritization process was undertaken to narrow down the list to the most critical barriers that constrain the adoption of Climate-Smart Agriculture (CSA) and Climate Information and Early Warning Systems (CIEWS) in Papua New Guinea.

This screening process was conducted during a dedicated national validation workshop facilitated by the Climate Change and Development Authority (CCDA), in collaboration with the Department of Agriculture and Livestock (DAL), Climate Finance Capacity Support Programme (CFCSP), and other sectoral agencies. The purpose of this session was to validate the findings from the desktop review and ensure alignment with local realities and policy priorities.

Workshop participants were provided with a matrix of identified barriers across eight standard categories:
1. Economic and Financial
2. Policy, Legal, and Regulatory
3. Technical
4. Human Resources
5. Infrastructure
6. Institutional and Organizational Capacity
7. Social, Cultural, and Behavioural
8. Information and Awareness

Each participant independently rated the identified barriers using a standardized scoring sheet during the validation workshop. To ensure transparency and build consensus, the individual scores were averaged across all participants. The scoring was based on a five-point scale, where a score of 1 indicated a barrier that was "Not Very Significant," 2 as "Not Significant," 3 as "Moderate," 4 as "Significant," and 5 as "Very Significant." This structured approach allowed for a consistent and participatory assessment of which barriers were most critical to address in the development of enabling measures for Climate-Smart Agriculture in Papua New Guinea

C. Barrier Identification and Solution Tree Design

Using a combination of problem tree and solution tree approaches, barriers were analyzed and translated into measures. This involved:

- Brainstorming and validation during Technical Working Group (TWG) sessions
- Use of structured templates to trace root causes and identify cross-cutting challenges (e.g., lack of credit access, poor rural infrastructure, fragmented extension services)
- Prioritization of barriers by impact and feasibility of intervention

D. Development of Enabling Measures

After the prioritization and classification of key barriers, the next critical step in the BAEF process was the development of enabling measures to overcome the identified constraints. This step followed the problem tree whereby each root barrier was systematically translated into targeted interventions aimed at facilitating the diffusion of adaptation technologies—in this case, **Climate-Smart Agriculture (CSA)** and **Climate Information and Early Warning Systems (CIEWS)**.

The design of enabling measures was informed by:

- Root-cause analysis of each barrier category **(Annex 1 to 2)**
- Stakeholder feedback from the Technical Working Group (TWG)
- Lessons from regional and global best practices in climate adaptation

Identified barriers were translated into practical solutions using a solution tree methodology, structured around**:** Institutional reforms Capacity building Infrastructure upgrades Policy alignment financial instruments (e.g., blended finance, subsidies, rural credit) Enabling measures were designed to address both Set A (centralized, investment-heavy) and Set B (community-based, inclusive) approaches.

E. Validation and Finalization

The final step in the Barrier Analysis and Enabling Framework (BAEF) process was a comprehensive validation and finalization phase, aimed at ensuring the credibility, technical soundness, and national alignment of the findings and proposed enabling measures.

This process involved multi-level review and stakeholder engagement, comprising technical assessments, expert peer reviews, and institutional endorsement mechanisms, as outlined below:

- The Technical Working Group (TWG)
- Independent national experts
- Advisors from UNEP-CCC and AIT

Feedback from these stakeholders was incorporated into the final BAEF report, ensuring national relevance and alignment with the NAP and NDCs.

1.1 Preliminary Targets for Technology Transfer and Diffusion Agriculture Sector

Papua New Guinea's agriculture sector faces critical challenges due to increasing climate variability, dependence on rain-fed systems, and low levels of technological adoption. The Technology Needs Assessment (TNA) has identified and prioritised two key adaptation technologies to enhance climate resilience, improve livelihoods, and promote sustainable agricultural productivity:

1. **Climate-Smart Agriculture (CSA)**
2. **Climate Information and Early Warning Systems (CIEWS)**

These technologies were selected based on their relevance to the country's agro-ecological zones, potential to address systemic vulnerabilities, and feasibility for scaling among smallholder farmers. The sections below provide a brief overview of each technology and propose preliminary deployment targets to inform the barrier analysis and enabling framework.

Preliminary Targets for CSA Deployment:

- scale up climate-smart agriculture across vulnerable provinces by 2030 (GoPNG, 2023).
- Establish agroecological field schools and CSA demo plots in at least 50 rural districts by 2027 (FAO, 2024).
- Provide access to climate-resilient seed varieties for 100,000 farming households by 2028 (Diao et al., 2024)
- Integrate CSA training modules into the National Agricultural Research Institute (NARI) and extension curriculum by 2026.

Preliminary Targets for CIEWS Deployment:

- Achieve nationwide coverage of agro-climate advisories by 2028 through SMS, radio, and extension services (GoPNG, 2023).
- Train 5,000 lead farmers and extension officers on interpreting and disseminating climate advisories by 2027 (IFAD, 2021).
- Install community-based early warning notice boards and alert systems in 100 high-risk rural communities by 2026 (World Bank, 2021).
- Develop and pilot localized seasonal forecasting tools for at least five agricultural zones by 2026.

1.2 Barrier Analysis and Possible Enabling Measures for Agriculture Technology

1.2.1 General Description of Technology Climate-Smart Agriculture (CSA)

Climate-smart agriculture (CSA) is an approach for transforming and reorienting agricultural development under the new realities of climate change (Lipper et al., 2014). The most commonly used definition is provided by the Food and Agriculture Organisation of the United Nations, which defines CSA as "agriculture that sustainably increases productivity, enhances resilience (adaptation), reduces/removes GHGS (mitigation) where possible, and enhances achievement of national food security and development goals". In this definition, the principal goal of CSA is identified as food security and development (FAO, 2013; Lipper et al., 2014); while productivity, adaptation, and mitigation are identified as the three interlinked pillars necessary for achieving this goal.

Climate-Smart Agriculture (CSA) refers to an integrated approach that aims to sustainably increase agricultural productivity, enhance resilience (adaptation), reduce greenhouse gas emissions where possible (mitigation), and enhance food security. In the PNG context, CSA emphasizes locally appropriate practices such as:

- Conservation agriculture (minimum tillage, mulching, cover cropping)
- Use of drought- and pest-resilient crop varieties (e.g., cassava, sweet potato)
- Agroforestry integration for soil health and shade regulation
- Improved soil and water management techniques
- Livelihood diversification and ecosystem-based approaches

PNG's highly dispersed rural population, combined with steep terrain and fragile soils, makes the transition to CSA both urgent and complex. To ensure uptake, targeted extension services, subsidies, and community-based demonstrations are essential.

Climate-Smart Agriculture (CSA) in Papua New Guinea aligns with the internationally recognized FAO framework, aiming to enhance productivity, resilience, and reduce emissions in the agriculture sector. PNG's national policies, including the National Climate Compatible Development Management Policy (CCCDMP 2014), the National Adaptation Plan (NAP 2023), and the Technology Needs Assessment (TNA 2025), have prioritized CSA as a key approach to achieving food security under climate change.

The following outlines the work of the Climate-Smart Agriculture (CSA) pillars in Papua New Guinea (PNG). This initiative is a comprehensive approach that integrates the Food and Agriculture Organization's (FAO) conceptual pillars with technologies that have been prioritized based on local needs and challenges:

1. **Pillar 1: Sustainably increase agricultural productivity and incomes (Productivity):**
   CSA technologies in PNG aim to increase yields while ensuring sustainable land and resource use. Relevant local technologies include:
    - Improved crop varieties (e.g., drought-tolerant sweet potato, cassava) – supported by NARI and national seed banks.
    - Agroforestry practices to provide shade, reduce erosion, and boost soil fertility.
    - Integrated nutrient management using organic compost and cover cropping.
    - Sustainable land management (SLM) on steep slopes, especially in the Highlands Region.

   FAO Alignment: increase agricultural productivity in a way that uses natural resources more efficiently, ensuring food security while minimizing environmental degradation (FAO, 2013).

2. **Pillar 2: Adapt and build resilience to climate change (Adaptation):**
   CSA aims to reduce the exposure of farmers to short-term risks, while also strengthening their resilience by building their capacity to adapt and prosper in the face of shocks and longer-term stresses.

   PNG's agriculture is highly exposed to El Niño-induced droughts, floods, and pest outbreaks. CSA adaptation strategies include:
   - Climate-resilient seed systems and local seed banks (e.g., Eastern Highlands model).
   - Post-harvest storage innovations (solar drying units, sealed grain storage) to reduce losses.
   - Community-based weather advisory services (linked to CIEWS) for planting and harvesting decisions.

- Contour farming and soil retention structures to reduce erosion and landslides in steep areas.

FAO Alignment: Build resilience through climate-risk-informed decision-making and diversified farming systems (FAO, 2013)

3. **Pillar 3: Reduce and/or remove greenhouse gas emissions, where possible (Mitigation):**
   Wherever and whenever possible, CSA should help to reduce and/or remove greenhouse gas (GHG) emissions. Although emissions from PNG agriculture are relatively low, CSA can reduce deforestation and promote low-emission techniques:
   - Agroforestry and tree crop integration (e.g., cocoa + shade trees).
   - Zero-burning land preparation and residue recycling.
   - Biogas from livestock waste for household energy in pilot areas.
   - Manure management and improved feeding systems for pigs and poultry.

   FAO Alignment: Reduce emissions where possible without compromising food production (FAO, 2013; Lipper et al., 2014).

Table 1 Cross-Cutting CSA Technology Enablers in PNG

CSA Conceptual Principle	PNG Practice/Policy Response
Integrated Planning	CCCDMP 2014 encourages mainstreaming climate risk into agriculture and land-use planning.
Context-Specific Solutions	NARI and DAL lead regional CSA trials (e.g., sweet potato trials in the Highlands).
Technology & Practice-Based	National CSA technology menu developed under the TNA
Landscape Approach	Agroforestry and integrated watershed management in Morobe and Madang Provinces.
Enabling Environment	NAP 2023 and MTDP IV support farmer extension, early warning systems, and innovation funds.
Inclusivity and Gender Focus	CCAFS-aligned pilot projects include women in farmer groups and seed production systems.

Table 2 Summary of Market Characteristics of the CSA Technology

Technology	Market Type	Description
Climate-Smart Agriculture (CSA)	Publicly Supported Hybrid	Practice-based approach adopted by farmers, with input support and extension aid.
Resilient Seed Varieties and Tools part of CSA	Consumer Good	Distributed to farmers with support from NGOs, NARI, or donor programs.
CSA Extension Services	Public Service	Delivered by government and university networks under agriculture programs.

Notes:
- CSA adoption relies heavily on enabling policies and financial mechanisms to support farmer-level uptake.
- Combining both technologies enhances anticipatory capacity and on-farm adaptive action.

1.2.2 Identification of Barriers for Technology Climate-Smart Agriculture (CSA)

The identification of barriers to the adoption of Climate-Smart Agriculture (CSA) in Papua New Guinea was conducted through a structured assessment involving literature review, expert interviews, and stakeholder consultations with the National Steering Committee (NSC) and Sectoral Working Groups (SWGs). This process aimed to determine challenges that prevent implementation and scaling of CSA technologies effectively.

Barriers to CSA in PNG were grouped into two categories: (1) economic and financial barriers, and (2) non-financial barriers. Non-financial barriers were further divided into six subcategories: policy, legal, and regulatory; technical; human resources; infrastructure; institutional and organizational capacity; and socio-cultural and information barriers.

1.2.2.1 Economic and Financial Barriers

Smallholder farmers represent more than **85% of PNG's agricultural labour force**, operating largely within **subsistence systems** that are vulnerable to climate shocks, market volatility, and input scarcity. Despite the promise of Climate-Smart Agriculture (CSA) to improve productivity and resilience, adoption is heavily constrained by a combination of **financial limitations, systemic underinvestment, and risk aversion**. These constraints are outlined below:

- **High Upfront Investment Costs:** CSA technologies such as drought-tolerant seed varieties, agroforestry tree seedlings, drip or sprinkler irrigation systems and composting units or small machinery (e.g., micro-tillers) often require significant initial investment that is unaffordable for most smallholder farmers. For instance, a basic drip irrigation setup for a 0.5-hectare plot may cost upwards of USD 300–500, well beyond the monthly income of many rural households in PNG. Moreover, CSA adoption is long-term and gradual, and many farmers cannot afford the delayed returns on these investments (FAO, 2013)

- **Limited access to credit and financial services for smallholder farmers**: access to formal financial institutions in rural PNG is extremely limited because of lack of collateral (customary land cannot be mortgaged), poor financial literacy, and limited presence of rural banks or microfinance providers offering agricultural loans. Many farmers depend on informal lending or moneylenders with high interest rates, which are unsustainable for CSA investment. Additionally, financial products tailored to climate risk mitigation (e.g., crop insurance or weather-indexed credit) are largely unavailable or in the early pilot phase (World Bank, 2021; IFAD, 2021)

- **Weak Private Sector Engagement:** PNG's agricultural input market is underdeveloped. Private companies are hesitant to invest in local seed production and distribution, climate-smart technologies (e.g., biochar stoves, solar drying units), and CSA advisory services or apps. This is due to poor road access, market fragmentation, small economies of scale, and a lack of enabling incentives. As a result, CSA tools are either unavailable or imported at high cost, limiting their affordability and scalability (FAO, 2013)

- **Low Capital Accumulation Due to Subsistence Farming:** Most rural households engage in subsistence agriculture, producing food primarily for household consumption, not for market sale. The disadvantage of this model includes cash income that could be reinvested in technology, Savings buffers for risky new practices, and Market engagement, which is essential for value chain-based CSA approaches. Without surplus capital or access to support systems, subsistence farmers often view CSA investments as too risky or inaccessible (Diao et al., 2024; Lipper et al., 2014)

1.2.2.2 Non-Financial Barriers

A. Policy, Legal, and Regulatory

Several related policy and regulatory issues are stopping the effective adoption and integration of CSA in the country, such as:

- **Lack of a National CSA Policy or Implementation Strategy:** PNG currently lacks a dedicated national policy or roadmap for CSA adoption, which leads to limited political prioritization and poor resource allocation for CSA initiatives. Although the National Adaptation Plan and Climate Compatible Development Management Policy acknowledge the vulnerability of agriculture, CSA is only referenced in broad terms without an operational framework (FAO, 2013)

- **Fragmented Agricultural, Food Security, and Climate Change Policies:** The agriculture and climate portfolios in PNG are governed by different ministries, including DAL, CCDA, and the Department of National Planning and Monitoring. However, policy coherence is weak due to overlapping mandates and fragmented strategies, minimal integration of climate resilience in sectoral plans (e.g., MTDP IV), and poor horizontal coordination between national and subnational agencies. This fragmentation slows CSA project approvals, complicates budgeting, and reduces the effectiveness of donor and development partner support (World Bank, 2021).

- **Weak Land Tenure Security Under Customary Ownership:** Over 90% of PNG's land is under customary ownership, governed by clan-based systems that often lack formal documentation or registration (GoPNG, 2014).

- **Limited policy incentives for CSA adoption:** Currently, PNG offers no structured incentives such as tax breaks for agroforestry or sustainable land-use businesses, subsidies or vouchers for CSA technologies like composting kits or drip irrigation, and public procurement policies favouring climate-resilient crops. Without economic incentives, adoption remains low, particularly among risk-averse smallholder farmers. Additionally, development partners' CSA pilots often operate in isolation without alignment to national fiscal mechanisms (FAO, 2013; CCAFS, 2015)

B. Technical Barriers

- **Limited Availability of CSA Technologies Suited to Local Conditions (e.g., climate-resilient crops):** Many CSA technologies, such as drought-tolerant crops, efficient irrigation systems, or soil moisture monitoring tools, are not readily available or accessible to smallholder farmers in PNG, and the current supply chain for these technologies is underdeveloped. For instance, climate-resilient crops such as drought-tolerant cassava or salt-tolerant taro are not widely available through local seed systems, and their dissemination remains limited to pilot initiatives (ACIAR, 2021; FAO, 2022).

- **Inadequate Research into Locally Adapted CSA Methods:** PNG faces a research gap in generating and adapting CSA technologies suited to local farming practices and conditions. The country's agricultural research infrastructure, led by institutions such as the National Agricultural Research Institute (NARI), lacks sufficient funding, human resources, and institutional support to carry out wide-scale adaptive trials (NARI, 2022). As a result, promising CSA innovations often remain in research pipelines without proper validation or upscaling (World Bank, 2021).

- **Outdated Farm Tools and Low Mechanisation Levels:** A significant number of PNG's smallholder farmers continue to rely on basic tools, such as bush knives and digging sticks, with little to no access to mechanized equipment like rotary tillers, planters, or threshers. High transport costs, lack of repair services, and import dependence make mechanisation economically unfeasible for most rural communities (GoPNG, 2020b).

- **Limited Access to Weather-/Climate-Resilient Inputs like Drought-Tolerant Seeds:** PNG's seed system is dominated by traditional exchange, with limited access to high-quality certified seeds tailored for drought, flood, or salinity stress. The availability of fast-maturing and climate-resilient varieties is insufficient to support adaptive farming, especially during El Niño-induced droughts. During the 1997 and 2015 El Niño events, the lack of appropriate seed varieties contributed to food insecurity for millions in the Highlands region (Allen & Bourke, 2001; Diao et al., 2024).

- **Weak Linkages Between Research Institutions and Farmers:** There is a disconnection between agricultural research institutions (e.g., NARI, UNITECH, UPNG) and the farming communities they aim to support. Extension services are underfunded and poorly staffed, with fewer than one agricultural extension officer available for every 1,000 farmers (ADB, 2019).

C. Human Resource Barriers

- **Lack of Trained Extension Officers with CSA Knowledge:** PNG suffers from a shortage of agricultural extension officers, with a ratio of less than one officer per 1,000 farming households (ADB, 2019). Even among existing staff, there is limited technical capacity in climate-smart agriculture practices, such as integrated pest management, agroforestry, or precision nutrient application. Most extension officers have not received specialized training in CSA, reducing their effectiveness in supporting farmers with adaptation strategies (World Bank, 2021)

- **Limited Farmer Training Programs on CSA Techniques:** Although various donor-funded pilot projects have introduced CSA approaches in select provinces, there remains a lack of structured, long-term farmer training programs across PNG. Training is often short-term, urban-centered, or narrowly focused, with few opportunities for continuous learning or scaling to remote highland and coastal areas (FAO, 2022).

- **High Turnover and Low Capacity Among Agricultural Staff:** Institutional instability and weak governance have led to frequent turnover of technical staff in the Department of Agriculture and Livestock (DAL) and research institutes. Many staff members leave their jobs, often due to limited incentives, career development pathways, or rural hardship postings, results in knowledge gaps and interrupted project continuity (GoPNG, 2020b; NARI, 2022).

- **Low Literacy and Education Levels in Rural Farming Communities:** Over 80% of PNG's population lives in rural areas, where literacy rates are significantly lower than the national average, particularly among women and older farmers. This limits the effectiveness of written manuals, training materials, and smartphone-based agricultural advisories (Bourke, 2010; World Bank, 2021).

- **Gender Gaps in Access to Training and CSA-Related Resources:** Women in PNG play a central role in agriculture, especially in subsistence production and market gardening. However, due to cultural norms and time burdens from unpaid care work, they are often excluded from training programs, access to improved technologies, land rights, and financial services (FAO, 2022; ACIAR, 2021).

D. Infrastructure Barriers

- **Poor Rural Road Networks Hinder Farmer Access to Markets, Inputs, and Services:** Many rural areas in Papua New Guinea are isolated due to poorly maintained road networks, particularly in the Highlands, Momase, and island provinces. Seasonal flooding, landslides, and the absence of all-weather roads make it difficult for farmers to transport goods, access inputs, and receive technical support. As a result, CSA practices that rely on timely delivery of agricultural inputs or access to markets, such as high-value perishable crops, are severely constrained (ADB, 2024).

- **Inadequate Post-Harvest Storage and Processing Infrastructure:** Many of PNG's smallholder farmers lack access to post-harvest infrastructure such as drying facilities, storage sheds, and basic crop processing tools. This contributes to high post-harvest losses—up to 30–50% for crops like vegetables and tubers—and limits income from surplus production. Without reliable storage, farmers have little incentive to adopt CSA innovations that increase yield or harvest volume (FAO, 2022).

- **Limited Irrigation Systems and Water Harvesting Facilities:** Less than 2% of PNG's agricultural land is irrigated, and rainfed agriculture dominates in both subsistence and commercial farming systems. During dry spells or El Niño events, farmers are often unable to maintain crop production due to the absence of small-scale irrigation systems, rainwater harvesting infrastructure, or groundwater use options. This barrier directly undermines the potential of CSA practices that require water reliability, such as high-yield cropping or dry season cultivation (GoPNG, 2020b; World Bank, 2021).

- **Unreliable Electricity and Mobile Coverage in Isolated Communities:** Only about 13% of rural households in PNG have access to electricity, and mobile phone coverage is still limited in many inland and island communities (ADB, 2019). This digital and energy divide prevents farmers from benefiting from cold storage systems, agro-processing equipment, and mobile-based CSA services such as weather forecasts, early warning systems, and market price alerts. Moreover, many CSA innovations increasingly rely on digital extension platforms and ICT-based decision tools that are not feasible in low-connectivity settings (GoPNG 2021).

E. Institutional and Organizational Capacity Barrier

- **Weak Coordination Across Key Ministries (Agriculture, Environment, Finance) :** Inter-agency collaboration in PNG remains weak and fragmented, which leads to overlapping mandates, policy inconsistencies, and inefficiencies in resource allocation (GoPNG, 2020b).

- **Limited Support for Farmer Groups or Cooperatives Implementing CSA Initiatives:** Farmer groups, cooperatives, and community-based organizations can often operate informally in PNG with little legal or financial support. Many lack access to capacity-building, revolving credit, and infrastructure to scale their impact (FAO, 2022).

- **Under-Resourced Public Agricultural Institutions:** Key public institutions, such as DAL, NARI, and NAQIA, face persistent funding shortfalls, outdated infrastructure, and limited staffing.

- **Slow or Inconsistent Execution of Climate Adaptation Programs at Local Levels:** Despite national-level commitments through the National Adaptation Plan (NAP) and Climate Compatible Development plans, provincial and district-level implementation remains slow and uneven. This is due to limited budget decentralization, bureaucratic delays, and capacity gaps in subnational governments (ADB, 2024).

F. Social, Cultural, and Information Barriers

- **Cultural resistance to change from traditional practices:** Agriculture is not just a livelihood but a cultural identity, deeply tied to land, clan structure, and ancestral practices. Traditional planting calendars, crop varieties, and land preparation methods are passed down through generations. As such, introducing CSA practices is often resisted, especially when perceived as foreign or contrary to customary norms (Bourke, 2010).

- **Gender norms restricting women's participation in CSA initiatives:** Women in PNG play a central role in food production, but often face cultural and social barriers to participating in training programs, farmer groups, and decision-making processes. Traditional gender roles often exclude women from land ownership and extension services (FAO, 2022; ACIAR, 2021). Furthermore, time constraints due to household responsibilities limit their ability to attend CSA trainings.

- **Limited intergenerational transfer of modern agricultural knowledge:** While traditional knowledge is still passed between generations, younger generations are increasingly disconnected from farming due to migration to urban centers or loss of interest in agriculture. At the same time, the transfer of modern CSA knowledge from trained older farmers or extension officers to youth is limited by the lack of formal platforms, digital access, or youth-focused agricultural programming (World Bank, 2021).

- **Perception of CSA practices as risky or unproven:** CSA practices require upfront investment—such as soil amendments, improved seeds, or new planting systems—may be seen as economically risky, especially in the absence of guarantees or proven demonstrations (GoPNG, 2020b), without trust in outcomes or visible local success stories, farmers are hesitant to adopt.

- **Low trust in government or external programs:** Decades of inconsistent service delivery, donor fatigue, and perceived corruption have contributed to low trust in government-led agricultural programs and foreign interventions in many communities. Farmers may be reluctant to engage with CSA programs if they believe they will be short-lived or politically motivated (ADB, 2024).

G. Information and Awareness Barriers

- **Limited Awareness of CSA Benefits Among Farmers and Communities:** Many smallholder farmers in PNG are unfamiliar with the concept of Climate-Smart Agriculture and its potential benefits—such as increased yields, improved resilience to droughts and floods, and reduced soil degradation. Without clear understanding or visible success stories, CSA is often seen as unnecessary or too risky. This low awareness level undermines adoption rates, particularly in remote or underserved areas.

- **Poor Dissemination of Climate and Weather Information to Rural Areas:** PNG's rural farmers often lack access to timely and localized climate information—such as rainfall forecasts, cyclone alerts, or planting advisories—which are essential for CSA decision-making. The limited reach of the PNG National Weather Service, coupled with infrastructure challenges (e.g., no mobile or radio signal), prevents critical weather updates from reaching farmers in time.

- **Lack of Access to Agricultural Extension Services:** Extension services in PNG are severely under-resourced. With a very low ratio of extension officers to farming households (often fewer than 1 per 1,000 farmers), many communities receive little to no formal guidance on CSA practices. Additionally, logistical challenges and budget constraints limit extension visits to remote areas.

- **Language and Literacy Barriers in Communicating CSA Messages:** PNG is home to over 800 languages, and literacy rates are low in many rural regions. Most CSA materials are written in English or Tok Pisin and are often too technical or text-heavy for communities with oral knowledge traditions. This limits comprehension and engagement, especially among women and elders who may have lower literacy levels.

- **Inadequate Early Warning Systems for Climate-Related Events:** Early Warning Systems (EWS) in PNG are underdeveloped and not fully integrated with agricultural decision-making. Many communities do not receive advance alerts for extreme weather events such as floods, droughts, or frosts, or lack training to respond. Additionally, CSA advisories (e.g., when to plant or harvest based on forecasts) are not embedded into EWS platforms.

Table 3 below provides a comprehensive summary of the various barriers associated with Climate-Smart Agriculture (CSA) technology. It includes detailed scoring derived from discussions and evaluations during the stakeholder workshop, highlighting the challenges identified by participants while assessing the feasibility and implementation of CSA practices.

Table 3 List of Barriers to CSA in PNG

Barrier Factors	Score
1. Economic and Financial Barriers	
High initial investment costs for CSA technologies (e.g., drip irrigation, improved seed varieties).	4
Limited access to credit and financial services for smallholder farmers.	3
Weak private sector investment in CSA-aligned agribusiness and innovation.	3
Dependence on subsistence farming, limiting capital accumulation and reinvestment.	4
2. Policy, Legal, and Regulatory Barriers	
Lack of a National CSA Policy or Implementation Strategy	3
Fragmented Agricultural, Food Security, and Climate Change Policies	3
Weak land tenure security, especially under customary land ownership (over 90% of land in PNG).	5
Limited policy incentives (e.g., tax breaks or subsidies) for CSA adoption.	4
3. Technical Barriers	
Limited availability of CSA technologies suited to local conditions (e.g., climate-resilient crops).	3
Inadequate research into locally adapted CSA methods.	3
Outdated Farm Tools and Low Mechanisation Levels	3
Limited access to weather/climate-resilient inputs like drought-tolerant seeds.	3
Weak linkages between research institutions and farmers.	4
4. Human Resource Barriers	
Lack of trained extension officers with CSA knowledge.	4
Limited farmer training programs on CSA techniques.	3
High turnover and low capacity among agricultural staff.	3
Low literacy and education levels in rural farming communities.	3
Gender gaps in access to training and CSA-related resources.	3
5. Infrastructure Barriers	
Poor rural road networks, limiting access to markets and agricultural inputs.	3
Inadequate storage and processing facilities, affecting post-harvest management.	4
Limited access to irrigation infrastructure and water conservation systems.	4
Unreliable electricity and communication networks in remote areas.	4
6. Institutional and Organizational Capacity Barriers	
Weak local governance structures and decentralization challenges.	4
Limited support for farmer cooperatives or groups promoting CSA.	4
Under-resourced agricultural institutions (budget, staffing, training).	4
Slow implementation and monitoring of climate adaptation programs.	3
7. Social, Cultural, and Behavioural Barriers	
Cultural resistance to change from traditional practices.	3
Gender norms restricting women's participation in CSA initiatives.	2
Limited intergenerational transfer of modern agricultural knowledge.	4
Perception of CSA practices as risky or unproven.	2
Low trust in government or external programs.	4
8. Information and Awareness Barriers	

Barrier Factors	Score
Limited awareness of CSA benefits among farmers and communities.	4
Poor dissemination of climate and weather information to rural areas.	4
Lack of access to agricultural extension services.	4
Language and literacy barriers in communicating CSA messages.	4
Inadequate early warning systems for climate-related events.	4

A total of 20 barriers met this criterion, including 19 rated as Significant (score 4) and one rated as Very Significant (score 5). These barriers, drawn from multiple thematic categories, are summarized below:

1. Economic and Financial Barriers
- High initial investment costs for CSA technologies – **4**
- Dependence on subsistence farming, limiting reinvestment – **4**

2. Policy, Legal, and Regulatory Barriers
- **Weak land tenure security** (customary land ownership) – **5**
- Limited policy incentives (e.g., tax breaks or subsidies) – **4**

3. Technical Barriers
- Weak linkages between research institutions and farmers – **4**

4. Human Resource Barriers
- Lack of trained extension officers with CSA knowledge – **4**

5. Infrastructure Barriers
- Inadequate storage and processing facilities – **4**
- Limited access to irrigation and water conservation systems – **4**
- Unreliable electricity and communication networks in remote areas – **4**

6. Institutional and Organizational Capacity Barriers
- Weak local governance structures and decentralization – **4**
- Limited support for farmer cooperatives or CSA groups – **4**
- Under-resourced agricultural institutions – **4**

7. Social, Cultural, and Behavioural Barriers
- Limited intergenerational transfer of modern knowledge – **4**
- Low trust in government or external programs – **4**

8. Information and Awareness Barriers
- Limited awareness of CSA benefits – **4**
- Poor dissemination of weather and climate information – **4**
- Lack of access to agricultural extension services – **4**
- Language and literacy barriers in CSA communication – **4**
- Inadequate early warning systems – **4**

The single very significant barrier—weak land tenure security under customary ownership—emerges as a foundational constraint, affecting investment confidence, access to credit, and long-term land management decisions. Meanwhile, other significant barriers such as high upfront costs, lack of trained extension personnel, inadequate irrigation and storage infrastructure, and low trust in government programs reveal the operational, institutional, and behavioral complexities faced by farmers and stakeholders alike.

By focusing on these high-impact barriers, the analysis provides a clear and evidence-based foundation for designing targeted enabling measures. Addressing these constraints is essential not only for facilitating the diffusion of CSA technologies but also for strengthening the overall resilience, inclusivity, and productivity of PNG's agricultural sector in the face of climate change

1.2.3 Identified Measures for Technology Climate-Smart Agriculture (CSA)

Identified measures for CSA technology are designed to overcome a wide range of economic, institutional, regulatory, technical, and socio-cultural constraints that limit the implementation of CSA in PNG. These interventions aim to support the implementation of CSA. The measures are structured to reflect the diverse needs of PNG's predominantly rural and subsistence-based farming population and are aligned with national development priorities and adaptation goals.

Based on the identified significant and very significant barriers, the following measures (**Table 4)** are proposed to address key constraints to the adoption of Climate-Smart Agriculture (CSA) technologies.

Table 4 Identified Measured for CSA Technology

Category	Barrier Description	Identify measure
Economic and Financial	High initial investment costs for CSA technologies	Establish CSA innovation grants or subsidies; Introduce blended finance mechanisms
Economic and Financial	Dependence on subsistence farming, limiting reinvestment	Promote income diversification (e.g., agroforestry, poultry, beekeeping)
Policy, Legal, and Regulatory	Weak land tenure security (customary land ownership)	Pilot community-based land registration; Legal recognition of customary land use agreements
Policy, Legal, and Regulatory	Limited policy incentives (e.g., tax breaks or subsidies)	Offer tax deductions or subsidies for CSA equipment and inputs
Technical	Weak linkages between research institutions and farmers	Launch research-extension-farmer platforms for knowledge exchange
Human Resource	Lack of trained extension officers with CSA knowledge	Integrate CSA into agricultural training colleges and certification programs
Infrastructure	Inadequate storage and processing facilities	Promote community-managed storage facilities with solar-powered cold rooms
Infrastructure	Limited access to irrigation and water conservation systems	Scale up low-cost water harvesting and drip irrigation systems
Infrastructure	Unreliable electricity and communication networks in remote areas	Support off-grid solar installations; Partner with telecoms for rural signal expansion
Institutional and Organizational	Weak local governance structures and decentralization	Provide technical assistance to local governments to develop CSA plans and budgets
Institutional and Organizational	Limited support for farmer cooperatives or CSA groups	Facilitate access to credit, training, and markets for farmer organizations

Category	Barrier Description	Identify measure
Institutional and Organizational	Under-resourced agricultural institutions	Increase public budget allocations and donor co-financing for CSA
Social, Cultural, and Behavioural	Limited intergenerational transfer of modern knowledge	Develop youth-led extension programs and promote CSA clubs in schools
Social, Cultural, and Behavioural	Low trust in government or external programs	Involve farmers in project planning and ensure transparency in fund use
Information and Awareness	Limited awareness of CSA benefits	Launch multi-media CSA awareness campaigns (radio, TikTok, village meetings)
Information and Awareness	Poor dissemination of weather and climate information	Partner with Met Services to deliver localized agro-weather forecasts via SMS or radio
Information and Awareness	Lack of access to agricultural extension services	Deploy digital extension platforms (voice/text apps in local languages)
Information and Awareness	Language and literacy barriers in CSA communication	Use visual and oral tools like storytelling and drama to communicate CSA practices
Information and Awareness	Inadequate early warning systems	Integrate CSA advisories into existing EWS and train communities on response actions

1.3 Barrier Analysis and Possible Enabling Measures for Climate Information and Early Warning Systems (CIEWS)

1.3.1 General Description of Climate Information and Early Warning Systems (CIEWS)

Climate Information and Early Warning Systems (CIEWS) in Papua New Guinea (PNG) refer to integrated networks of meteorological, hydrological, and community-based systems designed to monitor, forecast, and communicate climate-related risks. These systems are increasingly vital in PNG due to the country's high exposure to extreme climate events such as El Niño-induced droughts, intense rainfall, flooding, cyclones, and landslides—events that severely affect rural livelihoods, food production, infrastructure, and public health (GoPNG, 2023; ADB, 2024).

Climate Information and Early Warning Systems (CIEWS) in agriculture involve collecting, analysing, and disseminating timely weather and climate forecasts, agro-advisories, and disaster alerts. These systems are critical in PNG, where unpredictable rainfall, floods, and dry spells can devastate crop production and food availability.

CIEWS in PNG would leverage a combination of traditional knowledge and scientific data, disseminated via:

- Mobile phone alerts (SMS-based advisories)
- Community radio broadcasts and posters

- Village-based climate information boards
- Farmer training on interpreting and acting on weather forecasts

CIEWS must be tailored to the linguistic and literacy diversity across PNG's provinces, requiring close collaboration with local institutions, including the PNG National Weather Service (NWS), NARI, and local governments.

As illustrated in **Figure 1**, an effective drought early warning system, which is a core subset of CIEWS, provides multiple benefits to the agriculture sector in PNG. These include minimizing crop and yield loss, avoiding food shortages and famine, and protecting both surface and groundwater resources through timely irrigation planning. Moreover, CIEWS help sustain agricultural contributions to national GDP, maintain ecosystem functions, and prevent soil degradation and desertification. These interconnected benefits demonstrate how climate information systems support resilient agricultural development by ensuring early action and informed decision-making at both community and policy levels.

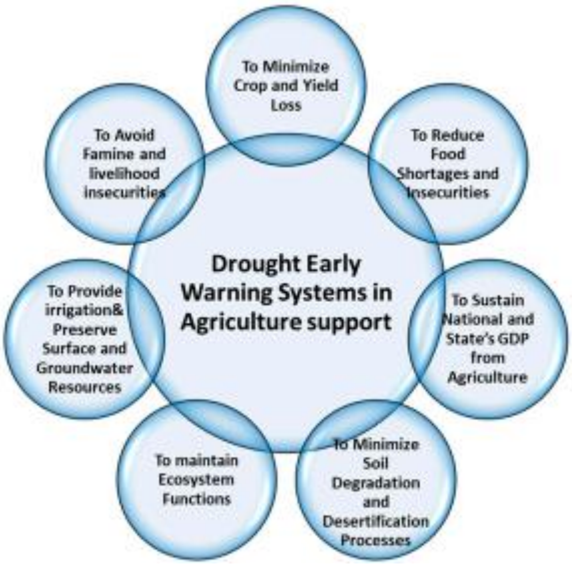

Figure 1 Drought Early Warning System as a Weather Smart Option in Climate Change and Agriculture

(Dhanya Praveen and Geethalakshmi Vellingiri, 2023)

In the agriculture sector, Climate Information and Early Warning Systems (CIEWS) in Papua New Guinea are increasingly integrated into community-level advisory services. For instance, seasonal weather forecasts and agro-climatic bulletins are disseminated in Tok Pisin and local dialects via FM radio, church networks, and agriculture extension officers. These services support critical on-farm decisions such as planting schedules, crop variety selection, harvest timing, and climate-related risk preparedness ((Bourke and Harwood, 2009)

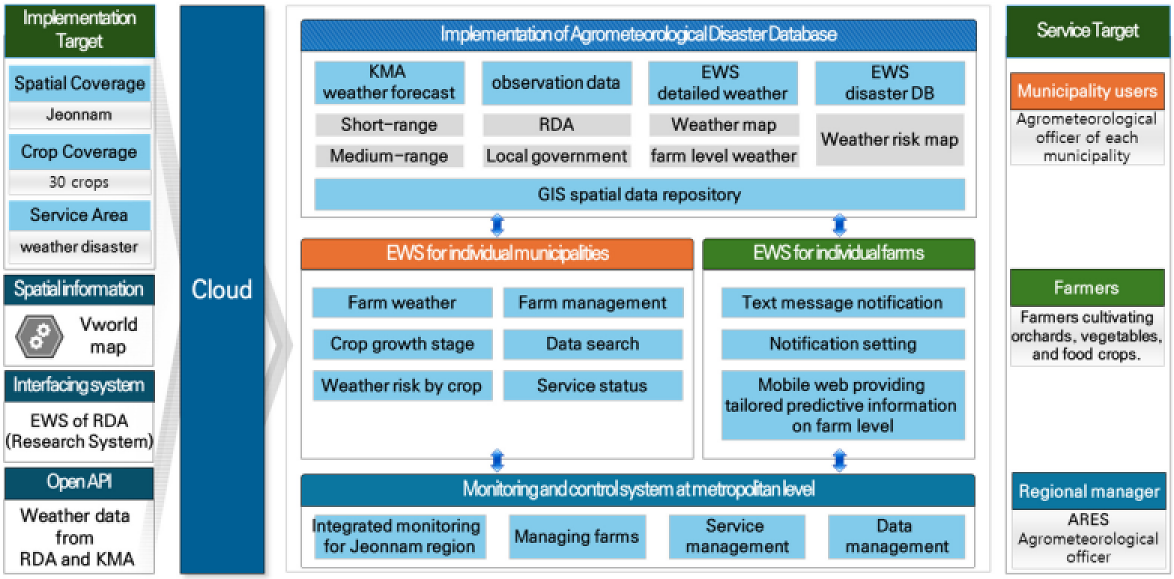

Figure 2 The system architecture diagram pf CIEWS Model
(Shin et al., 2025)

The diagram illustrates in **Figure 2** shows a comprehensive **CIEWS model** similar to what could be adapted in PNG. It includes components such as:

- Weather and observation data repositories (from national and regional services),
- GIS-based spatial data platforms for risk mapping,
- Early warning systems (EWS) tailored for both municipalities and individual farms,
- Direct mobile alerts and web-based dashboards to inform farm-level actions.

Similar to the implementation in Jeonnam, South Korea (shown in **Figure 2**), projects in PNG, such as SPREP's Community Climate Information Centres (CCICs), have begun to link scientific forecasts with traditional knowledge systems in areas like East Sepik and the Highlands. These localized systems aim to replicate risk-based forecasting, crop growth stage tracking, and farm management support, helping bridge the communication gap between national meteorological services and rural farmers. However, challenges remain. PNG continues to face limited coverage of meteorological infrastructure, low digital literacy, and fragmented coordination among sectors and agencies. This is identified in the National Adaptation Plan (NAP, 2023) and the Technology Needs Assessment (TNA, 2025).

Table 5 Summary of Market Characteristics of the CIEWS Technologies

Technology	**Market Type**	**Description**
Climate Information Systems (CIEWS)	Publicly Provided Good	Managed by national weather agencies and public institutions.
Mobile/SMS Forecast Dissemination Tools part of CIEWS	Hybrid (Public/Private)	Operated through partnerships with telecoms and agriculture departments.

Notes:

- CIEWS is a foundational public good but requires localisation and co-production with communities for trust and usability.
- Combining both technologies enhances anticipatory capacity and on-farm adaptive action.

1.3.2 Identification of Barriers for Climate Information and Early Warning Systems (CIEWS)

The identification of barriers to the adoption of Climate Information and Early Warning Systems (CIEWS) in Papua New Guinea was conducted through a structured assessment involving literature review, expert interviews, and stakeholder consultations with the National Steering Committee (NSC) and Sectoral Working Groups (SWGs). This process aimed to determine the key challenges that hinder the implementation, integration, and upscaling of CIEWS across priority sectors such as agriculture, health, and disaster risk reduction.

1.3.2.1 Economic and Financial Barriers

- **Inadequate Funding for Climate Monitoring Systems:** The lack of funding for climate monitoring systems in PNG makes it hard to install, run, and maintain key tools like weather stations, water gauges, and radar. The PNG National Weather Service and other agencies are often dependent on ad hoc development assistance to cover basic operations (GoPNG, 2023; SPREP, 2021).

- **High Cost of Technology Beyond Public and Private Reach**: The acquisition and deployment of advanced climate technologies, such as satellite-based remote sensing, Doppler radar, or climate data modelling tools, are prohibitively expensive for both public institutions and private actors in PNG (WMO, 2021; GoPNG, 2020).

- **Absence of Financial Sustainability Mechanisms**: In Papua New Guinea, many early warning systems are funded by donors and run as short-term projects. They bring helpful tools like climate info centers and radio bulletins, but they often don’t have long-term support. When donor money runs out, these projects usually stop or slow down (GoPNG, 2020)

1.3.2.2 Non-Financial Barriers

A. Policy, Legal, and Regulatory Barriers

- **Lack of a National Framework Integrating CIEWS with Agriculture:** Papua New Guinea lacks a unified national policy framework integrating climate information services with key sectors such as agriculture, health, and disaster risk management. While climate adaptation and agriculture policies exist separately, they are rarely harmonized to ensure that farmers and rural communities benefit from timely and actionable climate information. This policy gap limits the mainstreaming of CIEWS into agriculture extension programs, food security planning, and local disaster preparedness systems (GoPNG, 2023)

- **Fragmented Responsibilities and Overlapping Mandates**: Overlapping agencies mandates between NWS, DAL, NDC, and CCDA result in weak coordination and duplicative efforts, misaligned priorities, and inefficiencies in the development and dissemination of climate services (SPREP, 2021; GoPNG, 2020a).

- **Weak Legal Enforcement:** Climate-related laws and frameworks exist but are not implemented effectively due to institutional and regulatory weaknesses. (ADB, 2021; GoPNG, 2023)

- **No Obligation for Data Sharing Across Institutions:** Lack of regulatory frameworks enforcing inter-agency data exchange leads to fragmented and ineffective early warning systems (WMO, 2021; GoPNG 2020).

B. Technical Barriers

- **Limited Coverage and Granularity of Forecasting:** Most of PNG's current meteorological infrastructure is centralized in urban or provincial capitals, such as Port Moresby and Lae. These systems produce generalized national or regional forecasts that do not reflect the climatic variability experienced across the country's highly diverse topography and microclimates. As a result, rural communities—particularly in remote highlands or coastal areas—receive limited or irrelevant information, reducing the effectiveness of forecasts for local agricultural, disaster preparedness, or public health decisions (WMO, 2021; GoPNG, 2023).

- **Lack** of **Localized Climate Modelling**: Papua New Guinea lacks the technical capacity, computational infrastructure, and skilled personnel to produce high-resolution and downscaled climate models that are essential for early warning at the local level (GoPNG, 2020a; SPREP, 2021).

- **Inability to Incorporate Traditional Knowledge:** Traditional weather forecasting in PNG—based on natural indicators like animal behavior, plant cycles, and cloud patterns—remains a vital information source for many rural communities. However, there is currently no structured methodology to integrate these indigenous systems into formal CIEWS. The lack of mutual recognition between scientific and traditional knowledge systems undermines cultural acceptance, trust, and ultimately, the uptake of climate information services in local communities (Nalau et al., 2018)

C. Human Resources Barriers

- **Shortage of Skilled Personnel:** The country has a limited trained meteorologist, agro-meteorologists, hydrologists, climate modellers, and communication specialists. The shortage of skilled personnel is further exacerbated by the lack of advanced academic programs in climate science and insufficient incentives to retain skilled professionals in the public sector (WMO, 2019; GoPNG, 2023).

- **Limited Extension Capacity**: Agricultural extension officers play a crucial role in linking scientific climate information with end-users—especially farmers in rural and remote communities. However, in PNG, many extension officers are not trained to interpret seasonal forecasts, probabilistic models, or agro-climatic advisories. As a result, the communication of climate information often remains too technical or generic to support timely and actionable decisions by farmers (Bourke and Harwood, 2009)

D. Infrastructure Barriers

- **Sparse and Outdated Observation Networks:** Papua New Guinea's national meteorological infrastructure is critically underdeveloped. Many existing weather stations, especially those outside urban centers, are outdated, non-functional, or poorly maintained due to limited technical capacity and funding (WMO, 2021; GoPNG, 2023).

- **Lack of Rural Connectivity:** A significant number of farming communities in PNG do not have access to basic communication infrastructure such as mobile phone networks, radio signals, or the internet. The climate information often cannot reach the last mile, particularly in remote mountainous or island regions (GoPNG, 2020a; SPREP, 2021).

- **Insufficient Power Supply:** Many remote observation sites lack access to grid electricity or reliable solar power systems, resulting in frequent equipment downtimes. Without a consistent power supply, critical instruments such as automated weather stations, satellite receivers, and data loggers cannot function effectively, reducing the availability and quality of real-time climate data (ADB, 2021; WMO, 2019).

- **Poor Physical Access:** Poor road conditions and inadequate transport infrastructure in many parts of PNG create logistical challenges for installing, servicing, and repairing climate monitoring stations. In some regions, technical teams must travel by foot or boat, increasing maintenance costs and causing delays that further compromise system performance and coverage (GoPNG, 2023; ACIAR, 2021).

E. Institutional and Organizational Capacity Barriers

- **Weak Inter-Agency Coordination:** The responsible institution like PNG-NWS, DAL, and NDC often rarely engage in joint planning or integrated service delivery (GoPNG, 2023; GoPNG, 2020a).

- **Insufficient Institutional Mandates:** Some agencies involved in climate-sensitive sectors lack a clear legal or institutional mandate to deliver climate services. This lack of mandate leads to gaps in service delivery and poor alignment with community-level demands (SPREP, 2021).

- **Lack of Protocols and SOPs:** Standardized operating procedures (SOPs), protocols, and formal agreements for the collection, analysis, dissemination, and response to climate information are largely absent in PNG. Without clear protocols, many early warnings do not trigger structured action or follow-up at the local or provincial level (WMO, 2021; ADB, 2021).

F. Social, Cultural, and Information Barrier

- **Cultural Reliance on Traditional Indicators:** Many rural and Indigenous communities in PNG have long relied on traditional ecological knowledge (TEK) and natural signs—such as the behavior of animals, cloud patterns, or flowering of specific plants—to predict seasonal weather. The preference for ancestral methods of weather prediction may lead to mistrust of scientific forecasts. (Nalau et al., 2018)

- **Low Risk Perception:** Many farmers in PNG do not perceive climate risks (e.g. droughts, floods) as immediate threats or do not act on early warnings. This behavioural inertia reduces responsiveness, even when accurate forecasts are available (GoPNG 2020).

- **Gender Disparities in Access to Information:** In many parts of PNG, women and marginalized groups (e.g., people with disabilities, isolated tribes) face systemic barriers to receiving timely climate information. These groups often lack access to formal communication tools—such as mobile phones, radios, or community meetings dominated by male voices—and may be excluded from agricultural training or extension services (GoPNG, 2023)

- **Language and Dialect Diversity:** Papua New Guinea is home to over 800 languages and dialects, making it one of the most linguistically diverse countries in the world. This presents a significant challenge for the standardization, translation, and dissemination of climate information across regions. Messages may be misunderstood or not received at all if they are not delivered in locally appropriate languages and formats, limiting the reach and impact of early warnings (SPREP, 2021; WMO, 2021)

G. Information and Awareness Barriers

- **Limited Public Awareness Campaigns:** Many rural communities in Papua New Guinea are unaware that climate information services exist or that such information can inform their decisions regarding farming, fishing, or disaster preparedness. National-level efforts to raise awareness have been limited in scope and reach, especially outside urban centers (GoPNG, 2023; GoPNG, 2020a).

- **Ineffective Communication Channels:** Even when accurate forecasts or warnings are produced, they often fail to reach end users on time or in actionable formats. Communication pathways—such as FM radio, SMS, or public loudspeakers—are inconsistently used or not tailored to the local context (SPREP, 2021)

- **Low Interpretation Skills:** Many smallholder farmers in PNG are not trained to understand probabilistic forecasts or agro-advisories (e.g., interpreting rainfall likelihood or the timing of El Niño events). Without sufficient explanation or local extension support, information may not lead to meaningful action (WMO, 2021).

- **Lack of Trust Due to Forecast Inaccuracy:** Inconsistent or inaccurate forecasts in the past—caused by limited data coverage or flawed modeling—have led to distrust in official climate information systems (Nalau et al., 2018)

Table 6 below provides a comprehensive summary of the various barriers associated with Climate Information and Early Warning Systems (CIEWS) technology. It includes detailed scoring derived from discussions and evaluations during the stakeholder workshop. It highlights the challenges identified by participants while assessing the feasibility and implementation of Climate Information and Early Warning Systems (CIEWS) practice.

Table 6 List of Barrier to Climate Information and Early Warning Systems (CIEWS)

Barrier Factors	Score
Economic and Financial Barriers	
Inadequate funding for climate monitoring systems	4
High cost of technology often beyond the reach of public and private stakeholders.	4
Absence of financial sustainability mechanisms as Many CIEWS projects rely on short-term donor funding	4
Policy, Legal, and Regulatory Barriers	
Lack of a national framework integrating CIEWS with agriculture	4
Fragmented responsibilities: Different agencies (e.g., National Weather Service, Department of Agriculture and Livestock, National Disaster Centre) have overlapping or unclear mandates, causing coordination challenges.	4
Weak legal enforcement: Even where climate-related laws or policies exist, enforcement is often weak due to limited institutional capacity or unclear regulatory authority.	4
No obligation for data sharing across institutions.	3
Technical Barriers	
Limited coverage and granularity of forecasting: Most of PNG's existing meteorological systems are centralized, providing generalized forecasts that are not tailored to specific microclimates or agroecological zones.	4
Lack of localized climate modelling	4
Inability to incorporate traditional knowledge: The lack of methodologies for integrating traditional weather forecasting knowledge into modern CIEWS limits cultural relevance and uptake.	4
Human Resource Barriers	
Shortage of skilled personnel: PNG has a limited pool of trained meteorologists, agro meteorologists, climate modelers, and communication specialists.	3
Limited extension capacity: Agricultural extension officers are often not trained to interpret or deliver climate forecasts and early warnings in ways that farmers can act on.	4
Infrastructure Barriers	
Sparse and outdated observation networks: Many meteorological stations are non-functional or poorly maintained, leading to gaps in data collection and weak early warning signals.	4
Lack of rural connectivity: Many farming communities lack access to mobile networks, radio, or the internet, which can impede the timely receipt of weather alerts or forecasts.	4
Insufficient power supply: Remote stations often lack reliable electricity or solar backup, which affects equipment operation and data transmission.	4
Poor physical access: Inadequate roads and transport infrastructure delay climate monitoring equipment installation, repair, and maintenance.	4
Institutional and Organizational Capacity Barriers	
Weak inter-agency coordination: The agriculture, meteorology, and disaster risk management sectors often operate in silos with limited communication or joint planning.	3

Barrier Factors	Score
Insufficient institutional mandates: Some agencies lack a clear role or authority to deliver climate services to the agricultural sector.	3
Lack of protocols and SOPs: Few standardized operating procedures or agreements exist for collecting, analyzing, disseminating, or responding to climate information.	4
Social, Cultural, and Behavioural Barriers	
Cultural reliance on traditional indicators: Many farming communities rely on ancestral or observational methods for predicting weather and may distrust modern forecasts.	2
Low-risk perception: Farmers may not perceive climate risks as urgent or act on early warnings due to fatalism or past false alarms.	3
Gender disparities in access to information: Women and marginalized groups may have less access to formal communication channels like radio, community meetings, or mobile alerts.	4
Language and dialect diversity: PNG's linguistic diversity (over 800 languages) presents a huge barrier in standardizing messages across regions.	4
Information and Awareness Barriers	
Limited public awareness campaigns: Many farmers do not know that tailored climate information services exist, or how to use them in decision-making.	3
Ineffective communication channels: Even when forecasts or warnings are generated, they may not reach the end-users on time or in understandable formats.	4
Low interpretation skills: Farmers may receive weather information but not know how to act on it (e.g., when to plant, irrigate, or harvest).	4
Lack of trust due to forecast inaccuracy: Previous experiences with inaccurate forecasts can reduce trust and lead to underuse of future warnings.	3

A total of 19 barriers were identified as Very Significant (score 4) across multiple thematic categories. These barriers highlight critical constraints to the effective implementation of CIEWS in PNG and are summarized below:

1. Economic and Financial Barriers

- Inadequate funding for climate monitoring systems – **4**
- High cost of technology often beyond the reach of public and private stakeholders – **4**
- Absence of financial sustainability mechanisms due to reliance on short-term donor funding – **4**

2. Policy, Legal, and Regulatory Barriers

- Lack of a national framework integrating CIEWS with agriculture – **4**
- Fragmented responsibilities among agencies causing coordination challenges – **4**
- Weak legal enforcement due to limited institutional capacity – **4**

3. Technical Barriers

- Limited coverage and granularity of forecasting – **4**
- Lack of localized climate modelling – **4**
- Inability to incorporate traditional knowledge – **4**

4. Human Resource Barriers

- Limited extension capacity: Extension officers not trained to deliver actionable climate information – **4**

5. Infrastructure Barriers

- Sparse and outdated observation networks – **4**
- Lack of rural connectivity (mobile, radio, internet) – **4**
- Insufficient power supply at remote stations – **4**
- Poor physical access for equipment installation, repair, and maintenance – **4**

6. Institutional and Organizational Capacity Barriers

- Lack of protocols and standard operating procedures (SOPs) – **4**

7. Social, Cultural, and Behavioural Barriers

- Gender disparities in access to information – **4**
- Language and dialect diversity hindering standardized communication – **4**

8. Information and Awareness Barriers

- Ineffective communication channels for forecasts and warnings – **4**
- Low interpretation skills among users on how to apply forecast information – **4**

The significant barriers identified for Climate Information and Early Warning Systems (CIEWS) in Papua New Guinea highlights deep-rooted systemic and operational challenges across economic, technical, institutional, and social domains. Notably, core constraints include inadequate funding and unsustainable financing models, fragmented policy mandates, outdated forecasting infrastructure, limited rural connectivity, and the absence of localized and culturally relevant forecasting tools. These are compounded by weak extension services, gender and language-based information gaps, and low end-user capacity to interpret or act on forecasts.

By concentrating on these high-priority barriers, the analysis offers a robust basis for developing well-targeted enabling measures that improve the accuracy, accessibility, and trustworthiness of climate information. Overcoming these barriers is not only vital for enhancing the reach and effectiveness of CIEWS but also pivotal for building climate resilience across PNG's agriculture, disaster risk management, and rural development sectors.

1.3.3 Identified Measures for Climate Information and Early Warning Systems (CIEWS)

Identified measures for Climate Information and Early Warning Systems (CIEWS) are designed to address a broad spectrum of economic, institutional, regulatory, technical, infrastructural, and socio-cultural constraints that hinder the development, delivery, and uptake of CIEWS in Papua New Guinea.

The proposed measures are tailored to PNG's predominantly rural, linguistically diverse, and subsistence-based communities' unique needs, ensuring equitable access to timely and actionable climate information. Importantly, these measures are aligned with PNG's national development priorities, climate adaptation goals, and sectoral plans, such as the National Adaptation Plan (NAP, 2023) and the Disaster Risk Reduction Framework, to promote resilience and reduce vulnerability to climate-related hazards.

Based on the identified significant barriers, the following measures **(Table 7)** are proposed to address key constraints to the adoption of Climate Information and Early Warning Systems (CIEWS) technologies.

Table 7 Identified Measured for CIEWS Technology

Category	Barrier Description	Identify measure
Economic and Financial Barriers	Inadequate funding for climate monitoring systems	Integrate CIEWS into national climate finance strategies (e.g., NDCs, NAPs) and secure GCF/GEF support
Economic and Financial Barriers	High cost of technology often beyond the reach of public and private stakeholders	Promote regional procurement and deploy low-cost, community-based weather stations
Economic and Financial Barriers	Absence of financial sustainability mechanisms due to reliance on short-term donor funding	Establish dedicated budget lines and attract CSR investment for CIEWS maintenance
Policy, Legal, and Regulatory Barriers	Lack of a national framework integrating CIEWS with agriculture	Develop a national Agri-CIEWS strategy aligned with NAP and food security plans
Policy, Legal, and Regulatory Barriers	Fragmented responsibilities among agencies causing coordination challenges	Create a national CIEWS roadmap defining roles, timelines, and funding sources
Policy, Legal, and Regulatory Barriers	Weak legal enforcement due to limited institutional capacity	Strengthen legal mandates and adopt enforceable legislation for climate information dissemination
Technical Barriers	Limited coverage and granularity of forecasting	Install community-level AWS and improve agroecological mapping
Technical Barriers	Lack of localized climate modelling	Train national experts in downscaled forecasting using participatory tools like PICSA and ODK
Technical Barriers	Inability to incorporate traditional knowledge	Integrate indigenous indicators with scientific forecasting through hybrid models
Human Resource Barriers	Limited extension capacity: Extension officers not trained to deliver actionable climate information	Train extension workers and provide toolkits integrating forecasts with farming advice
Infrastructure Barriers	Sparse and outdated observation networks	Rehabilitate weather stations with upgraded sensors and mobile monitoring kits
Infrastructure Barriers	Lack of rural connectivity (mobile, radio, internet)	Partner with telecom providers and explore satellite-based alert systems
Infrastructure Barriers	Insufficient power supply at remote stations	Install solar-powered backup systems for AWS and communication nodes
Infrastructure Barriers	Poor physical access for equipment installation, repair, and maintenance	Integrate logistics and resilient infrastructure into rural development planning
Institutional and Organizational Capacity Barriers	Lack of protocols and standard operating procedures (SOPs)	Develop and disseminate SOPs for planning, response, and feedback loops

Category	Barrier Description	Identify measure
Social, Cultural, and Behavioural Barriers	Gender disparities in access to information	Ensure inclusive outreach using women□□□s groups and tailored communication channels
Social, Cultural, and Behavioural Barriers	Language and dialect diversity hindering standardized communication	Use multilingual, voice-based, and symbolic messaging formats for alerts
Information and Awareness Barriers	Ineffective communication channels for forecasts and warnings	Use multi-channel delivery (SMS, radio, posters) and public notice boards
Information and Awareness Barriers	Low interpretation skills among users on how to apply forecast information	Provide simplified, visual translations of advisories and build local trust through engagement

1.4 Linkages of the Barriers Identified

The barrier assessment for **Climate-Smart Agriculture (CSA)** and **Climate Information and Early Warning Systems (CIEWS)** reveals strong interconnections between economic, institutional, technical, infrastructural, and socio-cultural barriers. Recognizing these interdependencies allows for the design of integrated measures that are cost-efficient, community-centric, and scalable across both climate-resilient agriculture and early warning sectors.

Table 8 Linkages of the Barriers Identified for CSA and CIEWS in PNG

Category	CSA Barrier	CIEWS Barrier	Shared Barrier
Economic & Financial	High initial CSA investment costs; subsistence limits reinvestment	High cost of monitoring tech; donor-dependent funding	Inadequate financing mechanisms and high upfront costs for climate-resilient services
Policy, Legal, & Regulatory	Weak land tenure security; limited CSA incentives	No framework linking CIEWS with agriculture; fragmented agency mandates	Absence of integrated CSA-CIEWS policy and legal coordination
Technical	Weak farmer–research linkage; lack of CSA field trials	Lack of localized forecasting; no integration of traditional knowledge	Poor translation of research and climate data into localized, actionable tools
Human Resource	CSA extension agents lack training	Extension officers not equipped to deliver climate information	Inadequate extension capacity and training for agrometeorological services
Infrastructure	Poor access to irrigation, storage, and processing; unreliable rural power	Sparse AWS network; poor telecom and energy for CIEWS	Weak rural infrastructure and energy access for both agri and climate services

Category	CSA Barrier	CIEWS Barrier	Shared Barrier
Institutional & Organizational	Weak local governance; under-resourced ag institutions	Lack of CIEWS protocols; fragmented inter-agency SOPs	Limited institutional coordination and unclear mandates across climate and agriculture sectors
Socio-Cultural & Behavioural	Low intergenerational transfer; mistrust in programs; gender exclusion	Gender disparity in info access; language diversity	Social exclusion and cultural mismatch in delivery of services
Information & Awareness	Limited CSA awareness; poor info access; language barriers	Ineffective climate communication; low literacy in forecast application	Inaccessible and poorly disseminated advisory information

The barrier assessment **(table 8)** shows that Climate-Smart Agriculture (CSA) and Climate Information and Early Warning Systems (CIEWS) in Papua New Guinea face many similar challenges. Both are limited by high start-up costs, poor access to funding, and over-reliance on donor support. Weak policies and unclear roles among government agencies make coordination difficult.

Technically, both lack localized tools, don't fully use traditional knowledge, and suffer from poor connections between researchers and users. There's also a shortage of trained staff, especially in rural areas, which limits service delivery. In terms of infrastructure, problems like poor roads, weak electricity, and a lack of proper facilities affect both sectors. Institutional challenges such as weak planning systems and overlapping duties make things worse.

Social and cultural issues—like low trust in government and language barriers—reduce community involvement and slow the adoption of new ideas. Poor communication and low awareness further limit the impact of both CSA and CIEWS. These shared challenges show the need for joined-up solutions that support both technologies together.

1.5 Enabling Framework for Overcoming the Barriers in Agriculture Sector

To effectively address the interlinked barriers that hinder the adoption of climate-resilient technologies in Papua New Guinea (PNG), this enabling framework is structured into two levels:

Level 1: Cross-Cutting (Systemic) Enabling Measures
These address shared barriers and propose synergistic actions for simultaneous uptake of CSA and CIEWS:

Table 9 Cross-Cutting (Systemic) Enabling Measures CSA and CIEWS

Category	Shared Barrier	Synergistic Enabling Measure
Economic & Financial	Inadequate financing mechanisms and high upfront costs for climate-resilient services	Integrate CSA and CIEWS into national climate finance (NAP/NDC); co-design low-interest CSA-CIEWS loans; blended finance via GCF for joint infrastructure
Policy, Legal, & Regulatory	Absence of integrated CSA-CIEWS policy and legal coordination	Develop national CSA-CIEWS strategy; mandate climate services in agri-policy; adopt inter-agency data-sharing regulations
Technical	Poor translation of research and climate data into localized, actionable tools	Launch CSA-CIEWS joint research-extension hubs; co-produce forecasts using local indicators and scientific models
Human Resource	Inadequate extension capacity and training for agrometeorological services	Co-train extension agents; certify dual agro-climate roles; embed CSA-CIEWS in tertiary training curricula
Infrastructure	Weak rural infrastructure and energy access for both agri and climate services	Co-invest in solar-powered AWS and CSA facilities; integrate weather-linked storage, ICT platforms, and off-grid irrigation
Institutional & Organizational	Limited institutional coordination and unclear mandates across climate and agriculture sectors	Create Inter-Ministerial CSA-CIEWS Committee; harmonize SOPs, joint M&E, and local implementation plans across sectors
Socio-Cultural & Behavioural	Social exclusion and cultural mismatch in delivery of services	Establish gender-inclusive CSA-CIEWS demo farms; use local champions; integrate traditional + modern forecasting in outreach
Information & Awareness	Inaccessible and poorly disseminated advisory information	Deploy low-literacy tools (pictograms, voice alerts); integrate CSA tips into forecasts; use Farmer Field Schools, church groups, and mobile apps for dissemination

Level 2: Technology-Specific Alternative Measures

This level presents two alternative sets of measures for each technology. Each set is designed to achieve the same goal but offers different approaches and trade-offs in terms of investment, sustainability, and stakeholder involvement.

A. Climate-Smart Agriculture (CSA)

Measure Set A	**Measure Set B**
Provide input subsidies (e.g., for seeds, compost, irrigation kits).	Establish CSA innovation hubs for farmer-led adaptation trials.
Launch performance-based CSA grants through agriculture departments.	Use public-private partnerships to scale CSA demonstrations and input delivery.

Train extension officers through government agriculture colleges.	Deploy digital learning tools and mobile advisory apps for self-paced CSA uptake.
Incorporate CSA into district development planning and budgeting.	Enable CSA cooperatives to manage local implementation and training.

Expected Outcomes:

- **Set A** delivers short-term uptake through public sector leadership and financial incentives.
- **Set B** promotes long-term sustainability through innovation, private sector engagement, and farmer ownership.

B. Climate Information and Early Warning Systems (CIEWS)

Measure Set A	**Measure Set B**
Upgrade national AWS network and integrate with meteorological forecasting systems.	Establish community-based monitoring using low-cost weather sensors.
Disseminate forecasts via SMS, radio, and posters in local languages.	Develop interactive apps and gamified platforms for youth and farmers.
Train disaster officers and extension agents on forecast interpretation.	Embed CIEWS literacy in schools and civic education programs.
Link forecast information to government early action protocols (e.g., drought relief).	Co-develop forecast-based action plans with communities and CSOs.

Expected Outcomes:

- **Set A** emphasizes institutional capacity and nationwide coverage with high infrastructure investment.
- **Set B** fosters community ownership, local innovation, and decentralized knowledge transfer.

This two-level enabling framework provides a flexible yet coordinated roadmap to scale up CSA and CIEWS in Papua New Guinea. Level 1 targets systemic constraints through integrated national policy and institutional reform, while Level 2 offers tailored strategies for each technology to suit different implementation contexts. The inclusion of two alternative measure sets per technology allows decision-makers to select the approach best aligned with resource availability, political priorities, and community needs.

Chapter 2
Infrastructure Sector

Papua New Guinea's infrastructure sector is acutely vulnerable to climate change impacts, including coastal inundation, inland flooding, landslides, sea-level rise, and cyclones. As a geographically diverse and ecologically sensitive country, PNG relies heavily on a robust infrastructure system to ensure connectivity, service delivery, and disaster response. However, the exposure of roads, bridges, public buildings, and energy facilities to climate hazards places development gains at risk and impedes sustainable growth (GoPNG, 2023; UNEP, 2021).

Disruptions caused by extreme weather events—such as road washouts in highland regions and flooding of low-lying towns—highlight the fragility of PNG's infrastructure network. These disruptions limit market access, delay emergency services, and increase the cost of recovery and reconstruction. In informal settlements and remote provinces, the absence of resilient infrastructure exacerbates existing development inequalities, leaving communities more vulnerable to climate-induced displacement, food insecurity, and health risks (World Bank, 2021; Kiele et al., 2013).

Among these, two technologies—**Climate-Resilient Infrastructure (CRI)** and **Early Warning Systems (EWS)**—have been identified as top priorities due to their high composite scores and strong alignment with PNG's National Adaptation Plan (NAP 2023) (GoPNG, 2023). CRI provides a foundational solution by enhancing the durability and adaptive capacity of physical assets, while EWS plays a critical role in reducing disaster risks through improved preparedness and response mechanisms (UNDRR, 2019; WMO, 2023).

To support the diffusion of these technologies, the Technology Needs Assessment (TNA) will proceed to the next phase: **Barrier Analysis and Enabling Framework (BAEF)** development. BAEF was developed through a systematic and participatory process aligned with the Technology Needs Assessment (TNA) methodology (UNFCCC, 2013). The process began with the identification of key stakeholders, conducted during Phase 1 of the TNA process, to ensure inclusivity and relevance (UNEP, 2010). This was followed by the identification of potential barriers, which was informed by a comprehensive literature review, stakeholder consultation meetings, and brainstorming sessions (Klein et al., 2007; FAO, 2022). The analysis of these barriers employed logical problem tree methodologies, drawing on insights from expert consultations and inputs from the technical working group (TWG). To develop measures for overcoming the identified barriers, the solution tree method was applied, complemented by participatory discussions within the TWG (UNFCCC, 2013). Subsequent screening and validation of the proposed barriers and enabling measures were conducted through stakeholder validation meetings, ensuring accuracy and consensus. The draft BAEF report was then prepared under the guidance of TNA adaptation consultants. Finally, the development of the final report involved thorough review by national experts and formal endorsement by the Ministry of Environment, Conservation and Climate Change (MECCC) and the National TNA Steering Committee (NTASC) (GoPNG, 2023).

2.1 Preliminary Targets for Technology Transfer and Diffusion Infrastructure Sector

Papua New Guinea's infrastructure sector is increasingly exposed to the adverse effects of climate change, including intense rainfall, flooding, landslides, cyclones, and coastal inundation. These climate hazards severely affect transportation networks, public utilities, and essential community infrastructure, particularly in rural and vulnerable regions (GoPNG, 2023; World Bank, 2021). Through the Technology Needs Assessment (TNA) process, two key adaptation technologies have been prioritised:

1. **Climate-Resilient Infrastructure (CRI)**
2. **Early Warning Systems (EWS)**

These technologies were selected for their transformative role in reducing risk, protecting economic and social assets, and supporting PNG’s national climate adaptation goals.

Preliminary Targets for CRI Deployment:

- By **2030**, upgrade **40%** of rural and feeder roads in high-risk provinces (e.g., East Sepik, Gulf, Morobe) using climate-resilient engineering standards (GoPNG, 2023).
- Retrofit at least **500 public buildings** (health clinics, schools, district centers) to meet resilience criteria by **2028** (World Bank, 2022).
- Integrate mandatory climate risk screening into all publicly funded infrastructure projects by **2026**, by MTDP IV (GoPNG, 2023).
- Publish **CRI technical guidelines** for transport, health, education, and utilities infrastructure by **2025** (UNEP, 2021).

Preliminary Targets for EWS Deployment:

- Achieve **multi-hazard EWS coverage** in all **22 provinces** by **2029**, prioritizing areas most exposed to floods, landslides, and coastal hazards (GoPNG, 2023).
- Install at least **150 new hydro-meteorological monitoring stations** in high-risk rural areas by **2027** (GoPNG,2014).
- Establish **community-based early warning systems (CBEWS)** in **300 at-risk villages** by **2026** in collaboration with local governments and NGOs (SPREP, 2021).
- Integrate EWS into disaster preparedness curricula in **all primary schools** and local government contingency plans by **2025** (GoPNG, 2023).

2.2 Barrier Analysis and Possible Enabling Measures for Climate-Resilient Infrastructure (CRI)

2.2.1 General Description of Technology Climate-Resilient Infrastructure (CRI)

Climate-Resilient Infrastructure (CRI) refers to infrastructure systems that are planned, designed, constructed, and maintained to anticipate, absorb, adapt to, and recover from the adverse impacts of climate change. In the Papua New Guinea (PNG) context, where extreme weather events, sea-level rise, flooding, landslides, and heat stress are intensifying due to climate change, CRI is essential for safeguarding development gains and reducing vulnerability across sectors.

PNG’s infrastructure systems—particularly in transport (roads, bridges, airstrips), water supply, energy, and coastal protection—are highly vulnerable due to the country’s rugged topography, scattered island geography, and limited maintenance capacity. Poor-quality infrastructure and high exposure to climate hazards contribute to frequent service disruptions, damage, and high repair costs, especially in rural and remote areas (GoPNG, 2020a; World Bank, 2021).

CRI in PNG therefore emphasizes the integration of climate risk assessments into infrastructure planning and design, with a focus on:

- Elevated and flood-proofed roads, culverts, and bridges to withstand heavy rainfall and landslides.
- Coastal protection structures and nature-based solutions (e.g., mangrove rehabilitation, vetiver systems) to buffer erosion and sea-level rise.
- Climate-proofed water and sanitation systems, particularly in low-lying and peri-urban areas prone to flooding.
- Resilient housing and public buildings designed for cyclones, high winds, and temperature variability.

The adoption of CRI technologies in PNG requires not only technical innovations but also enabling policies, community engagement, and institutional coordination to ensure long-term sustainability and cost-effectiveness.

By prioritizing CRI under the TNA Adaptation process, PNG seeks to:

- Improve infrastructure reliability under current and future climate conditions.
- Reduce economic and social losses from disaster-related disruptions.
- Support climate-resilient development aligned with PNG's Vision 2050, the Medium-Term Development Plan (MTDP IV), and the National Adaptation Plan (NAP).

This technology also contributes to broader co-benefits such as improved access to markets, reduced poverty, and enhanced gender inclusion through safer and more reliable infrastructure services.

Table 10 Summary of Market Characteristics of the Technologies in the Infrastructure Sector

Technology	Market Type	Description
Climate-Resilient Infrastructure (CRI)	Public Investment	Infrastructure assets built or retrofitted through public financing and procurement.
CRI Design Guidelines & Tools	Public Good	Technical standards and manuals developed and disseminated by government.

2.2.2 Identification of Barriers for Technology Climate-Resilient Infrastructure (CRI)

The identification of barriers to the adoption of Climate-Resilient Infrastructure (CRI) in Papua New Guinea was conducted through a structured assessment involving literature review, expert interviews, and stakeholder consultations with the National Steering Committee (NSC) and Sectoral Working Groups (SWGs). This process aimed to determine challenges that prevent the effective implementation and scaling of CRI technologies.

Barriers to CRI in PNG were grouped into two categories: (1) economic and financial barriers, and (2) non-financial barriers. Non-financial barriers were further divided into six subcategories: policy, legal, and regulatory; technical; human resources; infrastructure; institutional and organisational capacity; and socio-cultural and information barriers.

2.2.2.1 Economic and Financial Barriers

- **High upfront costs for climate-resilient designs and materials:** Climate-resilient infrastructure often requires more robust engineering, elevated materials standards, and context-specific designs that can withstand extreme weather events (e.g., cyclones, floods, landslides). In PNG, building resilient bridges, roads, or coastal defences often costs significantly more than conventional infrastructure. These additional costs discourage uptake, especially in budget-constrained provinces (ADB, 2021; World Bank, 2020; TNA-PNG, 2025).

- **Insufficient national budget allocation**: Although infrastructure is a priority in PNG's Medium-Term Development Plans (MTDP IV), public budget allocations remain limited and uneven. Much of the available budget is absorbed by routine maintenance or emergency repairs post-disaster, leaving little room for forward-looking investment in resilience-building. Capital investment is often delayed or scaled back (GoPNG, 2020a; IMF, 2024).

- **Dependence on donor funding:** PNG remains heavily reliant on development partners (e.g., ADB, World Bank, Australia, EU) to fund large infrastructure projects. This dependency limits the government's ownership and long-term planning for CRI. It can also lead to fragmented approaches, delays in implementation, and reduced focus on locally appropriate designs (GoPNG, 2023)

- **Lack of financial mechanisms (e.g., green bonds, resilience-linked loans):** PNG lacks access to innovative financing mechanisms such as climate-resilience bonds, blended finance models, or adaptation funds linked to performance metrics. The absence of these instruments restricts opportunities to mobilize private capital and leverage concessional climate finance to scale CRI projects. Institutional and regulatory frameworks to support these instruments are underdeveloped (GCF, 2021; UNESCAP, 2022)

1.2.2.2 Non-Financial Barriers

A. Policy, Legal, and Regulatory

- **Absence of climate-resilience mandates in infrastructure codes:** PNG's building codes and infrastructure design standards (e.g., for roads, bridges, drainage) are outdated and generally do not incorporate climate projections such as increased rainfall intensity, sea-level rise, or temperature variability. Without formal mandates, infrastructure continues to be designed for historical conditions, leaving it vulnerable to failure under future climate scenarios (ADB, 2021; World Bank, 2020).

- **Lack of land use planning laws incorporating climate risks:** Formal land use planning systems in PNG are weak, particularly in rural and informal urban areas. Infrastructure projects are frequently sited in climate-sensitive zones—e.g., floodplains, unstable slopes, or erosion-prone coastlines—due to the absence of enforceable zoning laws or risk-based spatial planning. Customary land tenure (over 90% of PNG land) adds further complexity (UNESCAP, 2022; GoPNG, 2021)

B. Technical Barriers

- **Insufficient climate data to inform infrastructure design:** Infrastructure planning in PNG is hampered by limited availability of localized, high-resolution climate data (e.g., rainfall intensity curves, sea-level rise projections, flood maps). Many provinces do not have meteorological or hydrological monitoring stations, making it difficult to integrate projected climate risks into structural design parameters. This results in under-engineered infrastructure vulnerable to future hazards (World Bank, 2020; TNA-PNG, 2025; SPREP, 2021).

- **Limited access to resilient construction materials:** Resilient materials such as cyclone-rated roofing, rust-proof bridge reinforcements, and moisture-resistant construction blocks are either unavailable or prohibitively expensive in remote areas. Transport and logistics challenges further increase material costs, leading to substitution with lower-quality alternatives that are not climate-resilient (ADB, 2021; GoPNG MTDP IV, 2023).

- **Poor integration of climate science into planning tools:** Despite global advances in GIS-based planning, climate risk modelling, and scenario mapping, these tools are underutilized in PNG due to low institutional capacity, lack of trained staff, and limited access to software or internet infrastructure—particularly at the provincial and district levels. This restricts proactive planning for CRI (GoPNG, 2023).

- **Limited experience in climate-resilient design:** Many local engineers, contractors, and planners in PNG have not received formal training in climate-resilient infrastructure design. International standards (e.g., from ISO, PIANC, ASCE) are rarely used, and local capacity-building efforts have been sporadic and project-based. This leads to conventional infrastructure being rebuilt repeatedly after disasters (Hook, 2024)

- **Low incorporation of indigenous and local knowledge:** Indigenous knowledge—including site selection strategies, seasonal behaviour patterns, and building techniques adapted to local environments—is often overlooked in formal infrastructure design. This can lead to culturally inappropriate or poorly situated infrastructure, increasing the risk of climate-related failure or social rejection (UNESCAP, 2022; GoPNG, 2023).

C. Human Resource Barriers

- **Shortage of climate-literate planners and engineers:** PNG faces a critical shortage of professionals with expertise in climate-resilient infrastructure design. Many engineers, urban planners, and architects lack formal training in climate risk modelling, infrastructure vulnerability assessments, and resilience-based lifecycle management. This hinders the development and maintenance of infrastructure capable of withstanding future climate conditions (ADB, 2021; GoPNG, 2023).

- **Lack of interdisciplinary training:** Infrastructure planning in PNG is traditionally siloed, with engineers trained in technical design and environmental scientists trained in climate issues. Few professionals are trained across both domains, leading to gaps in designing integrated, climate-informed solutions. Academic institutions have yet to fully mainstream climate resilience into engineering and planning curricula (GoPNG, 2020a)

- **Capacity gaps in rural and district-level governments:** Local governments are critical actors in project implementation and site monitoring, but often lack technical staff trained in CRI. This leads to poorly supervised construction, lack of adaptation considerations in approvals, and weak monitoring of environmental and structural compliance. The situation is more acute in remote provinces (GoPNG, 2023).

- **Brain drains and retention issues:** PNG continues to experience high turnover of skilled professionals, particularly in public sector engineering, planning, and environmental roles. Many seek higher-paying jobs with international agencies, NGOs, or overseas. The lack of competitive salaries, limited career growth, and poor working conditions in government roles exacerbate the human resource gap (IMF, 2024; GoPNG, 2023).

D. Infrastructure Barriers

- **Vulnerable baseline infrastructure:** A significant portion of PNG's existing infrastructure—especially roads, bridges, airstrips, and wharves—was built decades ago and does not meet modern resilience standards. These assets are often located in hazard-prone areas, poorly maintained, and easily damaged by flooding, landslides, and cyclones. Repair and replacement costs after climate-related disasters are high and recurring. (ADB, 2021; World Bank, 2020; GoPNG NAP, 2023).

- **Inaccessible remote areas:** PNG's challenging terrain, dispersed island geography, and lack of connective road networks make constructing and maintaining CRI especially difficult. Many remote areas can only be accessed by air, boat, or foot, increasing logistical costs, delaying response times, and hindering materials delivery for resilient construction (GoPNG, 2023)

- **Limited maintenance culture and poor asset management:** Infrastructure maintenance is often underfunded or reactive rather than preventative. There is no standardized national asset management system, and local governments frequently lack inventories or maintenance schedules. Over time, this leads to structural deterioration, service disruption, and higher vulnerability to climate hazards (World Bank, 2020; ADB, 2021)

- **Unregulated informal settlements in hazard-prone areas:** Rapid urbanization, combined with weak enforcement of land-use policies, has led to the proliferation of informal settlements in floodplains, unstable slopes, and coastal zones. These areas lack basic infrastructure services, increasing the pressure on governments to retrofit CRI in locations that are already difficult and expensive to serve (GoPNG, 2020a).

E. Institutional and Organizational Capacity Barrier

- **Weak inter-agency coordination:** Agencies responsible for infrastructure DWH, CEPA, NDMO and DNPM frequently operate in silos with minimal coordination. This results in fragmented CRI planning, duplication of efforts, and conflicting priorities between infrastructure development and climate adaptation goals (GoPNG, 2023)

- **Low institutional capacity for long-term planning:** Many government agencies focus on addressing immediate infrastructure needs (e.g., post-disaster reconstruction or political priorities) without integrating long-term climate projections or lifecycle cost analysis into planning processes. Strategic foresight and risk-informed decision-making remain limited. (ADB, 2021; World Bank, 2020; GoPNG, 2023).

- **Slow procurement and bureaucratic processes:** Lengthy and complex procurement procedures, coupled with limited capacity in contract and project management, delay the execution of CRI projects. These delays reduce responsiveness to emerging climate risks and discourage the private sector from innovating or engaging in climate-resilient construction (IMF, 2024; UNESCAP, 2022)

- **Absence of resilience monitoring and evaluation (M&E) frameworks:** Post-construction monitoring systems in PNG rarely assess the climate resilience performance of infrastructure over time. There are no standardized indicators or reporting mechanisms to evaluate how infrastructure is coping with climate stressors, resulting in limited learning and adaptation of design practices (GoPNG, 2023; Hook, 2024)

- **Weak enforcement of existing regulations:** Even where basic standards exist, enforcement is often inconsistent due to capacity constraints within regulatory agencies, lack of trained inspectors, and limited political will. As a result, many developments proceed without proper approvals or compliance, particularly in rural and peri-urban areas (GoPNG, 2023)

- **Overlapping institutional roles and fragmented governance:** CRI development requires coordination across multiple sectors—transport, planning, disaster management, environment, and housing. In PNG, these responsibilities are often split across agencies with poor coordination, leading to regulatory gaps, duplication of efforts, or policy conflicts. Local-level governments often lack clarity on their mandates in relation to national authorities (GoPNG, 2020a; GoPNG, 2023).

F. Social, Cultural, and Information Barriers

- **Public preference for low-cost infrastructure:** Both community members and some local decision-makers in PNG often prefer infrastructure options that are immediately affordable rather than those designed for long-term climate resilience. This short-term cost-saving mindset is driven by limited budgets, lack of awareness about future climate risks, and the urgent need for basic services. Consequently, resilience features—such as elevated structures or reinforced materials—are frequently omitted from designs (ADB, 2021; GoPNG, 2023).

- **Lack of community engagement in infrastructure design:** Many CRI projects in PNG are implemented through top-down processes with limited input from local communities. This lack of engagement leads to missed opportunities to integrate local knowledge about historical climate events, settlement patterns, or culturally significant areas. It can also result in poor user ownership, resistance to maintenance, or infrastructure that does not meet actual needs (Hook, 2024; GoPNG NAP, 2023).

G. Information and Awareness Barriers

- **Low awareness of climate risks in infrastructure planning:** Many decision-makers at the provincial, district, and ward levels are not fully aware of how climate change will affect physical infrastructure over time. This knowledge gap leads to reactive planning and contributes to continued investment in conventional infrastructure that may not withstand future climatic extremes (GoPNG, 2023; ADB, 2021).

- **Lack of communication between scientists and engineers:** Climate data and impact assessments are often available through meteorological or academic institutions but are presented in technical language that is not easily interpreted by infrastructure engineers or planners. This weak link between research and practice results in a disconnect between climate science and infrastructure design (SPREP, 2021; UNESCAP, 2022; World Bank, 2020)

- **Limited public education campaigns:** Public understanding of climate-resilient infrastructure and its long-term benefits remains low. There are few national campaigns or local outreach programs promoting climate-smart construction practices or explaining the risks of inadequate infrastructure under climate change (Hook, 2024).

- **Poor dissemination of risk maps and early warnings:** Hazard maps (flood zones, landslide risk areas, cyclone pathways) and early warning data are often developed but not consistently shared with planners, local governments, or communities. Infrastructure projects frequently proceed without incorporating this essential risk information (GoPNG, 2023; World Bank, 2020).

- **No national platform for CRI knowledge sharing:** There is no centralized digital platform or knowledge hub where practitioners, policy makers, and communities can access climate-resilient infrastructure guidelines, case studies, or lessons learned. This prevents the scaling-up of good practices and contributes to duplicated efforts (UNESCAP, 2022)

Table 11 below provides a comprehensive summary of the various barriers associated with CRI technology. It includes detailed scoring derived from discussions and evaluations during the stakeholder workshop, highlighting the challenges identified by participants while assessing the feasibility and implementation of CRI practices.

Table 11 List of Barriers to Climate Resilient Infrastructure (CRI)

Barrier Factors	Score
Economic and Financial Barriers	
High upfront costs for climate-resilient designs and materials	4
Insufficient national budget allocation	4
Dependence on donor funding	4
Lack of financial mechanisms: PNG lacks innovative financing instruments such as green bonds, climate adaptation funds, or resilience-linked loans.	4
Policy, Legal, and Regulatory Barriers	
Absence of climate-resilience mandates in infrastructure codes: Building codes and engineering standards in PNG often do not integrate up-to-date climate risk assessments.	4
Weak enforcement of existing regulations	4
Overlapping roles between local governments, departments of transport, planning, environment, and others create inefficiencies.	4
Lack of land use planning laws incorporating climate risks: Urban development and infrastructure placement often ignore flood zones, landslide-prone areas, or coastal erosion risks.	4
Technical Barriers	
Insufficient climate data to inform infrastructure design: Engineers and planners lack access to high-resolution climate projections (e.g., sea-level rise, flood mapping).	4
Limited access to resilient construction materials: Materials suited for extreme conditions (e.g., cyclone-resistant roofing, corrosion-resistant bridges) are expensive or unavailable in many regions.	4
Poor integration of climate science into planning tools: Tools like GIS or climate risk modelling are underutilized due to a lack of training or software access.	3
Limited experience in climate-resilient design: Many engineers and contractors are unfamiliar with international best practices or standards for CRI.	4
Low incorporation of indigenous and local knowledge: Formal infrastructure planning often ignores traditional coping mechanisms and settlement patterns.	4
Human Resource Barriers	
Shortage of climate-literate planners and engineers: PNG faces a skills gap in climate-resilient design, modelling, and infrastructure lifecycle management.	4
Lack of interdisciplinary training: Few professionals are trained in infrastructure development and climate risk assessment.	3
Capacity gaps in rural and district-level governments: Local governments often lack skilled personnel to plan, approve, or monitor CRI projects.	4
Brain drain and retention issues: Skilled professionals often leave public sector jobs or PNG altogether for better opportunities abroad.	4
Infrastructure Barriers	
Vulnerable baseline infrastructure: Much of PNG's existing infrastructure (roads, bridges, ports) is already in poor condition and highly susceptible to climate risks like flooding, landslides, or cyclones.	4

Barrier Factors	Score
Inaccessible remote areas: Many parts of PNG are geographically isolated, making construction and maintenance of CRI logistically and financially challenging.	4
Limited maintenance culture: Poor infrastructure asset management practices lead to deterioration and increased vulnerability over time.	4
Unregulated informal settlements: The expansion of unplanned housing in hazard-prone areas increases the need for resilient infrastructure, which is currently not being addressed.	4
Institutional and Organizational Capacity Barriers	
Weak inter-agency coordination: Ministries responsible for infrastructure, environment, disaster management, and planning often operate in silos.	4
Low institutional capacity for long-term planning: Many agencies focus on short-term infrastructure needs without incorporating future climate scenarios.	3
Slow procurement and bureaucratic processes: Delays in tendering and approvals discourage innovation and efficiency in resilient infrastructure development.	4
Absence of resilience monitoring and evaluation frameworks: There's little systematic tracking of infrastructure resilience performance post-construction.	4
Social, Cultural, and Behavioural Barriers	
Public preference for low-cost infrastructure: Communities and decision-makers often prioritize immediate cost savings over long-term resilience.	4
Lack of community engagement in design: Infrastructure projects often proceed without consulting local populations on climate risks or past experiences.	4
Information and Awareness Barriers	
Low awareness of climate risks in infrastructure planning: Many local governments and community leaders are unaware of how climate change will impact roads, buildings, and other assets.	4
Lack of communication between scientists and engineers: Climate projections and impact studies are often not translated into usable formats for infrastructure practitioners.	4
Limited public education campaigns: The general population is not well-informed about the benefits of climate-resilient infrastructure or the risks of conventional approaches.	4
Poor dissemination of risk maps and early warnings: Infrastructure projects often proceed without access to critical hazard or vulnerability data.	4
No national platform for CRI knowledge sharing: Best practices, case studies, or local success stories are limited in accessible formats.	4

A total of **30 barriers** were identified as **Significant** (score of 4) across multiple thematic categories. These barriers represent critical constraints to the design, implementation, and sustainability of climate-resilient infrastructure in Papua New Guinea and are summarized below:

1. Economic and Financial Barriers

- High upfront costs for climate-resilient designs and materials – **4**
- Insufficient national budget allocation – **4**

- Dependence on donor funding – **4**
- Lack of financial mechanisms: PNG lacks innovative financing instruments such as green bonds, climate adaptation funds, or resilience-linked loans – **4**

2. Policy, Legal, and Regulatory Barriers
- Absence of climate-resilience mandates in infrastructure codes – **4**
- Weak enforcement of existing regulations – **4**
- Overlapping roles between local governments, departments of transport, planning, environment, and others – **4**
- Lack of land use planning laws incorporating climate risks – **4**

3. Technical Barriers
- Insufficient climate data to inform infrastructure design – **4**
- Limited access to resilient construction materials – **4**
- Limited experience in climate-resilient design – **4**
- Low incorporation of indigenous and local knowledge – **4**

4. Human Resource Barriers
- Shortage of climate-literate planners and engineers – **4**
- Capacity gaps in rural and district-level governments – **4**
- Brain drain and retention issues – **4**

5. Infrastructure Barriers
- Vulnerable baseline infrastructure – **4**
- Inaccessible remote areas – **4**
- Limited maintenance culture – **4**
- Unregulated informal settlements – **4**

6. Institutional and Organizational Capacity Barriers
- Weak inter-agency coordination – **4**
- Slow procurement and bureaucratic processes – **4**
- Absence of resilience monitoring and evaluation frameworks – **4**

7. Social, Cultural, and Behavioural Barriers
- Public preference for low-cost infrastructure – **4**
- Lack of community engagement in design – **4**

8. Information and Awareness Barriers
- Low awareness of climate risks in infrastructure planning – **4**
- Lack of communication between scientists and engineers – **4**
- Limited public education campaigns – **4**
- Poor dissemination of risk maps and early warnings – **4**
- No national platform for CRI knowledge sharing – **4**

The identification of these thirty very significant barriers underscores the urgent need for a comprehensive and coordinated enabling framework to support the planning, financing, and implementation of climate-resilient infrastructure in Papua New Guinea. Addressing these barriers will require a multi-level strategy involving policy reform, institutional strengthening, capacity building, and increased public and private investment. By prioritizing these critical constraints, stakeholders can ensure that infrastructure development in PNG not only meets current service delivery needs but is also equipped to withstand the escalating impacts of climate change—safeguarding communities, livelihoods, and national development goals well into the future.

2.2.3 Identified Measures for Technology Climate-Resilient Infrastructure (CRI)

Identified measures for CRI technology are designed to overcome a wide range of economic, institutional, regulatory, technical, and socio-cultural constraints that limit the implementation of CRI in PNG. These interventions aim to support the implementation of CRI. The measures are structured to reflect the diverse needs of PNG's predominantly rural and subsistence-based farming population and are aligned with national development priorities and adaptation goals.

Table 12 Identified Measured for CRI Technology

Category	Barrier Description	Identify measure
Economic and Financial	High upfront costs for climate-resilient designs and materials	Introduce targeted subsidies or tax exemptions for climate-resilient materials; support bulk procurement via provinces
Economic and Financial	Insufficient national budget allocation	Integrate CRI into MTDP and PIP with dedicated line items and climate budget tagging
Economic and Financial	Dependence on donor funding	Develop co-financing models using government seed capital and donor leverage
Economic and Financial	Lack of financial mechanisms (e.g., green bonds, adaptation funds)	Establish a CRI Trust Fund financed through CSR from extractive industries
Policy, Legal, and Regulatory	Absence of climate-resilience mandates in infrastructure codes	Update the PNG Building Act and National Building Code to mandate climate risk assessments
Policy, Legal, and Regulatory	Weak enforcement of existing regulations	Introduce climate-informed physical planning guidelines and pilot in high-risk districts
Policy, Legal, and Regulatory	Overlapping roles between local governments and national departments	Revise mandates to reduce overlaps between agencies through operational frameworks
Policy, Legal, and Regulatory	Lack of land use planning laws incorporating climate risks	Amend land use laws to integrate zoning based on flood, landslide, and erosion risk zones
Technical	Insufficient climate data to inform infrastructure design	Establish a National Climate Data Portal; integrate climate layers into GIS tools
Technical	Limited access to resilient construction materials	Support decentralized supply chains and establish provincial resilient materials hubs
Technical	Limited experience in climate-resilient design	Mainstream climate science into planning software; provide open-source tools and training
Technical	Low incorporation of indigenous and local knowledge	Develop a National CRI Design Toolkit and deploy mobile technical advisory units
Human Resource	Shortage of climate-literate planners and engineers	Establish climate engineering certification programs and CRI curriculum modules in universities
Human Resource	Capacity gaps in rural and district-level governments	Expand provincial training institutes and deploy mobile technical advisory units
Human Resource	Brain drain and retention issues	Implement performance-based retention schemes for climate-skilled public professionals

Category	Barrier Description	Identify measure
Infrastructure	Vulnerable baseline infrastructure	Prioritize climate-resilient retrofits; establish provincial CRI infrastructure plans
Infrastructure	Inaccessible remote areas	Promote modular or prefabricated CRI structures for remote and hazard-prone areas
Infrastructure	Limited maintenance culture	Establish asset management protocols and maintenance incentives
Infrastructure	Unregulated informal settlements	Formalize climate-sensitive upgrading plans for informal settlements
Institutional and Organizational	Weak inter-agency coordination	Establish a National CRI Task Force to streamline coordination and planning
Institutional and Organizational	Slow procurement and bureaucratic processes	Create technical planning units in infrastructure ministries with climate focus
Institutional and Organizational	Absence of resilience monitoring and evaluation frameworks	Establish CRI procurement unit within CSTB with delegated authority
Social, Cultural, and Behavioural	Public preference for low-cost infrastructure	Introduce community-based cost-benefit analysis tools in local planning processes
Social, Cultural, and Behavioural	Lack of community engagement in design	Institutionalize community consultation in all CRI design and feasibility processes
Information and Awareness	Low awareness of climate risks in infrastructure planning	Run radio dramas, tok save sessions, and school clubs to raise awareness
Information and Awareness	Lack of communication between scientists and engineers	Conduct 'Engineer Meets Village' dialogues using visual and interactive tools
Information and Awareness	Limited public education campaigns	Integrate CRI topics into civics and science curricula (grades 6□□□10)
Information and Awareness	Poor dissemination of risk maps and early warnings	Develop an open-access Infrastructure Climate Risk Portal for local governments and public
Information and Awareness	No national platform for CRI knowledge sharing	Launch a PNG Resilient Infrastructure Knowledge Hub for professional learning

2.3 Barrier Analysis and Possible Enabling Measures for Early Warning Systems (EWS)

2.3.1 General Description of Early Warning Systems (EWS)

Early Warning Systems (EWS) for infrastructure in Papua New Guinea (PNG) refer to integrated technological and institutional frameworks that support the early detection, monitoring, communication, and response to climate-induced hazards threatening physical infrastructure. These systems are increasingly vital due to PNG's acute vulnerability to disasters such as flash floods, landslides, cyclones, and coastal erosion, which frequently disrupt roads, bridges, ports, schools, and health facilities (GoPNG, 2023; ADB, 2024).

Figure 3 shows the EWS for infrastructure resilience aim to reduce the vulnerability of essential infrastructure systems and support proactive risk-informed planning. The core functions of infrastructure-related EWS align with international frameworks and consist of four pillars: (1) hazard identification and risk profiling, (2) continuous monitoring and predictive modelling, (3) timely warning communication to infrastructure managers and local authorities, and (4) coordinated emergency preparedness and response protocols (WMO, 2018; UNDRR, 2022). In PNG, these systems are supported by the PNG National Weather Service (NWS), Geohazards Management Division, and the National Disaster Centre (NDC), along with satellite inputs and localized early action protocols developed by provincial Works and Disaster Coordination Offices (SPREP, 2021; GOPNG, 2023).

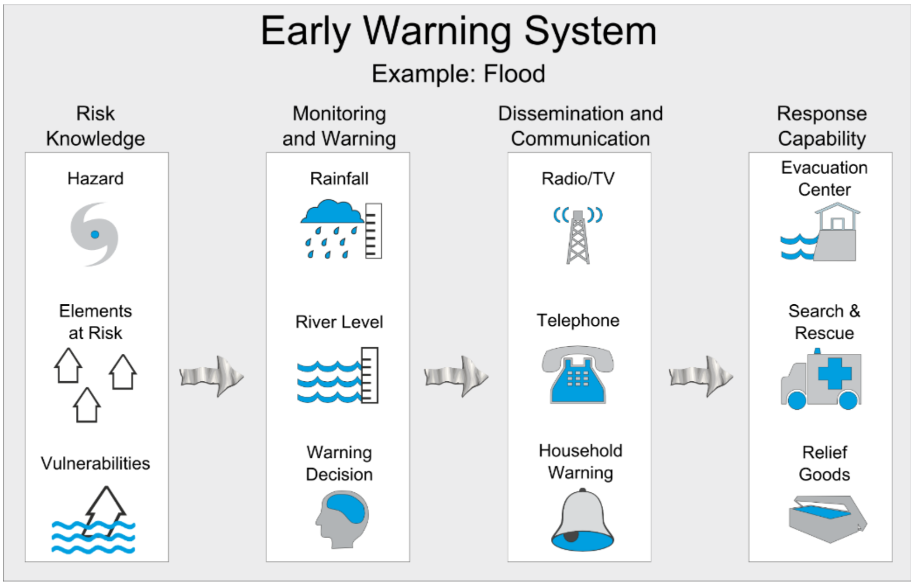

Figure 3 Early Warning System Model (Neussner, 2009)

Drawing from models in Fiji and the Philippines, where EWS have been successfully localized and embedded into infrastructure resilience strategies, PNG is working to strengthen decentralized hazard monitoring and real-time communication to mitigate disruptions to its critical infrastructure. For example, in the Philippines, the Department of Public Works and Highways (DPWH) integrates rainfall-triggered landslide EWS with road closures and structural alerts using automated gauges and geotechnical sensors (ADB, 2021)

As shown in **Figure 4**, a flood early warning system tailored to PNG's infrastructure sector helps reduce service disruptions, protect human lives, and minimize economic losses by enabling timely interventions such as road closures, structural reinforcements, and rerouting of transport and logistics. In mountainous regions such as Simbu and Eastern Highlands, EWS using rainfall intensity sensors and slope stability indicators provide lead time for evacuation and infrastructure shutdowns before landslide-triggering events occur. Likewise, in coastal provinces like Manus, Bougainville, and East Sepik, EWS combined with sea-level rise monitoring are critical for port infrastructure planning and community-based evacuation (World Bank, 2020)

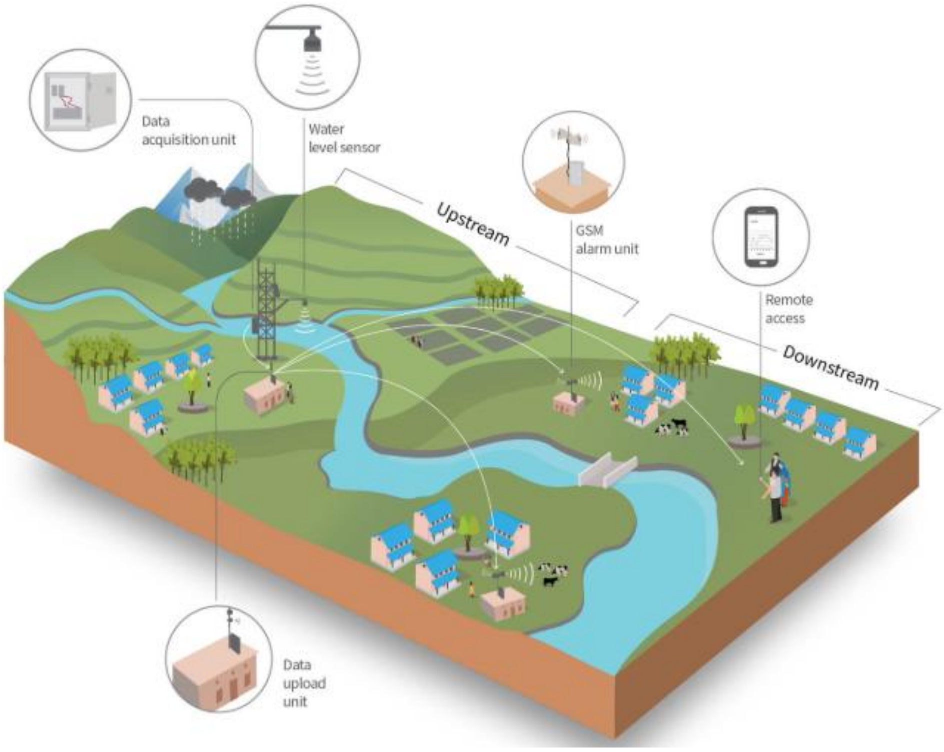

Figure 4 Community Based Flood Early Warning Systems
(ICIMOD, 2019)

In practice, the infrastructure EWS system in PNG remains a developing framework, with recent advancements including the integration of real-time hydrological data and road hazard monitoring into national platforms such as the National Emergency Operations Centre (NEOC) (ADB, 2017; GoPNG, 2020a). These systems are gradually being extended to district-level through pilot initiatives under the SPREP Infrastructure Resilience Program and the Pacific Resilience Facility, which provide both digital tools and institutional capacity-building (SPREP, 2021; UNCDF, 2022).

Table 13 Summary of Market Characteristics of EWS Technology

Technology	Market Type	Description
Early Warning Systems (EWS)	Public Good	Operated by public agencies with wide societal benefits.
EWS Dissemination Channels (SMS, radio)	Hybrid (Public/Private)	Co-managed with telecom companies and media broadcasters.
Community-Based Alert Systems (EWS)	Public Service	Local implementation coordinated by disaster offices and NGOs.

Notes:

- EWS effectiveness is linked to institutional coordination, trust in forecasts, and accessibility of communication channels

2.3.2 Identification of Barriers for Early Warning Systems (EWS)

The identification of barriers to the adoption of Early Warning Systems (EWS) in Papua New Guinea was conducted through a structured assessment involving literature review, expert interviews, and stakeholder consultations with the National Steering Committee (NSC) and Sectoral Working Groups (SWGs). This process aimed to determine the key challenges that hinder the implementation, integration, and upscaling of EWS across priority sectors such as agriculture, health, and disaster risk reduction.

2.3.2.1 Economic and Financial Barriers

- **Limited National Funding for EWS Infrastructure:** Although PNG is increasingly vulnerable to climate-related disasters such as floods, landslides, and coastal storms, public funding allocated to climate monitoring and EWS infrastructure remains severely constrained. Most real-time hydrological monitoring equipment, slope sensors, and flood gauge networks are funded through international grants or pilot initiatives, rather than through consistent national investments. For example, automated weather stations installed along critical bridges in Oro, Simbu, and East Sepik are maintained under SPREP supported projects—not government budgets (SPREP, 2021; GoPNG, 2020a).

- **Over-Reliance on Donor and External Funding**: The development and operationalization of EWS in PNG have largely depended on external donors, including the Asian Development Bank (ADB), Green Climate Fund (GCF), and regional platforms such as the Pacific Resilience Facility. While these funding sources have helped initiate key pilot projects (e.g., mobile flood alert systems and CCICs), the absence of sustained national financial commitment creates uncertainty around the continuity and scaling of these systems once donor funding ends. This over-reliance hampers institutional ownership and often results in fragmented coverage and disjointed coordination across provinces (ADB, 2021; UNCDF, 2022; SPREP, 2021)

- **No Dedicated Budget Lines for EWS Maintenance**: One of the most critical financial gaps is the lack of earmarked funding for ongoing maintenance and calibration of EWS infrastructure. Even where sensors or communications systems are installed, many fall into disrepair due to lack of basic upkeep budgets or spare parts procurement channels. This is particularly evident at the district and LLG levels, where Public Works officers often lack discretionary funding to inspect, recalibrate, or repair damaged monitoring stations. Moreover, EWS maintenance is not integrated into the Public Investment Program (PIP) or the Medium-Term Development Plan (MTDP III), meaning it is often overlooked during budget allocation cycles (GoPNG, 2020a)

1.3.2.2 Non-Financial Barriers

A. Policy, Legal, and Regulatory Barriers

- **Absence of a National EWS Strategy:** Papua New Guinea currently lacks a unified national strategy specifically focused on EWS for infrastructure or multi-hazard early warning. While EWS elements are mentioned in the National Adaptation Plan (NAP, 2023) and Disaster Risk Reduction Framework (2017–2030), there is no comprehensive blueprint to guide investment, coordination, standardization, and maintenance of EWS systems. This results in ad-hoc implementations by individual provinces or donor programs, without long-term sustainability or interoperability (GoPNG, 2023; UNDRR, 2021; ADB, 2017)
- **Fragmented Mandates Across Sectors**: EWS responsibilities in PNG are fragmented across multiple ministries, including the Department of Works, Department of Transport, CEPA, National Weather Service (NWS), and the National Disaster Centre (NDC). There is no legally binding coordination framework defining which agency leads, funds, maintains, or reports on EWS infrastructure. This often results in duplication, delays in emergency communication, or failure to act on warning data. Provinces are left without clear guidance or authority to establish local EWS systems (GoPNG , 2020; GoPNG, 2023)
- **Lack of Legal Enforcement on Hazard Monitoring**: Even where hazard monitoring systems exist—such as volcano observatories, hydrological sensors, or seismic stations—there is no binding regulation mandating that data must be shared in real time with EWS stakeholders or local infrastructure agencies. This limits the effectiveness of early action protocols, especially in fast-onset disasters like landslides or flash floods. Legal mandates are needed to ensure timely reporting and public access to risk data, similar to Indonesia's BMKG framework, which legally requires inter-agency data exchange for tsunami and flood alerts (UNDRR and WMO, 2022; SPREP, 2021)

B. Technical Barriers

- **Gaps in Hazard Detection Infrastructure:** PNG has a limited network of operational early warning hardware, including automated weather stations (AWS), river level gauges, seismographs, and tsunami detection buoys. Many existing units are concentrated in urban centers such as Port Moresby, Lae, and Madang, leaving large portions of the Highlands, Sepik Basin, and outer islands with no real-time hazard monitoring (GoPNG, 2023; ADB, 2017). This makes it extremely difficult to issue timely alerts before infrastructure failures, such as bridge washouts, landslides, or coastal inundation (ADB, 2017; SPREP, 2021; GoPNG, 2020a)

- **Lack of Integration Between Hazard Monitoring Systems**: Various hazard-specific systems—those monitoring floods, earthquakes, volcanic eruptions, or tropical cyclones—operate in technical and institutional silos. The PNG Geohazards Division, National Weather Service, and Department of Works all operate data collection systems, but they rarely interconnect or share real-time alerts. For instance, volcanic activity data from Rabaul Volcanological Observatory (RVO) is not consistently shared with infrastructure engineers managing nearby roads or evacuation centers. This lack of interoperability delays coordinated warnings and inhibits infrastructure managers from taking anticipatory action (e.g., rerouting traffic, reinforcing assets, or activating emergency plans) (UNDRR and WMO, 2022)

- **Limited Use of GIS and Real-Time Data Platforms:** Despite efforts by international partners to introduce GIS-based risk platforms, many district- and provincial-level planners and infrastructure officers still lack access to—or training in—real-time hazard mapping and forecast visualization. As a result, roads, schools, and bridges continue to be sited in floodplains, unstable slopes, and cyclone-prone zones without adequate risk assessment. The lack of dynamic early warning dashboards also impairs the ability of infrastructure managers to assess compound risks and initiate maintenance or evacuation protocols (OpenDRI, 2019; World Bank, 2020)

- **Absence of Multi-Hazard Early Warning Systems (MHEWS):** Most EWS initiatives in PNG remain single-hazard focused (e.g., flood early warning or cyclone tracking), and are not designed to handle compound or cascading events, such as earthquakes triggering landslides that block roads or severe rainfall coinciding with volcanic mudflows. This is a critical gap in a country where multiple hazards often strike simultaneously or sequentially. Without a unified multi-hazard platform, infrastructure managers are unable to prioritize responses or allocate resources effectively (UNDRR, 2022; ADB, 2021)

C. Human Resources Barriers

- **Lack of Skilled Technical Staff:** There is a national shortage of qualified meteorologists, hydrologists, geologists, ICT specialists, and systems engineers needed to design, calibrate, and maintain EWS infrastructure. The PNG National Weather Service (NWS) and the Geohazards Management Division have limited staff capacity, with fewer than 20 field-trained meteorological officers nationwide (GoPNG, 2023). As a result, many critical tasks—such as installing river gauges, interpreting satellite data, or issuing real-time alerts—are either delayed or outsourced to external consultants (GoPNG, 2020a; ADB, 2017; SPREP, 2021)

- **Limited Training for Infrastructure Operators:** Port authorities, airport operators, power utility engineers, and road maintenance supervisors often lack training in interpreting early warning messages or taking proactive measures (e.g., shutting down vulnerable infrastructure or activating detour protocols). For example, during major flood events in East Sepik and Central Province, many local Works Department staff lacked clarity on whether forecasted rainfall intensity levels merited bridge closure or evacuation alerts (World Bank, 2020).

- **Inadequate Education and Continuous Learning Programs:** Papua New Guinea currently lacks dedicated academic or technical training programs focused on EWS design, data analytics, or systems operations. While UNITECH and UPNG offer environmental science and engineering courses, there are no structured degree or diploma programs focused on early warning technology, multi-hazard risk modelling, or climate risk communication.

D. Infrastructure Barriers

- **Poor Communication and Energy Networks:** Many components of modern EWS—such as automated flood sirens, SMS alert systems, and real-time sensor networks—are reliant on a stable mobile signal and electricity supply. In PNG, however, both are frequently unreliable or non-existent in rural and high-risk zones. According to the National Information and Communication Technology Authority (NICTA), more than 40% of PNG's population has no reliable mobile coverage, and electricity access in some provinces is below 15% (NICTA, 2023; World Bank, 2020). This infrastructure deficit makes it impossible to deploy fully functional EWS in many of the areas most prone to landslides, floods, and cyclones—such as Sandaun, Gulf, Chimbu, and Milne Bay. In these regions, community reliance on visual cues or radio announcements continues to dominate, delaying response times and increasing vulnerability (World Bank; 2020; NICTA, 2023; GOPNG, 2021; ADB, 2017)

- **Insufficient Integration of EWS with Infrastructure Assets:** PNG's roads, bridges, health facilities, schools, and coastal structures are rarely equipped with embedded hazard sensors or automated response mechanisms. For example, most bridges lack upstream flood-level sensors or systems that can trigger automatic road closures when thresholds are breached. Public buildings such as schools and health posts are also not connected to any centralized warning system, making it difficult to coordinate evacuations or safety measures during disaster events (GoPNG, 2023; SPREP, 2021).

E. Institutional and Organizational Capacity Barriers

- **Fragmented Coordination Among Agencies:** In PNG, responsibilities for EWS-related functions are scattered across multiple institutions—including the National Weather Service (NWS), Geohazards Management Division, National Disaster Centre (NDC), Department of Works, Department of Transport, and National ICT Authority (NICTA). However, there is no unified strategy, shared vision, or legally binding coordination framework to align these actors toward common EWS goals (GoPNG, 2020a; GoPNG NAP, 2023; UNDRR, 2022)

- **No Institutionalized Maintenance Systems:** Once EWS hardware (e.g., sensors, sirens, data loggers) is installed, there is rarely a formal mechanism to ensure regular testing, calibration, or repair. Many systems installed in past donor-supported programs are now non-functional due to a lack of scheduled maintenance, missing spare parts, or the absence of operational budgets. PNG lacks a centralized asset management system that tracks the status and performance of EWS components across ministries and provinces (SPREP, 2021; World Bank, 2020; UNDRR, 2021)

- **Data-Sharing Restrictions**: Even when hazard data is available (e.g., rainfall thresholds, river levels, seismic activity), it is often not shared promptly with relevant agencies due to Lack of inter-agency MoUs or data-sharing protocols, Absence of standard operating procedures (SOPs) for joint response, and Concerns about data ownership, liability, or misinterpretation. This fragmentation undermines the timeliness and usefulness of early warnings, especially for infrastructure stakeholders who need precise, localized, and actionable information to protect roads, bridges, schools, and utilities (ADB, 2017; GoPNG (2023)

F. Social, Cultural, and Information Barrier

- **Preference for Traditional Knowledge Over Scientific Alerts:** Many rural and indigenous communities in PNG still rely on traditional ecological knowledge—such as animal behavior, sky color, or tree blooming patterns—to anticipate natural hazards. In regions such as Western Province, Chimbu, and Manus, local elders may prioritize ancestral interpretations over meteorological forecasts or government-issued alerts (Mercer et al., 2009; SPREP, 2021); GoPNG, 2022)

- **Language Diversity and Communication Barriers:** PNG is the most linguistically diverse country in the world, with over 800 distinct languages spoken across its provinces. This makes it extremely difficult to issue standardized EWS messages that are understandable, trusted, and actionable at the community level. While Tok Pisin, English, and Hiri Motu are official languages, many rural populations primarily communicate in local dialects. EWS alerts sent via SMS, radio, or printed notices often fail to reach marginalized or low-literacy groups, particularly women, elders, and people with disabilities. The result is uneven comprehension and delayed action, especially in communities along major river systems or in remote coastal settlements where physical infrastructure is already weak and timely evacuation is critical (UNDRR, 2022; SPREP, 2021)

G. Information and Awareness Barriers

- **Poor Dissemination Mechanisms:** Dissemination infrastructure is often broken, unreliable, or inaccessible, especially in rural and remote parts of PNG. SMS messages are frequently delayed due to low mobile network coverage or power outages. Radio stations may lack staff or broadcasting reach, and many households do not own radios or phones. In places like Gulf Province and Western Highlands, these gaps leave communities cut off from timely alerts—even when national agencies issue them correctly (NICTA, 2023); World Bank, 2020; GoPNG, 2020a)

- **Lack of Local-Level Simulations or Drills:** Even well-designed systems fail in real emergencies when populations are unfamiliar with how to respond. In PNG, few local-level EWS programs include regular evacuation drills or public simulation exercises. Without this practice, even infrastructure managers (e.g., school principals, transport officers) are often unsure how to trigger or follow protocols during hazard events like flash floods or landslides. In contrast, Vanuatu and the Philippines have embedded routine drills into school calendars and community preparedness programs to ensure early warning messages translate into immediate, practiced responses (ADB, 2017; UNDRR, 2021)

- **Infrequent Updates and Inconsistent Alerts** : PNG has no centralized, real-time alerting platform that consistently updates warnings across agencies and user groups. This results in conflicting messages—such as meteorological advisories being issued while district offices remain unaware or give contradictory instructions. These inconsistencies reduce public trust and credibility, which discourages timely responses in future events (SPREP, 2021)

Table 14 below comprehensively summarises the various barriers associated with Early Warning Systems (EWS) technology. It includes detailed scoring derived from discussions and evaluations during the stakeholder workshop, highlighting the challenges identified by participants while assessing the feasibility and implementation of Early Warning Systems (EWS) practice.

Table 14 List of Barrier to Early Warning Systems (EWS)

Barrier Factors	Score
Economic and Financial Barriers	
Limited national funding for EWS infrastructure	4
Over-reliance on donor and external funding	4
There are no dedicated budget lines for EWS maintenance.	4
Policy, Legal, and Regulatory Barriers	
Absence of a national EWS strategy	**3**
Outdated building and zoning codes: These often don't include EWS integration or requirements, especially in areas prone to natural disasters.	**4**
Fragmented mandates across sectors: The Department of Transport, Department of Works, National Disaster Centre, and others have no clear legal responsibilities for EWS-related infrastructure.	**4**
Lack of legal enforcement on hazard monitoring: Regulatory gaps exist in requiring real-time data reporting from agencies responsible for volcanoes, weather, or seismic activity.	**3**
Technical Barriers	
Gaps in hazard detection infrastructure: There's limited coverage of automated weather stations, seismographs, river gauges, and tsunami buoys across PNG's vast and rugged terrain.	**3**
Lack of integration between hazard monitoring systems: Systems tracking floods, earthquakes, and volcanic activity are often siloed, delaying coordinated warnings.	**3**
Limited use of GIS and real-time data platforms: Local planners and infrastructure managers often lack access to dynamic hazard maps or early warning dashboards.	**3**
Absence of multi-hazard early warning systems: Most systems are single-hazard-focused and not designed to handle compound events (e.g., earthquake-triggered landslides).	**3**
Human Resource Barriers	
Lack of skilled technical staff: There's a national shortage of meteorologists, geologists, hydrologists, data scientists, and systems operators to design and maintain EWS.	**3**
Limited training for infrastructure operators: Many infrastructure managers (e.g., at ports, airports, and power grids) are not trained to interpret and act on early warnings.	**3**
Urban-rural capacity divide: Skilled personnel are concentrated in Port Moresby and a few urban centres, while rural and hazard-prone areas are underserved.	**4**
Inadequate education and continuous learning programs: Few programs exist to build long-term EWS expertise in universities or technical institutions.	**3**

Barrier Factors	Score
Infrastructure Barriers	
Poor communication and energy networks: Many EWS components (sirens, sensors, SMS alerts) rely on mobile networks and electricity, both of which are unreliable or absent in rural PNG.	**4**
Insufficient integration of EWS with infrastructure: Bridges, roads, and public buildings often lack embedded sensors or protocols to respond to warnings (e.g., automatic road closures or evacuation signals).	**4**
Institutional and Organizational Capacity Barriers	
Fragmented coordination among agencies: Agencies involved in meteorology, infrastructure, disaster management, and communications often lack shared goals or data platforms.	**3**
No institutionalized maintenance systems: After installation, there are few mechanisms in place to regularly test or maintain warning systems.	**4**
Data-sharing restrictions: Lack of MOUs or SOPs between agencies means critical hazard data may not be shared quickly or in usable formats.	4
Social, Cultural, and Behavioural Barriers	
Preference for traditional knowledge: In some regions, communities still rely on natural indicators or ancestral knowledge, ignoring scientific alerts.	**3**
Language diversity: With over 800 languages spoken, crafting effective, understandable alerts that reach everyone is a major challenge.	**4**
Information and Awareness Barriers	
Poor dissemination mechanisms: Alerts may be issued but never reach the right people due to broken channels (e.g., no signal, low phone ownership, lack of radios).	**4**
Lack of local-level simulations or drills: Even good systems fail during real events without practice because people don't know how to respond.	**4**
Infrequent updates and inconsistent alerts: Delayed or inconsistent warning messages confuse the public and lower alert credibility.	**4**

A total of 14 barriers were identified as Significant (score of 4) across multiple thematic categories. These barriers represent critical constraints to the deployment, functionality, and sustainability of Early Warning Systems (EWS) in Papua New Guinea and are summarized below:

1. Economic and Financial Barriers
- Limited national funding for EWS infrastructure – 4
- Over-reliance on donor and external funding – 4
- No dedicated budget lines for EWS maintenance – 4

2. Policy, Legal, and Regulatory Barriers
- Outdated building and zoning codes lacking EWS integration – 4
- Fragmented mandates across sectors with no clear legal responsibilities – 4

3. Human Resource Barriers
- Urban-rural capacity divide, with rural areas underserved – 4

4. Infrastructure Barriers
- Poor communication and energy networks hindering EWS functionality – 4

- Insufficient integration of EWS into infrastructure (e.g., no embedded sensors or protocols) – 4

5. Institutional and Organizational Capacity Barriers

- No institutionalized maintenance systems for EWS – 4
- Data-sharing restrictions between key agencies – 4

6. Social, Cultural, and Behavioural Barriers

- Language diversity challenges for crafting effective, understandable alerts – 4

7. Information and Awareness Barriers

- Poor dissemination mechanisms (e.g., broken channels, low device access) – 4
- Lack of local-level simulations or drills to reinforce preparedness – 4
- Infrequent updates and inconsistent warning messages – 4

The identification of these fourteen significant barriers highlights the pressing need for a coordinated and robust enabling framework to strengthen Early Warning Systems (EWS) in Papua New Guinea. Overcoming these constraints will require integrated efforts across policy reform, institutional coordination, workforce development, and sustained investment in both technology and community outreach. By addressing these critical weaknesses—ranging from funding gaps and regulatory fragmentation to rural service inequities and poor alert dissemination—stakeholders can build a more responsive and inclusive national EWS system. This will not only reduce disaster-related losses but also enhance climate resilience and safeguard the well-being of vulnerable communities across PNG.

2.3.3 Identified Measures for Early Warning Systems (EWS)

Identified measures for Early Warning Systems (EWS) are designed to address a broad spectrum of economic, institutional, regulatory, technical, infrastructural, and socio-cultural constraints that hinder the development, delivery, and uptake of EWS in Papua New Guinea.

Table 15 Identified Measured for EWS Technology

Category	Barrier Description	Identify Measure
Economic and Financial	Limited national funding for EWS infrastructure	Develop co-financing mechanisms leveraging government seed capital and external funds (e.g., ADB, GCF) for scaling EWS infrastructure
Economic and Financial	Over-reliance on donor and external funding	Engage the private sector through CSR and shared value models to co-invest in EWS infrastructure (e.g., sensors on telecom towers)
Economic and Financial	No dedicated budget lines for EWS maintenance	Establish specific budget lines at national and provincial levels for EWS operation and maintenance (O&M)
Policy, Legal, and Regulatory	Outdated building and zoning codes lacking EWS integration	Amend Building and Physical Planning Acts to mandate EWS components (e.g., alarms, signage, safe zones) in infrastructure design
Policy, Legal, and Regulatory	Fragmented mandates across sectors with no clear legal responsibilities	Legislate clear roles and establish a centralized EWS Coordination Unit under the NDC

Category	Barrier Description	Identify Measure
Human Resource	Urban-rural capacity divide, with rural areas underserved	Deploy mobile technical support units and expand provincial training centers; offer rural service incentives
Infrastructure	Poor communication and energy networks hindering EWS functionality	Deploy solar-powered, low-bandwidth EWS infrastructure and partner with telecom/power utilities to host EWS devices
Infrastructure	Insufficient integration of EWS into infrastructure (e.g., no embedded sensors or protocols)	Embed EWS features into infrastructure design standards and implement smart retrofitting in public assets
Institutional and Organizational	No institutionalized maintenance systems for EWS	Develop and enforce a national EWS maintenance and calibration protocol, with assigned responsibilities at national and subnational levels
Institutional and Organizational	Data-sharing restrictions between key agencies	Develop MOUs and SOPs for real-time inter-agency hazard data exchange and alert generation
Social, Cultural, and Behavioural	Language diversity challenges for crafting effective, understandable alerts	Establish community-based EWS committees; co-design local alert formats; integrate indigenous knowledge into protocols
Information and Awareness	Poor dissemination mechanisms (e.g., broken channels, low device access)	Strengthen multi-channel alert systems (e.g., SMS, FM radio, megaphones, posters) and install low-tech relay stations
Information and Awareness	Lack of local-level simulations or drills to reinforce preparedness	Institutionalize annual community-based drills and school simulations linked to alert systems
Information and Awareness	Infrequent updates and inconsistent warning messages	Establish a national EWS message validation and update protocol with standardized templates and alert levels

2.4 Linkages of the Barriers Identified

The barrier assessment for **Climate-Resilient Infrastructure (CRI) and Early Warning Systems (EWS)** in Papua New Guinea highlights a high degree of overlap across economic, policy, technical, institutional, and socio-cultural domains. These shared barriers illustrate the systemic nature of constraints affecting climate adaptation technologies. For instance, infrastructure that lacks embedded early warning capabilities reflects a convergence of technical, financial, and institutional deficiencies. Similarly, limitations in community engagement, risk awareness, and communication systems hinder the effectiveness of both resilient infrastructure and early warning delivery. Recognizing these interlinked barriers is essential to developing integrated and synergistic enabling frameworks that can deliver scalable, cost-effective, and climate-resilient outcomes across sectors **(table 16)**.

Table 16 Linkages of the Barriers Identified for CRI and EWS in PNG

Category	CRI Barrier	EWS Barrier	Shared Barrier
Economic & Financial	High upfront costs for resilient designs; limited national budget; reliance on donor support	Limited funding for infrastructure and maintenance; over-reliance on donors	Inadequate domestic financing and lack of long-term funding mechanisms
Policy, Legal & Regulatory	Outdated building codes; fragmented mandates; absence of land-use risk integration	No national EWS strategy; outdated zoning laws; overlapping agency roles	Weak policy frameworks and institutional fragmentation
Technical	Limited climate-resilient design capacity; lack of risk data integration into planning tools	Poor hazard detection coverage; lack of integrated monitoring systems	Inadequate access to climate and hazard data; weak design integration
Infrastructure	Vulnerable and inaccessible infrastructure; informal settlements lacking resilient features	Poor communication/energy networks; lack of embedded sensors	Infrastructure gaps reducing resilience and weakening EWS functionality
Institutional & Organizational	Weak inter-agency coordination; slow procurement and planning processes	Lack of maintenance systems; poor inter-agency data sharing	Institutional inefficiencies and coordination failures
Human Resource	Shortage of climate-literate engineers and planners, especially at local levels	Rural-urban technical capacity divide; lack of trained operators	Human resource constraints in subnational implementation
Social, Cultural & Behavioural	Public preference for low-cost infrastructure; limited consultation in design	Language diversity; traditional beliefs overriding alerts	Low community engagement and culturally fragmented risk communication
Information & Awareness	Limited public awareness of climate risks in infrastructure planning	Weak dissemination channels; lack of drills; inconsistent messages	Poor risk communication, low preparedness, and lack of continuous awareness

The barrier assessment reveals significant overlaps between CRI and EWS across multiple domains. Both sectors face economic and financial constraints, including high upfront costs and dependence on donor funding, highlighting the need for long-term, domestic financing solutions. In the policy and regulatory domain, outdated codes and fragmented institutional mandates hinder effective integration of resilience and early warning requirements. Technical limitations—such as the lack of localized climate and hazard data—impede risk-informed design for both infrastructure and EWS.

Infrastructure-related challenges include poor communication and energy systems and the absence of embedded resilience features, undermining the functionality of both CRI and EWS. On the institutional level, weak coordination and inadequate maintenance systems further constrain performance. Both technologies also suffer from human resource deficits, particularly in rural areas where skilled staff are lacking. Social and cultural barriers, including low community engagement and language diversity, reduce the effectiveness of outreach and preparedness. Finally, limited awareness and risk communication systems contribute to low public readiness and system credibility.

2.5 Enabling Framework for Overcoming the Barriers in Infrastructure Sector

To effectively address the interlinked barriers that hinder the adoption of climate-resilient infrastructure (CRI) and early warning systems (EWS) in Papua New Guinea (PNG), this enabling framework is structured into two levels:

Level 1: Cross-Cutting (Systemic) Enabling Measures
These measures target shared barriers and propose integrated solutions to advance both CRI and EWS simultaneously.

Table 17 Cross-Cutting Enabling Measures for CRI and EWS

Category	Shared Barrier	Synergistic Enabling Measure
Economic & Financial	Inadequate domestic financing and over-reliance on donor funding	Develop blended finance models with government seed capital; establish CRI-EWS co-financing facilities via GCF/ADB.
Policy, Legal, & Regulatory	Outdated regulations and fragmented mandates	Create a unified national CRI-EWS strategy; update Building and Planning Acts to mandate integration of EWS.
Technical	Limited data infrastructure and localized toolkits	Establish national CRI-EWS data integration platforms and localize GIS-based hazard mapping systems.
Human Resource	Shortage of skilled staff, especially in rural areas	Deploy mobile technical units; establish joint training programs and certification tracks for CRI-EWS experts.
Infrastructure	Weak foundational infrastructure, especially in rural areas	Deploy solar-powered EWS infrastructure; embed EWS sensors in resilient infrastructure design standards.
Institutional & Organizational	Lack of coordination and unclear mandates	Establish a National CRI-EWS Coordination Unit under NDC; create inter-agency MOUs and data SOPs.
Social, Cultural & Behavioural	Low community engagement and communication barriers	Form local CRI-EWS committees; co-design alerts with community input; integrate traditional knowledge.
Information & Awareness	Poor dissemination and low EWS literacy	Use multilingual alerts; run public drills and school simulations; institutionalize EWS education in curricula.

Level 2: Technology-Specific Alternative Measures

Level 2 of the enabling framework presents technology-specific alternative sets of measures for each prioritized technology—Climate-Resilient Infrastructure (CRI) and Early Warning Systems (EWS). These alternatives are designed to offer flexibility in implementation, allowing decision-makers to choose approaches that align best with available resources, local capacities, and stakeholder contexts.

A. Climate-Resilient Infrastructure (CRI)

Measure Set A	**Measure Set B**
Provide subsidies or tax relief for climate-resilient materials.	Promote public-private partnerships for resilient retrofitting.
Develop national CRI technical guidelines.	Pilot CRI innovation hubs at subnational level.
Prioritize retrofitting of key infrastructure (schools, clinics).	Integrate smart sensors and modular resilient designs in new infrastructure.
Incorporate CRI into national and provincial planning budgets.	Enable community-based CRI maintenance programs.

Expected Outcomes:

- Set A ensures rapid institutional alignment and technical guidance.
- Set B fosters long-term innovation and local ownership.

B. Early Warning Systems (EWS)

Measure Set A	**Measure Set B**
Expand AWS network and national hazard detection coverage.	Promote low-cost community-based hazard sensors.
Standardize alert protocols and use SMS/radio posters.	Use gamified and app-based platforms to improve public engagement.
Train national agencies on SOPs and emergency response.	Conduct localized training through church groups and CSOs.
Establish centralized verification and update protocols.	Enable community-led drills and integrate indigenous signals into alerts.

Expected Outcomes:

- Set A enhances technical capacity and national coordination.
- Set B increases grassroots ownership and resilience.

This two-tier enabling framework provides an integrated and flexible roadmap to accelerate the uptake of CRI and EWS technologies. Level 1 resolves systemic and institutional challenges through cross-sectoral action, while Level 2 provides implementers with distinct but complementary pathways to operationalize each technology according to local needs and capacities.

Chapter 3
Conclusions

The barrier assessments conducted for Climate-Smart Agriculture (CSA), Climate Information and Early Warning Systems (CIEWS), Climate-Resilient Infrastructure (CRI), and Early Warning Systems (EWS) in Papua New Guinea reveal a high degree of interconnection across economic, technical, institutional, and socio-cultural domains. These interlinkages highlight that many challenges—such as high upfront costs, limited financing mechanisms, weak policy alignment, poor infrastructure, and insufficient human resources—are not technology-specific but systemic, affecting multiple adaptation priorities simultaneously.

Recognizing these shared constraints, the enabling frameworks for both agriculture and infrastructure sectors have been designed around two levels. Level 1 proposes cross-cutting, systemic measures that address common barriers through integrated financing models, updated policy and regulatory tools, institutional coordination, and inclusive community-based approaches. These include co-financing facilities, unified national strategies, shared data systems, and joint training programs. Level 2, on the other hand, offers technology-specific alternative measures that provide flexible implementation pathways—whether through centralized, government-led interventions or decentralized, community-driven solutions.

This overlap creates a strong case for **integrated, cross-sectoral solutions**. Instead of addressing each technology in isolation, PNG can:

- **Maximize cost-efficiency** by pooling resources (e.g. blended finance for CRI-EWS or CSA-CIEWS infrastructure).
- **Strengthen governance** through unified strategies and multi-sector coordination units.
- **Build joint technical platforms** (e.g. shared data systems, interoperable early warning dashboards).
- **Deliver co-benefits** like improved community preparedness, food security, and infrastructure resilience in one effort.

Together, these frameworks promote efficiency, scalability, and ownership by aligning national climate goals with local development needs. They also emphasize the value of combining modern science with traditional knowledge, strengthening institutional linkages, and building community trust and participation. Moving forward, implementing these coordinated strategies will be critical for building climate-resilient systems that safeguard lives, infrastructure, and livelihoods in PNG's diverse and vulnerable regions.

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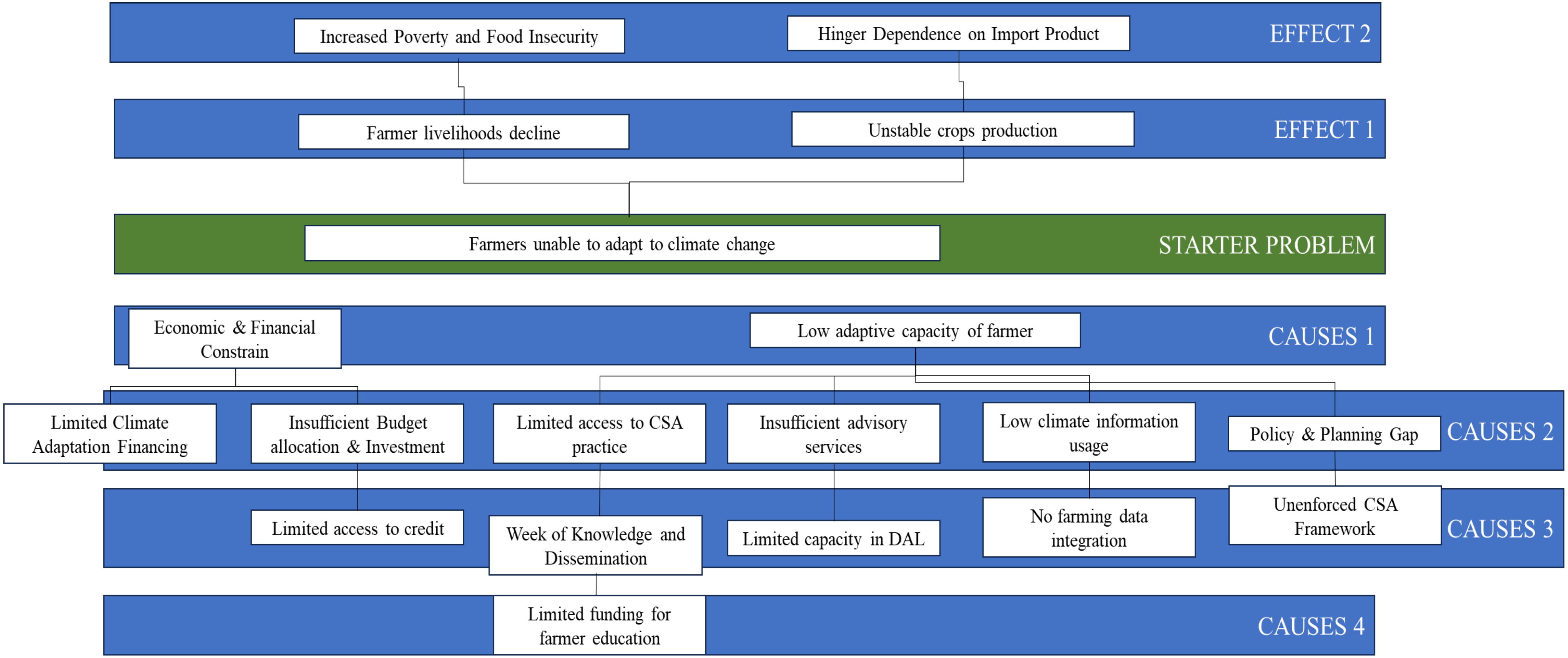
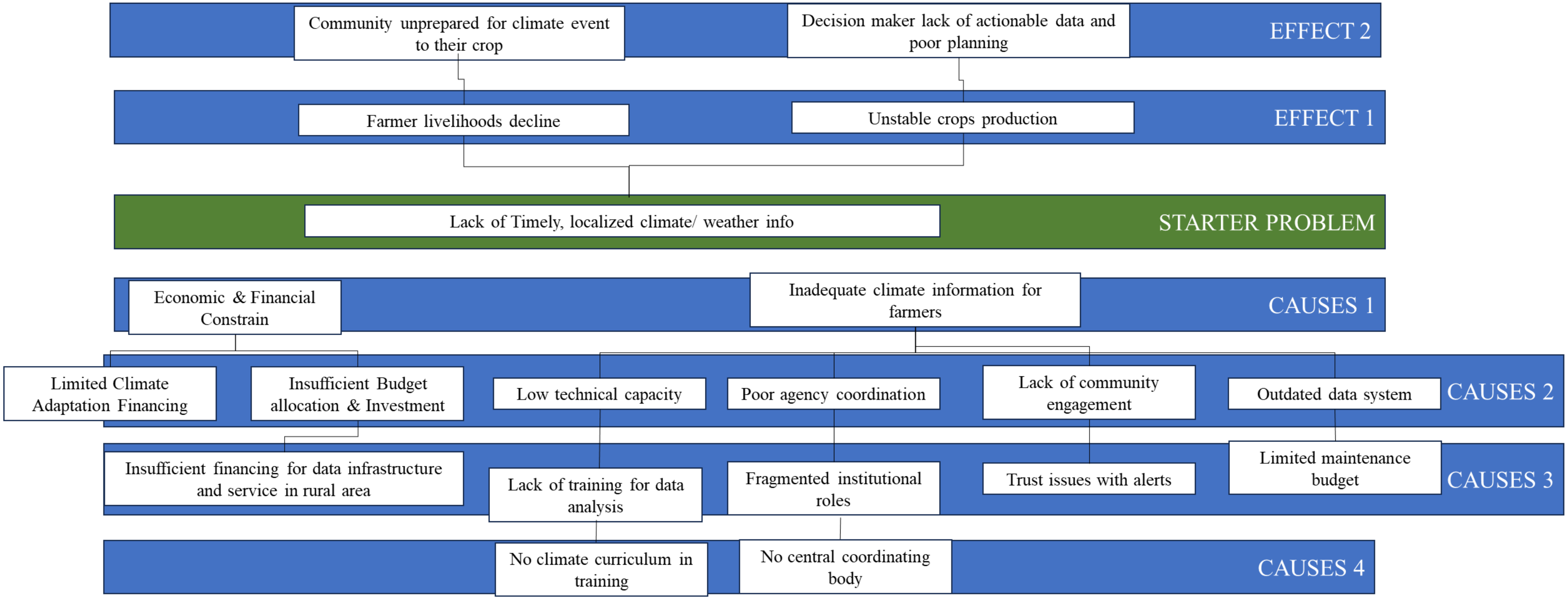
List of Annexes

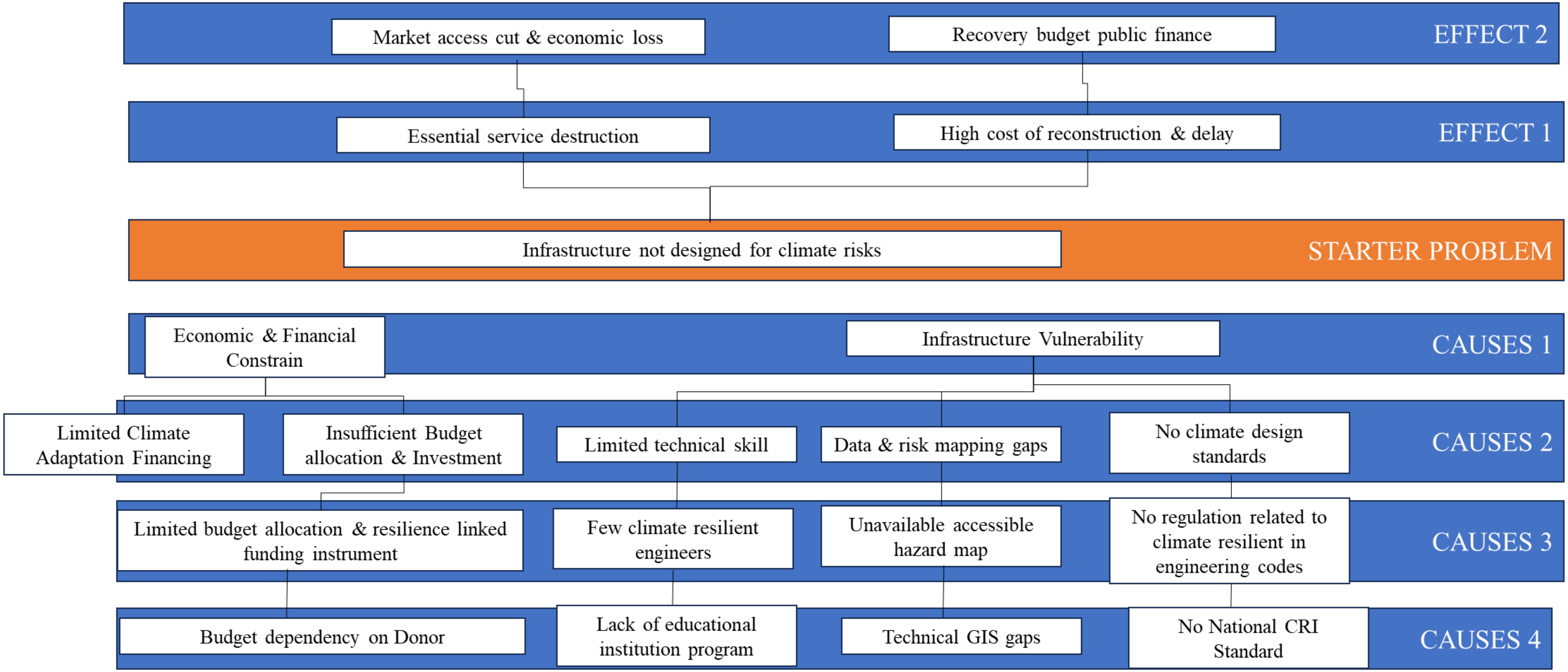
Annex 1: CSA Problem Tree



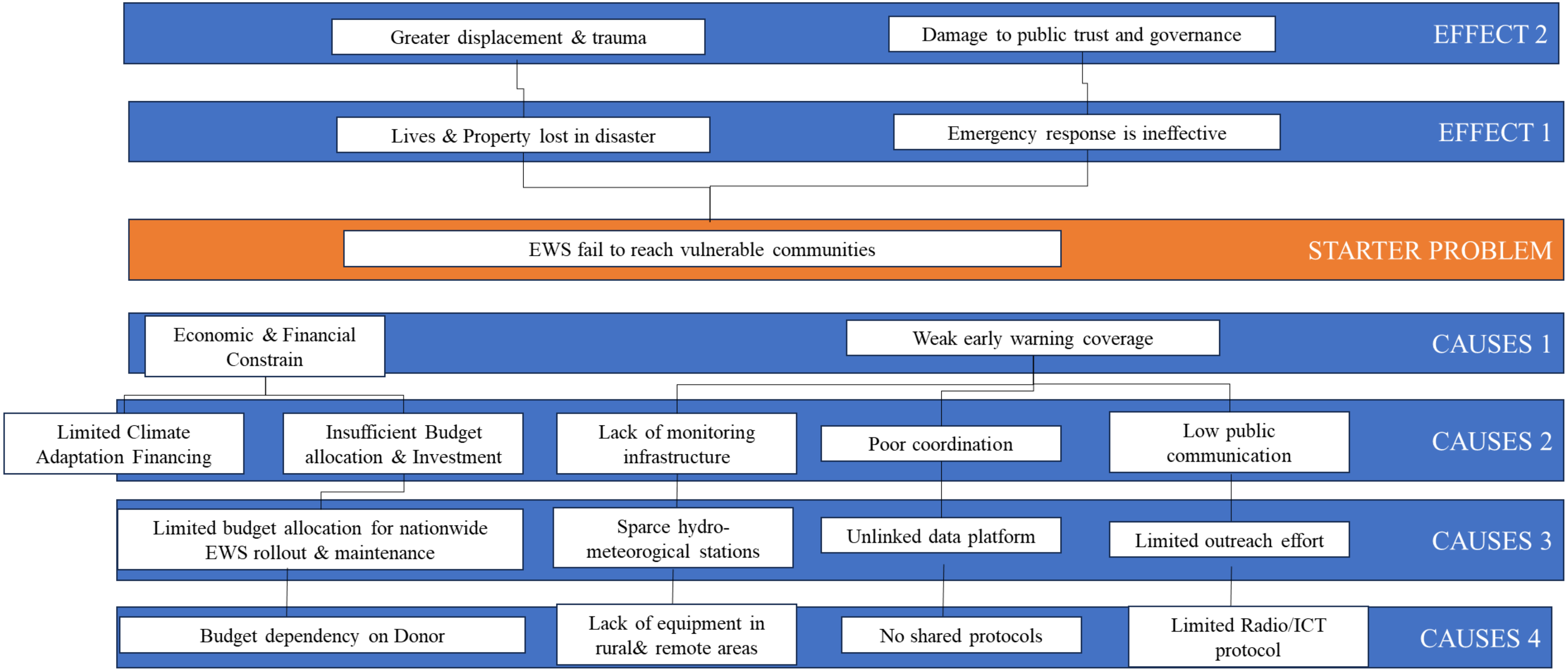
Annex 2: CIEWS Problem Tree



Annex 3: CRI Problem Tree



Annex 4 : EWS Problem Tree



Annex 5: List of stakeholders involved and their contacts

TNA WORKSHOP PARTICIANTS LIST - PNG CLIMATE CHANGE AND DEVELOPMENT AUTHORITY

DATE: 25 MARCH 2025: VENUE - CCDA

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