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Roots of Resilience: Scaling Impact Through Market Integration and Innovation - GAP ANALYSIS

Asian Development Bank | University of Southern Queensland

Disclaimer

The draft document aims to initiate meaningful discussions among industry leaders, government agencies, and other stakeholders about a proposed program designed to protect perennial plantations, including coffee, cocoa, and cashew nuts, as well as small-scale agroforestry, from the physical and financial impacts of climate disasters.

Please note that this document is still in draft form and should not be cited.

For more information, please contact:

Brett Sutton

Senior Agribusiness Climate-Smart Agriculture Advisor
Private Sector Operations Department
Asian Development Bank
Email: bsutton.consultant@adb.org

Shahbaz Mushtaq

Acting Director and Professor of Economics and Finance,
Centre for Applied Climate Sciences
University of Southern Queensland, Australia
Email: Shahbaz.Mushtaq@unisq.edu.au

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Executive summary

This gap analysis reviews the state of climate information services, adaptation and resilience programs, agricultural risk transfer solutions, and ongoing Adaptation Fund (AF) projects in Southeast Asia, with particular attention to perennial crops with coffee, cocoa, cashew nut, and small-scale forestry. The findings highlight persistent systemic gaps that constrain smallholder farmers' adaptive capacity and resilience to climate change.

Climate Information and Services

Climate Information Services (CIS) are increasingly available through global, regional, and national platforms. However, significant gaps remain in **translation, tailoring, and delivery** of this information to smallholder farmers. While advanced models and datasets exist, information is often too technical, fragmented across institutions, and insufficiently localized to guide on-farm decision-making. Farmers cultivating perennial crops require **crop-specific, actionable advisories** (e.g., on rainfall timing, drought probability, or pest/disease outbreaks), yet these are seldom provided. Weak integration between CIS and agricultural extension services further reduces usability and trust among farmers.

Adaptation and Resilience Practices for Perennial Crops

Adaptation practices are emerging but remain largely project-based and fragmented, rather than embedded in national agricultural strategies. Agroforestry, shade management, water conservation, and climate-resilient cultivars show promise, yet adoption rates are limited by financial constraints, delayed returns on investment, and insufficient extension support. Cocoa and coffee producers face shifting cultivation zones due to rising temperatures, while cashew farmers experience increasing yield volatility linked to erratic rainfall. Small-scale forestry is constrained by unclear tenure, weak incentives, and limited institutional capacity. Without systematic scaling, adaptation remains gradual and unsustainable.

Traceability and Adaptation

Traceability systems, particularly blockchain and sustainability certification schemes, are expanding in coffee and cocoa supply chains in response to global market demands. These tools primarily track **compliance with environmental and social standards**, but they rarely integrate **climate adaptation indicators** such as adoption of resilient practices or exposure to climate risks. This disconnect represents a missed opportunity to leverage market-based mechanisms for incentivizing climate-smart agriculture and channelling adaptation finance directly to smallholder farmers.

Agricultural Risk Transfer and Index Insurance

Agricultural risk transfer solutions, especially index-based insurance, remain underdeveloped in Southeast Asia. Uptake is constrained by **low awareness, and affordability barriers**. Perennial crops present particular challenges due to their long production cycles and complex yield-loss dynamics, which are poorly captured in existing insurance models. Current insurance schemes are rarely linked to CIS or broader adaptation programs, reducing their effectiveness as part of an integrated resilience strategy.

Adaptation Fund Projects in Southeast Asia

The Adaptation Fund supports a range of projects in the region, including community-based adaptation, ecosystem restoration, and capacity building for CIS. Notable initiatives strengthen watershed management, promote climate-resilient agriculture, and support smallholder access to finance. However, AF-funded programs remain **limited in scale** relative to the needs of perennial crop sectors. While they have piloted innovative solutions and enhanced institutional capacity, challenges persist in **sustaining**

and scaling impacts beyond project lifetimes. Few large-scale AF initiatives explicitly target coffee, cocoa, cashew, or small-scale forestry.

Key Conclusions

The analysis identifies critical gaps that hinder effective adaptation of perennial crop systems in Southeast Asia:

- **Information gap**: Climate information is available but not localized, trusted, or actionable for smallholders.
- **Practice gap**: Proven climate-smart practices exist but remain fragmented and under-adopted.
- **Traceability gap**: Market-driven traceability systems are not yet aligned with adaptation and resilience objectives.
- **Finance gap**: Agricultural risk transfer solutions for perennial crops are underdeveloped and inaccessible.
- **Scaling gap**: Adaptation Fund projects provide valuable pilots but lack the scale and direct targeting needed to transform perennial crop resilience.

1. Climate information: availability, accessibility, readiness

Southeast Asia stands as one of the world's most vulnerable regions to the escalating impacts of climate change. The region confronts a complex array of environmental threats, including rising sea levels, more frequent and intense extreme weather events such as floods, droughts, and typhoons, and significant losses in biodiversity. This inherent vulnerability is compounded by the region's demographic and economic characteristics: a large and expanding population, extensive low-lying coastlines, and a profound reliance on the agricultural sector and natural resources for economic stability and livelihoods[1][2].

The agricultural, forestry, and fisheries sectors are particularly susceptible to these climatic shifts, yet they simultaneously hold immense potential for safeguarding food security and contributing to the achievement of global Sustainable Development Goals (SDGs)[3]. Observed climate impacts have already manifested in tangible ways, leading to notable reductions in crop yields, as evidenced by a 20% drop in Cambodia's national cashew production in 2022 and a similar 20% decrease in Vietnam's coffee production during the 2023-24 season. Beyond yield reductions, farmers are experiencing impaired crop quality, increased incidence of pests and diseases, stunted crop growth, delays in fruiting and harvesting, and widespread economic losses. Projections paint an even more concerning picture, with forecasts suggesting the potential elimination of suitable robusta coffee cultivation sites in Vietnam by 2050 and the loss of half of the optimal land for major crops globally by 2100.

In the face of intensifying climate threats, Climate Information Services (CIS) emerge as an indispensable resource for empowering local communities and smallholder farmers to effectively manage escalating climate risks. These services enable informed decision-making and proactive adaptation to changing environmental conditions. CIS functions by translating complex scientific climate data, encompassing historical observations, real-time monitoring, and future predictions and projections, into user-relevant and actionable advice. This includes critical information about the onset of seasons, detailed temperature and rainfall projections, and timely warnings for extreme weather events[4].

The utility of CIS extends beyond immediate risk management; these services are pivotal for guiding the broader transformation of agri-food systems towards green and climate-resilient practices. By providing the necessary data and insights, CIS supports the achievement of internationally agreed goals such as the Sustainable Development Goals (SDGs) and the Paris Agreement. The role of CIS is not merely to offer a supplementary tool but to act as a foundational enabler for effective climate change adaptation. It underpins and enhances the efficacy and scalability of other climate-smart agricultural (CSA) strategies, such as agroforestry, improved water management, and the adoption of stress-tolerant crop varieties. Without accessible, relevant, and timely climate information, the potential benefits and return on investment of these adaptation efforts are significantly diminished. Therefore, investments in CIS should be conceptualized and implemented not merely as standalone projects but as integral, foundational components of broader climate change adaptation and sustainable development initiatives in Southeast Asia. This perspective underscores their systemic importance for building regional resilience across all climate-sensitive sectors.

[1] NIC, 2009. Southeast Asia and Pacific Islands: The Impact of Climate Change to 2030 – A commissioned Research Report. https://www.dni.gov/files/documents/climate2030_southeast_asia_pacific_islands.pdf

[2] Nunes LJR, Meireles CIR, Gomes CJP, Ribeiro NMCA. The Impact of Climate Change on Forest Development: A Sustainable Approach to Management Models Applied to Mediterranean-Type Climate Regions. Plants (Basel). 2021 Dec 27;11(1):69. doi: 10.3390/plants11010069. PMID: 35009073; PMCID: PMC8747560.

[3] ASEAN MULTI-SECTORAL FRAMEWORK FOR CLIMATE CHANGE: AGRICULTURE AND FORESTRY TOWARDS FOOD AND NUTRITION SECURITY AND ACHIEVEMENT OF SDGs. https://asean.org/wp-content/uploads/2012/05/ASEAN-Multisectoral-Framework-for-climate-change.pdf

[4] Sebastian L, Bernardo EB. 2019. Making the Smallholder Farmers in Southeast Asia Climate Smart - The CCAFS R4D Thrust. In: Shirato Y, Hasebe A, eds. Climate Smart Agriculture for the Small-Scale Farmers in the Asian and Pacific Region. Taipei, Taiwan: Food and Fertilizer Technology Center (FFTC) for the Asian and Pacific Region and National Agriculture and Food Research Organization (NARO) of Japan. 201-226 p. https://hdl.handle.net/10568/107003

1.1. Availability of Climate Information and Services

1.1.1. Types of Climate Information and Products

The global infrastructure for climate information is robust, with the World Meteorological Organization (WMO) Climate Services Information System (CSIS) serving as the "operational core" for the routine production, archiving, analysis, modeling, exchange, and processing of climate data worldwide. The core functions of CSIS are comprehensive, encompassing the provision of raw climate data, continuous climate monitoring, short-to-medium-term climate prediction, long-term climate projection, and the crucial delivery of user-targeted climate information.

The spectrum of climate information available spans a wide range of temporal and spatial scales. This includes daily weather observations, which provide foundational data on temperature, precipitation, and evaporation. It extends to medium-term forecasts, such as the expected onset of seasons and seasonal outlooks for rainfall and temperatures, which are vital for agricultural planning. Furthermore, the system provides longer-term climate trends and projections, offering insights into future climatic conditions[5]. Advanced Global Climate Models (GCMs) and Regional Climate Models (RCMs) are instrumental in generating these future climate change projections. For Southeast Asia, these models can provide high-resolution data, often downscaled to 25 km, extending up to the year 2100. User surveys in the region have identified primary areas of interest for climate information, including the annual cycle of temperature and precipitation, mean and extreme temperature and precipitation events, and the critical patterns of monsoons[6].

While there is a high level of scientific and technical sophistication in the production of climate information, from global modeling efforts to regional datasets like the Southeast Asian Climate Assessment & Dataset (SACA&D), a notable qualitative observation from users reveals a "low capacity to interpret and correctly use the information"[6]. This indicates a significant disconnect: the sheer volume and scientific rigor of available climate information do not automatically translate into practical usability or actionability for the average end-user, particularly smallholder farmers. The information exists, and it is scientifically sound, but it is not consistently presented in a format that can be readily understood, trusted, or directly applied to on-farm decision-making. This suggests that the mere availability of technically advanced climate information does not guarantee effective adaptation outcomes. A crucial bottleneck lies in the "translation, tailoring, packaging, and communication" phase of the climate services value chain, which must effectively bridge the gap between complex scientific output and the practical decision-making needs and comprehension levels of diverse user groups.

1.1.2. Key Providers and Regional Initiatives

The provision of climate information and services in Southeast Asia involves a diverse ecosystem of actors, ranging from national government bodies to international organizations and regional collaborative platforms. National Meteorological and Hydrological Services (NMHSs) are foundational institutions, responsible for observing weather and climate, providing essential hydromet services, and tailoring these services for various users, including critical early warning systems[7]. Vietnam's National Hydro-Meteorological Service (NHMS), for instance, operates and maintains over 90% of the country's observation networks and provides comprehensive climate prediction services.

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[5] GIZ, Climate services to support adaptation and livelihoods. https://asean-crn.org/wp-content/uploads/2021/09/Full-Brief_03_CIS_Paper-Series_Aug-2021.pdf

[6] Rosanna Amato and David Hein. Southeast Asia Climate Analysis and Modelling Framework. https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/applied-science/precis/southeast_asia_climate_framework.pdf

[7] World Bank and GFDRR, 2018. Strengthening the Regional Dimension of Hydromet Services in Southeast Asia A Policy Note with a Focus on CAMBODIA, LAO PDR, and VIETNAM. https://www.gfdrr.org/sites/default/files/publication/Strengthening%20the%20regional%20dimension%20of%20Hydromet_June%202018_Web.pdf

At the regional level, entities such as Regional Climate Centers (RCCs) and Climate Outlook Forums (RCOFs) play a vital role. The ASEAN Climate Outlook Forum (ASEAN COF) exemplifies such a platform, facilitating the collaborative development of consensus-based seasonal climate outlooks. These outlooks are crucial for supporting regional decision-making and advancing sustainable development initiatives across the member states.

International organizations are also significant contributors to the climate information landscape in Southeast Asia. The World Meteorological Organization (WMO) leads global initiatives like the Global Framework for Climate Services (GFCS) and supports regional projects aimed at strengthening Early Warning Systems (EWS). The Food and Agriculture Organization (FAO) actively promotes Climate-Smart Agriculture (CSA) initiatives, supports agro-climatic monitoring systems, and strives to enhance agricultural productivity and resilience within the region. The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) has notably developed the Climate-Smart Village (CSV) approach, which integrates participatory research-for-development to enhance the productivity and climate resilience of smallholder farmers across various countries in Southeast Asia. Beyond these, a consortium of international development partners, including the Asian Development Bank (ADB), World Bank, United Nations Development Programme (UNDP), Japan International Cooperation Agency (JICA), and United States Agency for International Development (USAID), provide substantial financial and technical support for hydromet services, climate-resilient infrastructure, and a wide array of adaptation projects throughout the region.

ASEAN itself has established crucial initiatives to foster regional cooperation on climate change. The ASEAN Climate Change Initiative (ACCI) and the ASEAN Multi-Sectoral Framework on Climate Change: Agriculture, Fisheries and Forestry towards Food Security (AFCC) serve as key platforms for this collaboration. The ASEAN Climate Resilience Network (ASEAN-CRN) actively contributes to scaling Climate-Smart Villages (CSVs) and advancing climate-smart technologies and practices across the member states.

The extensive array of international and regional organizations, alongside national bodies, demonstrates a widespread recognition of the urgency for CIS and climate adaptation efforts in Southeast Asia. This proliferation of actors, while indicative of strong commitment and diverse expertise, inherently carries the risk of fragmentation, duplication of efforts, and the emergence of inconsistent standards or approaches if not rigorously coordinated. The explicit mention of "disparities in standards and inconsistent reporting" hindering access to climate finance directly supports this concern[8]. This suggests that a lack of harmonization among these numerous initiatives can undermine their collective impact and efficiency. While the availability of institutional support and initiatives is high, the overall effectiveness of CIS delivery and uptake in the region will critically depend on enhanced coordination, the establishment of common standards, and improved interoperability among these diverse actors and platforms. A more unified regional strategy for CIS implementation could significantly maximize the collective impact and ensure that resources are utilized most effectively.

1.1.3. CIS for Perennial Crop Adaptation: Focus on Coffee, Cocoa, and Cashew

Perennial crops, which form a significant economic backbone for many Southeast Asian countries, are particularly susceptible to the adverse effects of climate change. These impacts include escalating temperatures, unpredictable rainfall patterns leading to droughts or floods, and increased outbreaks of pests and diseases. Climate Information Services (CIS) provide crucial, timely information that enables

[8] ASCC Research and Development Platforms Programme. Access to Finance: Issues and Challenges to ASEAN. ASEAN Socio-Cultural Community Flagship Report No. 6 (2024). ASCC Research and Development Platform on Climate Change https://asean.org/wp-content/uploads/2024/11/ASCC-RD_Trend-Report_CC6-2024.pdf

farmers to plan and adapt effectively, particularly concerning the onset of seasons, temperature and rainfall projections, and warnings for extreme weather events.

Coffee: In Vietnam, a major global coffee producer, climate change poses a severe threat. Projections indicate that suitable cultivation sites for robusta coffee could be eliminated by 2050 under certain climate scenarios. Key adaptation strategies being promoted include the adoption of agroforestry, specifically shade-emphasized coffee systems, which help moderate microclimates, reduce air temperatures by up to 5°C, and increase moisture levels, thereby delaying the loss of cultivation suitability. Other strategies involve the development of new climate-adapted robusta varieties and crop diversification. Vietnam's National Sustainability Curricula for both Robusta and Arabica coffee provide practical knowledge and best practices for sustainable production and climate change adaptation, supporting farmers in meeting market requirements[9]. Projects like the Green Climate Fund's FP125 in Vietnam aim to strengthen smallholder coffee farmers' access to agro-climate information, credit, and markets to manage water insecurity. Nestle's Nescafé Plan in Vietnam has demonstrated success by providing training, distributing high-yield and disease-resistant coffee varieties, and promoting improved water management, leading to significant increases in yields (from 2 to nearly 3 tons per hectare) and farmer income (up to 100% increase).

Cocoa: Indonesia, a leading cocoa producer, faces significant challenges from altered precipitation patterns, rising temperatures, and extreme weather events, including increased fungal attacks and prolonged droughts[10]. Agroforestry is highlighted as a critical climate-smart adaptation strategy for cocoa. This practice enhances soil health, reduces erosion, boosts crop productivity by creating a more biodiverse and resilient ecosystem, and diversifies income streams for farmers[11]. Projects such as the Landscape Approach to Sustainable and Climate Change Resilient Cocoa and Coffee Agroforestry (LASCARCOCO) in Indonesia actively train 6,500 cocoa and coffee farmers in sustainable agroforestry practices, promote climate-friendly landscape management, and establish transparent and traceable supply chains. The Cocoa Life Indonesia program has demonstrated tangible benefits, reporting an annual income increase of 37% and a cocoa yield increase of up to 10% for participating farmers through targeted training in climate-smart farming techniques.

Cashew: Cashew cultivation in Cambodia is particularly vulnerable to climate risks, including delayed rainfall, prolonged dry spells, and rising temperatures, which result in reduced yields and compromised nut quality[12]. Recommended adaptation strategies include mulching, conservation agriculture, various soil and water conservation measures, drip irrigation, and the breeding of climate-resilient cashew varieties. The SCALA program in Cambodia facilitates multi-stakeholder consultations, actively promotes climate-resilient practices, works to improve post-harvest infrastructure, and provides access to green loans for farmers and cooperatives. Developing a domestic processing industry for cashews in Cambodia is estimated to significantly increase national income by US$30-40 million annually, adding substantial value to the raw crop.

While coffee, cocoa, and cashew are all perennial crops facing climate change impacts in Southeast Asia, the specific threats and optimal adaptation strategies vary considerably. For instance, coffee's sensitivity to temperature often necessitates shade, while cashew's vulnerability to drought requires specific water conservation measures. This implies that generalized climate information is insufficient for effective adaptation. CIS must therefore provide highly tailored, crop-specific advisories that are directly integrated

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[9] Bracken, P., Burgess, P. J., & Girkin, N. T. (2023). Opportunities for enhancing the climate resilience of coffee production through improved crop, soil and water management. Agroecology and Sustainable Food Systems, 47(8), 1125–1157. https://doi.org/10.1080/21683565.2023.2225438.

[10] Bunn et al, 2017. Global climate change impacts on cocoa. 2017 International Symposium on Cocoa Research (ISCR), Lima, Peru, 13 -17 November 2017. https://www.icco.org/wp-content/uploads/T4.152.-GLOBAL-CLIMATE-CHANGE-IMPACTS-ON-COCOA.pdf

[11] Friedman, 2014. Cocoa in a Changing Climate: Projecting Hot Spots of Vulnerability https://www.researchgate.net/publication/269616565_Cocoa_in_a_Changing_Climate_Projecting_Hot_Spots_of_Vulnerability

[12] Rupa and Rejani, 2013. Impacts of climate change on cashew and adaptation strategies. https://www.researchgate.net/publication/286986608_Impact_of_Climate_Change_on_Cashew_and_Adaptation_Strategies

with recommended agricultural practices. The success stories cited, such as those from Nestlé and Cocoa Life, underscore that effective adaptation for these crops involves not just data, but also practical training, financial support, and market linkages, all of which are informed by precise climate information. A "one-size-fits-all" approach to CIS for perennial crops will be ineffective. Successful implementation requires a deep understanding of crop-specific vulnerabilities and adaptation pathways, ensuring that CIS directly informs, supports, and is integrated into these tailored solutions, rather than being a separate, generic information stream.

1.2. Accessibility of Climate Information and Services

1.2.1. Dissemination Channels and Strategies

The effective dissemination of Climate Information Services (CIS) to smallholder farmers in Southeast Asia relies on a diverse array of communication channels and strategic approaches. Primary channels include traditional media outlets such as newspapers, bulletins, radio, and television, which remain crucial for reaching a broad audience. These are complemented by trained intermediaries, notably agricultural extension officers, who provide direct, localized guidance. In addition, digital platforms have gained prominence, encompassing short messaging service (SMS), the internet, mobile phone applications, and various social media platforms[13, 14].

Among smallholder farmers, radio, television, and SMS are consistently reported as the most prevalent and accessible communication channels, reflecting their widespread reach and ease of use in rural areas. Governments in countries like Indonesia, Malaysia, Myanmar, the Philippines, and Thailand actively leverage popular social media platforms such as Facebook, Twitter, and Instagram to extend their reach and disseminate climate-related information to wider audiences[14].

Beyond traditional and digital media, innovative strategies are being employed to enhance knowledge transfer. "Roving workshops," for instance, provide practical, hands-on experiences with climate-smart agriculture (CSA) and Climate-Smart Villages (CSVs) to community leaders and prospective implementers. This approach allows for direct engagement and experiential learning, fostering a deeper understanding of adaptation practices. The effectiveness of CIS uptake has also been enhanced through the co-production of services with farmers, a participatory approach that integrates various communication methods. This includes forecast visualization, face-to-face interactions, printed media, and smartphone applications, ensuring that the information is relevant and actionable for the end-users[14]. Specific digital tools and platforms are also emerging as key components of dissemination. The Zalo messaging app in Vietnam, for example, delivers agro-climatic bulletins, while the Laos Climate Services for Agriculture (LaCSA) national platform reaches thousands of beneficiaries, demonstrating the potential of tailored digital solutions[15].

The extensive array of dissemination channels, from traditional broadcast media to advanced digital platforms, coupled with the documented preferences of different user groups (e.g., women often preferring radio and social groups[14]), strongly indicates that no single channel can effectively reach the diverse smallholder farming population in Southeast Asia. Relying exclusively on digital means, for instance, would inevitably exclude a significant portion of the farming community due to existing digital literacy gaps or infrastructure limitations. Therefore, a blended approach is essential to ensure broad reach and equitable

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[13] Pulhin et al, 2023. Climate Information Services in Southeast Asia: A systematic Review. The FFTC Journal of Agricultural Policy. https://ap.fftc.org.tw/system/files/journal_article/Climate%20Information%20Services%20in%20Southeast%20Asia%20A%20Systematic%20Review.pdf

[14] Ngigi MW, Muange EN. Access to climate information services and climate-smart agriculture in Kenya: a gender-based analysis. Clim Change. 2022;174(3-4):21. doi: 10.1007/s10584-022-03445-5. Epub 2022 Oct 12. PMID: 36247717; PMCID: PMC9554386.

[15] IKI. Applying seasonal climate forecasting and innovative insurance solutions to climate risk management in the agriculture sector in Southeast Asia. https://www.international-climate-initiative.com/en/project/applying-seasonal-climate-forecasting-and-innovative-insurance-solutions-to-climate-risk-management-in-the-agriculture-sector-in-southeast-asia-18-ii-151-asia-m-agricultural-climate-risk-management/

access. To achieve widespread and equitable accessibility of CIS, a multi-pronged, integrated communication strategy is not merely an option but a strategic imperative. This approach must thoughtfully blend traditional and modern channels, ensuring consistency and interoperability across platforms to effectively cater to the varied needs, preferences, and socio-economic contexts of smallholder farmers.

1.2.2. Barriers to Access for Smallholder Farmers

Despite the diverse dissemination strategies, several significant barriers impede the accessibility and effective utilization of Climate Information Services (CIS) by smallholder farmers in Southeast Asia. These barriers are often interconnected, creating complex challenges for adaptation.

Digital Literacy and Infrastructure Gaps

A fundamental barrier to CIS accessibility is the significant lack of access to essential communication devices, such as mobile phones and televisions, and reliable internet connectivity in many rural areas[14]. While there has been an increase in smartphone adoption rates in the Asia Pacific region (reaching about 64% in 2019[16]), the actual access to and effective use of climate and geospatial products and services in Southeast Asia still lags behind other regions[16]. This disparity suggests a "digital paradox": high adoption rates of basic digital tools do not automatically translate into effective utility of complex digital services.

The design of many digital climate service applications often fails to account for the varying stages of digital adoption among farmers, potentially exacerbating existing digital divides and widening exclusion gaps for smallholders with limited education and digital access[16]. Many apps prioritize download metrics over tangible impact, leading to tools that are technically available but practically unhelpful in improving yields or reducing losses. Furthermore, poor documentation and a lack of transparency in the development of these applications erode user trust and hinder effective utilization[16]. The apparent contradiction between increasing smartphone penetration in Southeast Asia and the persistent challenges in accessing and utilizing digital climate services points to this "digital paradox." This suggests that simply providing hardware or connectivity is insufficient. The core problem lies in the design, usability, and relevance of the digital tools themselves, which often do not align with farmers' actual needs, existing digital literacy levels, or preferred modes of information consumption[16]. Bridging the digital divide for CIS therefore requires a shift from a technology-first approach to a user-centric design paradigm. This involves significant investment in capacity building for digital literacy, ensuring that digital tools are genuinely intuitive, culturally appropriate, and directly actionable for smallholder farmers, rather than merely being available.

Language, Cultural Context, and Information Tailoring

The linguistic diversity of Southeast Asia, coupled with the absence of a unifying language, significantly impedes effective knowledge exchange, even when multilingual applications are available. This challenge extends beyond mere translation; it involves the deeper issue of cultural and contextual relevance. In complex terrains within the region, highly localized microclimates and diverse farming methods are often poorly represented or captured by broad-scale digital climate information, making generic advisories less useful[17].

For CIS to be truly effective, it must be meticulously tailored to users' specific literacy levels, local contexts, and unique needs, moving beyond generic information. Traditional ecological knowledge (TEK) possessed by local communities is frequently overlooked, despite its potential to offer richer, context-specific insights into climate monitoring and adaptation strategies[5]. The barrier of language is more than a simple translation issue; it extends to the deeper challenge of cultural and contextual relevance. Effective CIS

[16] Simelton, E., & McCampbell, M. (2021). Do Digital Climate Services for Farmers Encourage Resilient Farming Practices? Pinpointing Gaps through the Responsible Research and Innovation Framework. Agriculture, 11(10), 953. https://doi.org/10.3390/agriculture11100953
[17] https://ccafs.cgiar.org/news/farmers-southeast-asia-learn-about-climate-smart-agriculture-practices

requires information to be not just linguistically accessible but also culturally resonant, incorporating indigenous knowledge systems, and presented in formats that align with local decision-making processes and social structures. The "last mile" of information delivery is therefore not just about physical reach, but about ensuring cognitive and cultural reception and integration. Successful CIS initiatives must adopt a participatory and co-production approach, actively engaging with local communities to integrate traditional wisdom with scientific data. This ensures that climate information is not only relevant and understandable but also trusted and actionable within diverse local contexts, fostering greater ownership and sustainability of adaptation strategies.

Trust, Relevance, and Actionability of Information

Farmers frequently report a prevailing "mistrust in weather and climate forecasts" and express concerns about the "lack of visual representations" in the information provided, which act as significant barriers to uptake[18]. The perceived reliability and trustworthiness of Climate Information (CI) directly influence farmers' willingness to access and utilize these services for adaptation decisions[14]. A notable gap in app development is the prioritization of download metrics over tangible impacts on yields, leading to the creation of tools that may not genuinely provide impactful advice to farmers. The absence or poor implementation of user feedback mechanisms in app development means that farmers' evolving needs and practical experiences are not adequately incorporated into service refinement[16]. The explicit mention of "mistrust" and the direct correlation between "trust in CI" and "access to seasonal forecasts, early warning systems, and advisory services" underscore a critical, often underestimated, barrier: the psychological and social dimension of trust. If farmers do not perceive the information as reliable, accurate, or actionable, its mere availability becomes irrelevant. This highlights that effective CIS is not solely about data quality but also about the credibility of its source and the clarity of its presentation. Building and sustaining trust is paramount for the widespread adoption of CIS. This requires consistent delivery of accurate, localized, and timely information, coupled with transparent communication, robust feedback mechanisms, and genuine farmer involvement in the design and continuous refinement of services to ensure their perceived relevance and utility.

Socio-economic Constraints and Gender Disparities

Smallholder farmers frequently face severe financial resource limitations, which directly impede their ability to acquire necessary communication platforms (e.g., radios, mobile phones) and invest in crucial adaptation strategies. Women farmers encounter additional, distinct barriers, including lower rates of mobile phone ownership and specific information needs and preferences. They often show a stronger preference for accessing information through traditional channels like radio and social groups, highlighting the need for gender-sensitive dissemination strategies. Furthermore, household size can negatively influence wives' access to seasonal forecasts and advisory services, potentially due to increased domestic responsibilities limiting their engagement with CIS platforms[14]. The data reveals that socio-economic status and gender are not merely demographic descriptors but active, intersecting barriers to CIS access. Lower income directly limits access to technology, while prevailing gender roles and responsibilities influence preferred communication channels and the perceived relevance of information. This signifies that existing societal inequalities are amplified within the context of climate information access, creating systemic disadvantages for already vulnerable groups. CIS initiatives must therefore adopt a deeply gender-sensitive and inclusive design, actively targeting vulnerable groups with tailored delivery methods and addressing underlying socio-economic constraints. This approach is essential to ensure equitable access to and tangible benefits from climate information for all smallholder farmers, thereby contributing to more just and resilient agricultural systems.

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[18] Baffour-Ata, F., P. Antwi-Agyei, E. Nkiaka, A. J. Dougill, A. K. Anning, and S. O. Kwakye, 2022: Climate Information Services Available to Farming Households in Northern Region, Ghana. Wea. Climate Soc., 14, 467–480, https://doi.org/10.1175/WCAS-D-21-0075.1.

1.3. Readiness for CIS Utilization and Adaptation

1.3.1. Institutional Capacity and Governance Frameworks

The institutional readiness for Climate Information Services (CIS) utilization and adaptation in Southeast Asia is characterized by varying capacities among national bodies and a complex landscape of regional governance frameworks.

Capabilities of NMHSs Across Southeast Asian Countries

National Meteorological and Hydrological Services (NMHSs) are pivotal in the provision of hydromet services. While the NMHSs in Cambodia, Lao PDR, and Vietnam provide a basic level of services, they generally lag behind other countries in the region concerning core capacities, advanced forecasting technology, and overall development[7].

Vietnam's National Hydro-Meteorological Service (NHMS) is comparatively more advanced, possessing "good technical and support staff" and managing over 90% of the country's observation networks. It provides climate prediction services, including climate outlooks and agro-meteorological forecasts. Despite these strengths, its existing systems are fragmented, and financial resources are often insufficient to meet the escalating demand for regional and local forecasting. The Vietnamese government has invested in modernizing NHMS facilities and is exploring commercialization programs to extend hydromet services to sectors like energy, agriculture, and transport[7].

In contrast, Cambodia's Department of Meteorology (DOM) faces significant limitations in technical expertise, human resources, and financial resources. It struggles to effectively operate newly acquired systems, such as S-band radar and modern forecaster workstations, due to a lack of experience and dedicated staff. Lao PDR's Department of Meteorology and Hydrology (DMH) is responsible for observations, forecasting, and early warning, and receives financial support from various international bodies, including the World Bank, ADB, Global Environment Facility, and FAO, to strengthen its national capacity. JICA has also provided long-term support, including the installation of C-band Doppler radar and expert training for its operations[7].

Regional Cooperation and Policy Support for CIS Integration

The Association of Southeast Asian Nations (ASEAN) demonstrates a strong commitment to addressing climate change through multisectoral dialogue and collaborative efforts with key partners[19]. Regional platforms, such as the ASEAN Climate Change Initiative (ACCI) and the ASEAN Multi-Sectoral Framework on Climate Change: Agriculture, Fisheries and Forestry towards Food Security (AFCC), are established to foster cooperation on climate change issues. The ASEAN Climate Resilience Network (ASEAN-CRN) actively identifies and promotes priorities for advancing climate-smart technologies, enhancing capacity building, facilitating greater access to climate finance, and strengthening regional coordination for climate action[8]. Policies designed to increase adaptive capacity, such as investments in climate-resilient infrastructure and enhanced climate risk and vulnerability assessments, are crucial for making public and private investments more resilient to climate change impacts[19].

While there is clear political will and a robust framework of regional initiatives and policy documents aimed at promoting climate action and CIS integration, the documented disparities in the capabilities of national NMHSs, as highlighted in the table above, reveal a significant gap. This gap exists between the aspirational goals outlined in high-level policy frameworks and the practical, on-the-ground capacity required for effective implementation. The frameworks are in place, but the national infrastructure, human capital, and

[19] UNFCCC, 2024. Climate Finance Access and Mobilization Strategy for the Member States of the Association of Southeast Asian Nations (2024–2031). https://unfccc.int/sites/default/files/resource/ASEAN_CF%20Strategy_Dec%202024.pdf

operational readiness to fully realize their objectives are often insufficient. Regional cooperation efforts must therefore evolve beyond merely establishing strategic frameworks to focus more intensely on tangible, on-the-ground capacity building and targeted resource allocation at the national and sub-national levels. This is crucial to ensure that high-level policies translate into effective CIS delivery and ultimately, enhanced climate resilience for communities across Southeast Asia.

Research, Development, and Extension Services for CIS Delivery

Increased investment in research, development, and extension services (RDE) is crucial for improving technologies and management systems related to climate change adaptation[8]. The Food and Agriculture Organization (FAO) actively leads training sessions focused on 'Agricultural meteorology for Climate-Smart Agriculture (CSA)'. The CGIAR's Climate-Smart Village (CSV) approach employs a participatory research-for-development methodology to identify and implement effective, context-specific technologies and practices.

Significant efforts are being made in research and development to produce valuable climate-smart technologies and practices, such as agroforestry and climate-adapted crop varieties. However, the persistent challenges reported by farmers in adopting these innovations, including low farmer knowledge, limited financial resources, and delayed profit returns for practices like agroforestry, indicate a substantial lag between the development of new solutions and their widespread uptake. Existing extension services, while intended to bridge this gap, often fall short in effectively facilitating this adoption. Strengthening the "last mile" of RDE for CIS means moving beyond simply developing new technologies. It requires a critical focus on improving the mechanisms for knowledge transfer, providing practical, hands-on training, and implementing financial de-risking strategies to accelerate the adoption of climate-smart practices by smallholder farmers. This ensures that innovations translate into tangible benefits on the ground.

1.3.2. User Capacity and Engagement

The readiness of smallholder farmers to utilize CIS and adapt to climate change is a complex interplay of their perceptions, knowledge, existing adaptive behaviors, and the effectiveness of capacity-building initiatives.

Farmer Perceptions, Knowledge, and Adaptive Behaviors

A high percentage of smallholder farmers (81.8%) perceive that the local climate is changing, with a majority reporting increased temperatures (71.9%) and decreased rainfall distribution (53.15%)[20]. Farmers demonstrate a high awareness of climate risk and its direct impacts on their livelihoods. Many are already independently adopting autonomous adaptation strategies, including adjusting their seasonal calendars, utilizing tolerant crop varieties, implementing integrated crop production models, and diversifying their income sources[21].

However, significant barriers hinder the implementation of more comprehensive adaptation strategies. These include market price fluctuations, a shortage of skilled labor, a lack of specific climate change information, and a perceived lack of capacity to learn and apply new techniques. A substantial portion of farmers (43.9%) perceive their capacity to access agricultural information and techniques related to climate change as poor to very poor[21]. The research clearly indicates that smallholder farmers possess a high level of awareness regarding climate change and its direct impacts on their agricultural practices and livelihoods[20]. This foundational awareness is a positive starting point. However, the concurrent reports of

[20] Belay A, Oludhe C, Mirzabaev A, Recha JW, Berhane Z, Osano PM, Demissie T, Olaka LA, Solomon D. Knowledge of climate change and adaptation by smallholder farmers: evidence from southern Ethiopia. Heliyon. 2022 Dec 5;8(12):e12089. doi: 10.1016/j.heliyon.2022.e12089. PMID: 36544823; PMCID: PMC9761729.

[21] Phuong, L. T. H., Biesbroek, G. R., Sen, L. T. H., & Wals, A. E. J. (2017). Understanding smallholder farmers' capacity to respond to climate change in a coastal community in Central Vietnam. Climate and Development, 10(8), 701–716. https://doi.org/10.1080/17565529.2017.1411240.

"lack of capacity to learn and apply techniques" and "poor to very poor" access to relevant information highlight a critical disconnect. Awareness alone is insufficient; the challenge lies in translating this knowledge into concrete, supported, and effective adaptive behaviours. Farmers understand the problem but often lack the means or specific guidance to act effectively. CIS initiatives should not assume that increased awareness automatically leads to adaptive action. Instead, they must strategically focus on providing practical, hands-on training, ensuring accessible and actionable information, and actively addressing the underlying socio-economic and informational barriers that prevent farmers from implementing necessary adaptation measures.

Capacity Building and Training Programs for CIS Uptake

Targeted training programs in Climate-Smart Agriculture (CSA) are vital for empowering smallholder farmers to enhance their resilience to climate change.[14] Vietnam's development of National Sustainability Curricula for both Robusta and Arabica coffee provides standardized knowledge and best practices specifically for sustainable production and climate change adaptation.[1]

Climate-Smart Villages (CSVs) serve as effective "real-life laboratories" and "field laboratories" for developing and demonstrating gender-sensitive CSA technologies and approaches. These initiatives also provide crucial platforms for youth participation in community-based climate actions.[36] Roving workshops are utilized to provide practical experiences with CSA and CSVs to community leaders and potential implementers, facilitating knowledge transfer and skill development[22]. The LASCARCOCO project in Indonesia exemplifies targeted training by instructing cocoa and coffee farmers in sustainable agroforestry practices, which enhance both productivity and climate resilience. The Cocoa Life Indonesia program has demonstrated significant success, leading to a 37% increase in farmer income and up to a 10% increase in cocoa yield through its training in climate-smart farming techniques, showcasing the tangible benefits of such programs[23].

The documented successes of localized initiatives like Climate-Smart Villages and specific training programs (e.g., Nestlé's Nescafé Plan, Cocoa Life, LASCARCOCO) clearly demonstrate that targeted capacity building can lead to significant improvements in farmer outcomes, including increased yields and income. These models prove the efficacy of integrated training and practical application. However, scaling these localized successes across the vast, diverse, and often remote smallholder farming population of Southeast Asia remains a formidable challenge, frequently constrained by limited resources, logistical reach, and the inherent need for highly context-specific adaptations. While pilot projects provide compelling evidence of effectiveness, a regional strategy for capacity building must prioritize the development of scalable models. This involves training local intermediaries, integrating lessons learned into national agricultural extension services, and ensuring that training content and delivery methods are adaptable to diverse agro-ecological and socio-cultural contexts to achieve widespread, sustainable impact.

Community-Based Approaches and Participatory Design of Services

Community-based approaches are fundamental to enhancing user readiness and ensuring the relevance of CIS. Climate-Smart Villages (CSVs) exemplify this by utilizing a "participatory research-for-development approach" to effectively identify and implement context-specific technologies and methods in agriculture. Direct engagement with local communities is essential for identifying and incorporating their traditional ecological knowledge (TEK) into climate services[5]. This integration can provide richer, more nuanced insights into climate monitoring and adaptation strategies, as TEK often offers invaluable local context and

[22] CGIAR. Climate-Smart Villages in Southeast Asia. https://www.cgiar.org/annual-report/performance-report-2019/climate-smart-villages-in-southeast-asia/
[23] Mondelez International. FIVE YEARS OF COCOA LIFE EMPOWERING COCOA FARMERS IN INDONESIA. https://www.cocoalife.org/progress/5-years-of-cocoa-life-empowering-cocoa-farmers-in-indonesia/

historical understanding. Increasing the roles of local stakeholders and community-based organizations (CBOs) is critical for enhancing farmer capacity and promoting continuous social learning in adaptation, fostering a sense of ownership and collective action.

The traditional "top-down technocratic approach" to climate adaptation is increasingly recognized as less effective[24]. The emphasis across various initiatives on "participatory research-for-development"[22] and the explicit call for incorporating "traditional ecological knowledge"[5] signal a crucial paradigm shift. This transition moves from a model where scientific solutions are simply delivered to society, to one where knowledge is co-produced with society. This ensures that climate information and adaptation strategies are not only scientifically sound but also culturally relevant, locally appropriate, and owned by the communities they are intended to serve. Future CIS initiatives and adaptation programs in Southeast Asia should prioritize genuine co-design and co-production with local communities. This involves moving beyond mere consultation to empower farmers and local stakeholders as active participants in developing, refining, and disseminating climate solutions, thereby fostering greater relevance, trust, and long-term sustainability.

1.3.3. Funding Landscape and Investment Gaps for Adaptation

Challenges in Mobilizing Climate Finance for Smallholders

The funding landscape for climate change adaptation in Southeast Asia, particularly for smallholder farmers, is marked by significant challenges and persistent investment gaps. Smallholder farmers in developing countries face substantial constraints in accessing financial services, with a staggering statistic indicating that only 1% of their long-term credit needs are met in South and Southeast Asia. The Philippines alone confronts an estimated USD 6 billion agricultural credit gap, primarily driven by high perceived risks by lenders, a mismatch between traditional lending practices and smallholder needs, and a critical lack of supply chain data.

Farmers often exhibit hesitation in adopting beneficial adaptation strategies like agroforestry due to limited financial resources and the delayed profit returns associated with such investments. Broader challenges associated with investing in adaptation include diverse funding needs, the absence of a standardized definition for adaptation, and the inherent context-specificity of adaptation projects, which makes them harder to scale and finance through traditional mechanisms. Private sector investment in climate adaptation for smallholder farmers remains nascent, despite Southeast Asia being identified as the most active region for investment in smallholder-relevant adaptation technology, attracting $1.9 billion since 2012. The substantial agricultural credit gap for smallholders is not solely a problem of insufficient capital; it is fundamentally shaped by the "risk perception" barrier to finance. This means that lenders perceive smallholder agriculture, especially climate adaptation measures with delayed returns like agroforestry, as high-risk investments. This perception, coupled with the inherent financial constraints of smallholders and the delayed profitability of certain climate-smart practices, creates a significant disincentive for both farmers to adopt and lenders to invest. Overcoming this requires innovative financial mechanisms that de-risk adaptation investments for smallholders and align financial incentives with long-term climate resilience goals.

Southeast Asia is profoundly vulnerable to climate change, with its agricultural sector and millions of smallholder farmers bearing a disproportionate burden. While there is a clear recognition of the imperative for Climate Information Services (CIS) and a proliferation of initiatives from national, regional, and international actors, significant disparities and challenges persist across the availability, accessibility, and readiness dimensions.

[24] Cuni-Sanchez, A., I. Twinomuhangi, A. Berta Aneseyee, B. Mwangi, L. Olaka, R. Bitariho, T. Soromessa, B. Castro, and N. Zafra-Calvo. 2022. Everyday adaptation practices by coffee farmers in three mountain regions in Africa. Ecology and Society 27(4):32. https://doi.org/10.5751/ES-13622-270432

The availability of scientific climate data and advanced modeling is substantial, yet a critical gap exists between this sophisticated information and its practical utility for end-users. This highlights that simply producing data is insufficient; effective CIS requires meticulous translation, tailoring, and packaging to meet the specific needs and comprehension levels of diverse farming communities. The numerous regional and international initiatives, while demonstrating commitment, face the risk of fragmentation and inconsistent standards, necessitating enhanced coordination and harmonization to maximize their collective impact.

Accessibility remains a formidable barrier, particularly for smallholder farmers. The "digital paradox" reveals that increasing smartphone penetration does not automatically translate into effective utilization of digital climate services, often due to app design flaws, low digital literacy, and a lack of transparency. Language and cultural differences present a "last mile" challenge that extends beyond mere translation to the deeper integration of traditional ecological knowledge and culturally resonant communication. Crucially, trust in climate forecasts is paramount, and its absence, coupled with socio-economic constraints and gender disparities, exacerbates inequalities in information access. The emerging role of traceability systems, especially digital ones, offers a promising, market-driven catalyst by linking sustainable practices to economic incentives, thereby promoting climate-smart agriculture through supply chain transparency.

Institutional readiness varies significantly across the region, with national meteorological and hydrological services exhibiting diverse capabilities. Despite high-level policy intent and regional cooperation frameworks, a substantial gap exists between aspirational goals and the on-the-ground capacity for effective implementation. Furthermore, while farmers are highly aware of climate risks and engage in autonomous adaptation, they often lack the practical means, specific guidance, and financial resources to adopt more comprehensive climate-smart practices. This "innovation-to-adoption lag" is a critical bottleneck.

To foster a more robust, equitable, and effective CIS ecosystem in Southeast Asia, the following recommendations are put forth:

1. **Prioritize User-Centric Design and Co-Production:** Shift from a "science-for-society" to a "science-with-society" approach. CIS initiatives should actively involve smallholder farmers and local communities in the co-design, development, and refinement of climate information products and services. This ensures that information is relevant, actionable, and trusted, integrating traditional ecological knowledge with scientific data.
2. **Implement Integrated, Multi-Channel Dissemination Strategies:** Acknowledge that no single channel can reach all diverse farming communities. Develop blended communication strategies that judiciously combine traditional media (radio, TV), trained intermediaries (extension officers), and tailored digital platforms (SMS, localized apps). Invest in digital literacy training alongside infrastructure development to ensure that digital tools are genuinely usable and beneficial.
3. **Strengthen Foundational Institutional Capacities:** Address the disparities in national meteorological and hydrological services through targeted investments in human resources, technical expertise, and modern forecasting technology. Regional cooperation efforts should focus on tangible capacity building and resource allocation at national and sub-national levels to bridge the gap between policy intent and implementation capacity.
4. **Develop Innovative Financial Mechanisms:** Overcome the "risk perception" barrier to finance by designing and scaling financial products (e.g., green loans, blended finance, climate-indexed insurance) that de-risk adaptation investments for smallholders. These mechanisms should be linked to the adoption of climate-smart agricultural practices and potentially integrated with traceability systems to unlock market-based incentives.

5. **Foster Sector-Specific and Context-Tailored Solutions:** Recognize that adaptation needs vary significantly across different perennial crops (e.g., coffee, cocoa, cashew) and agro-ecological zones. CIS should provide highly tailored, crop-specific advisories that are directly integrated with recommended agricultural practices, ensuring that information is precise and directly applicable to farmers' livelihoods.
6. **Enhance Monitoring, Evaluation, and Feedback Loops:** Establish robust systems for continuous monitoring and evaluation of CIS effectiveness, focusing on tangible impacts on farmer resilience, productivity, and income. Crucially, these systems must incorporate strong feedback mechanisms from end-users to ensure ongoing adaptation and improvement of services.

2. Perennial crops

Perennial crops play a vital role in the economies and livelihoods of Southeast Asian nations. However, their long-term nature makes them particularly vulnerable to the accelerating impacts of climate change and increasing climate variations. There has been a disconnection between the significant contributions of perennial crops and the insufficient attention and investment in climate adaptation strategies, particularly from governmental bodies that often prioritize staple annual crops. Addressing these gaps is crucial for ensuring food security, economic stability, and environmental sustainability in the face of a changing climate.

2.1. Role of perennial crops

Perennial crops are significant contributors to the economy of Southeast Asian countries, driving both national GDP and export revenues while being the major source of income and livelihood for millions of smallholder farmers.

2.1.1. Coffee

Coffee is a key cash crop in the region, contributing around 7.5 billion US$ in export earnings in 2024 alone. The major producers of coffee in the region include Vietnam, the world’s second-largest coffee exporter with approximately 1.5 million tonnes of coffee, valued at US$5.43 billion, in 2024, involvinh around 650,000 growers. Following Vietnam is Indonesia, which has approximately 1.8 million growers cultivating a diverse range (Arabica and Robusta) of coffee varieties, valued approximately US$1.1 billion in 2024. Papua New Guinea also makes a significant contribution, with 280,000 farmers recognised for their unique flavour profiles and sustainable cultivation practices. Cambodia and Laos have smaller, yet growing coffee sectors, with about 100,000 and 40,000 growers, respectively, working to enhance their market presence. Finally, the Philippines, although on a smaller scale, has a dedicated community of approximately 15,000 growers striving to revitalise the country’s coffee heritage.

2.1.2. Cocoa

Cocoa production in Southeast Asia involves a substantial number of smallholder farmers and plays a modest but growing role in national economies, particularly in terms of rural livelihoods. Indonesia is the region's largest cocoa producer, with around 1.7 million smallholder farmers representing 98% of cocoa plantations in the country, making cocoa a key agricultural commodity with export value of US$2.6 million in 2024. In Papua New Guinea, cocoa farming supports approximately 150,000 families and benefits about two million people, with over 80% of production coming from smallholders, contributing US$117 million exported value to the economy in 2023. The Philippines reported over 74,000 cacao farmers as of 2024, while Vietnam has more than 12,000 cocoa growers cultivating small plots. In Timor-Leste, projects like CACAO aim to assist up to 19,000 farmers, though national totals are unclear. Emerging sectors in Laos and Cambodia are supported by development projects targeting thousands of new farmers, with Cambodia having a few hundred early adopters. Across these countries, smallholder farmers—typically managing farms under 5 hectares—are central to cocoa cultivation, which, while not always a dominant contributor to GDP or export value, represents an important source of income and rural development.

2.1.3. Cashew nut

Cashew nut production in Southeast Asia is a key livelihood activity for hundreds of thousands of smallholder farmers and contributes notably to local economies through employment and export potential. Vietnam leads the region, with over 200,000 farming households involved and the broader industry employing up to half a million people, contributing US$4.37 billion to the nation's exported value in 2024. Cambodia had around 70,000 rural families growing cashew in 2018, with nearly 20,000 households registered with the national cashew association by 2024 with the exported value of approximately US$1.5 billion. Indonesia has an estimated 300,000–400,000 smallholders, especially in eastern provinces. Timor-Leste recorded approximately 6,500 small farms growing cashew across 3,200 hectares, within an agricultural sector employing a majority of the population. In Lao PDR, Philippines and Papua New Guinea, data on cashew farming is limited, however, the cashew value chain in these countries involves hundreds of thousands of people. Overall, cashew farming in the region is dominated by smallholders and plays an important role in rural employment and income generation, especially in Vietnam and Cambodia.

2.1.4. Small scale forestry

Small-scale forestry in Southeast Asia is an important livelihood component for millions of smallholder farmers, contributing to rural incomes and, in some countries, export-oriented plantation forestry. Indonesia leads the region, with around 15 million smallholders managing over 1.5 million hectares of planted forests, making a significant contribution to both the economy and timber production. Vietnam also has a well-established small-scale forestry sector, with approximately 1.5 million smallholder farmers, managing almost 2 million ha of forestry plantations. In other countries in the region, smallholders engage in tree management with varying levels of commercial intent with a large share of rural smallholders rely on forestry-related activities, such as fuelwood collection and non-timber forest products, as part of diversified agricultural livelihoods.

2.2. Impacts of climate change and climate variations

2.2.1. Coffee

Climate change and climate variations are significantly impacting coffee production across Southeast Asia, a region that includes major global producers like Vietnam and Indonesia. These impacts threaten not only the quantity and quality of coffee beans but also the livelihoods of millions of smallholder farmers. Rising temperatures cause heat stress in coffee plants, disrupting flowering and fruit development, which ultimately reduces yields and negatively impacts bean quality by altering their size, weight, and flavour profile. Simultaneously, erratic rainfall, characterized by prolonged droughts and excessive downpours, leads to water stress, poor cherry development, soil degradation, and increased susceptibility to diseases like root rot and coffee leaf rust, further exacerbating yield losses[25, 26]. Additionally, climate change's warmer and wetter conditions are creating favourable environments for the proliferation of major coffee pests and diseases, such as the coffee berry borer and coffee leaf rust, resulting in more prevalent and severe outbreaks that lead to significant crop losses and increased production costs.

Furthermore, as temperatures rise, the ideal altitudinal range for coffee cultivation is shifting upwards. This forces farmers to either seek new, higher-altitude lands (which may not be available or accessible) or

[25] Bilen, 2022. A Systematic Review on the Impacts of Climate Change on Coffee Agrosystems. https://doi.org/10.3390/plants12010102
[26] https://doi.org/10.61511/jcreco.v1i1.645

switch to more heat-tolerant but often less valuable Robusta varieties[1]. By 2050, up to 50% of currently suitable land for coffee cultivation globally may be lost, with significant implications for major producing nations like Vietnam and Indonesia. Altitude shifts in suitable growing zones are pushing farmers to cultivate coffee at higher elevations, often in limited or ecologically sensitive areas.

In 2016, Vietnam's coffee production declined by approximately 320,000 tons due to drought, resulting in an estimated financial loss of over USD700 million, which affected the livelihoods of thousands of smallholder coffee producers. One of the key coffee-producing regions, Dak Lak, experienced yield losses of up to 25%, resulting in a regional economic loss exceeding USD250 million.

These climatic challenges not only threaten regional coffee exports and rural incomes but also undermine long-term sustainability. Adaptation strategies, such as investing in climate-resilient coffee farming techniques and sustainable land management practices, are crucial for ensuring the long-term viability of coffee farming in the region.

2.2.2. Cocoa

Climate change and climate variations pose significant threats to cocoa production in Southeast Asia, a region that includes major producers like Indonesia and Malaysia. These impacts manifest in several ways. Cacao trees thrive within specific temperature ranges, and rising temperatures, especially prolonged periods above 32°C, lead to heat stress. This can reduce flowering, impair pod development, decrease bean size and weight, and negatively affect the cocoa's flavour profile[27]. While some areas like Malaysia already experience higher temperatures than West Africa, increased heat can still lead to higher evapotranspiration and moisture loss, stressing the trees. Besides, climate change is disrupting cocoa's crucial balance of wet and dry seasons, leading to erratic rainfall patterns that cause prolonged droughts, resulting in water stress, hindered flowering, smaller beans, and crop failure, while excessive rainfall or flooding promotes root rot, nutrient leaching, soil erosion, and increased susceptibility to fungal diseases like black pod. Warmer and more humid conditions driven by climate change are creating favourable environments for the proliferation and spread of cocoa pests and diseases such as fungal diseases becoming more prevalent and severe, causing significant crop losses. Changes in climatic conditions can also adversely affect the tiny midge pollinators that cocoa trees rely on for fertilization.

Additionally, as temperatures and rainfall patterns change, the optimal areas for cocoa cultivation are shifting. This may force farmers to adapt existing practices, relocate, or switch to alternative crops, impacting livelihoods and potentially contributing to further deforestation if new areas are cleared for cultivation.

2.2.3. Cashew nuts

Climate change and climate variations are significantly impacting cashew nut production in Southeast Asia, affecting various stages from flowering to nut quality and increasing vulnerability to pests and diseases. Erratic rainfall patterns, characterized by unseasonal heavy rains and prolonged droughts, severely disrupt cashew nut production by causing flower and immature fruit drop, poor nut setting, and increased susceptibility to fungal diseases, while also negatively impacting the nuts' biochemical content, ultimately reducing yield and quality[28]. Moreover, while cashews typically thrive in tropical climates, rising temperatures, particularly extreme heat above 37°C, negatively impact their growth, development, and yield, potentially decreasing production by 10-30% in regions like Cambodia. Besides, warmer, humid, and erratic weather conditions, exacerbated by climate change, create ideal breeding grounds for cashew pests and diseases like the tea mosquito bug and fungal pathogens, leading to significant crop damage and increased infestations.

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[27] Dewi Sasmita, K., Wardiana, E., Saefudin, Pranowo, D., Aunillah, A., Kholilatul Izzah, N., … Listyati, D. (2024). Challenges and Opportunities for Indonesian Cocoa Development in the Era of Climate Change. IntechOpen. doi: 10.5772/intechopen.112238

[28] http://dx.doi.org/10.1007/978-81-322-0974-4_17

Additionally, climate changes also result in shifting of cultivation areas as cashew cultivation, often in ecologically sensitive coastal areas vulnerable to sea-level rise and saltwater intrusion, faces an overall yield decline and reduced nut quality due to the combined pressures of temperature extremes, unpredictable rainfall, and increased pest and disease outbreaks, with Cambodia reporting a 30-40% reduction in production over the past four years.

2.2.4. Small scale forestry

Small-scale forestry in Southeast Asia is highly vulnerable to the impacts of climate change and variations, which exacerbate existing challenges like deforestation. Rising temperatures, altered rainfall patterns (leading to both droughts and increased heavy precipitation), and the heightened frequency of extreme weather events directly affect tree growth, health, and yield, threatening the biodiversity and carbon sequestration capacity of these forests. These climatic shifts also create more favourable conditions for pests and diseases, which can decimate tree populations. For the millions of people in Southeast Asia who depend on forests for their livelihoods, these impacts translate into reduced income, increased costs for adaptation, and heightened food and livelihood insecurity, particularly as suitable forest areas may shift or degrade.

2.3. Challenges of perennial crops to adapt to climate change and climate variations

Despite their economic importance, perennial crops in Southeast Asia face significant challenges in adapting to climate change, largely due to their inherent characteristics and prevailing governmental priorities.

Unlike annual crops, perennial crops such as coffee, cocoa, cashew, and rubber have long lifespans, often remaining productive for 20–30 years. This means that decisions made today, such as crop variety selection, site location, or planting method, lock farmers into long-term commitments that are difficult and costly to reverse if conditions become unsuitable (e.g., due to increased heat or altered rainfall). Establishing these crops requires substantial initial investments of time, funds, and labour, with delayed returns, making farmers risk-averse to adopting unproven or climate-resilient alternatives.

Furthermore, perennial crops are often not prioritized by government policies, which typically focus on staple cereals like rice, maize, or wheat for food security. As a result, there is limited access to extension services, subsidies, and climate-smart technologies for smallholder perennial crop growers. The absence of targeted climate adaptation support, such as tailored insurance, research on resilient varieties, or investment in long-term agroforestry systems, further compounds their vulnerability. Additionally, policies often focus on immediate food security through staple crops, neglecting the long-term economic and environmental contributions of perennial agriculture. These structural and policy gaps significantly hinder the capacity of smallholder farmers to adapt perennial systems to increasingly erratic climatic conditions across the region.

3. Adaptation and resilient program/practices for crops: availability, accessibility

3.1. Climate Change Adaptation and Resilience Practices for Perennial Crops

Addressing the multifaceted impacts of climate change on perennial crops in Southeast Asia necessitates a comprehensive suite of adaptation and resilience practices. These range from fundamental agronomic adjustments and ecological enhancements to the integration of advanced technological solutions and the implementation of robust sustainability certification schemes.

3.1.1. Agronomic and Ecological Practices

Agronomic and ecological practices form the bedrock of climate change adaptation for perennial crops, focusing on enhancing the intrinsic resilience of farming systems through sustainable land management.

3.1.1.1. Agroforestry and Shade Management

Agroforestry, defined by the integration of trees and shrubs with crops or livestock, is widely recognized as a highly climate-resilient system[29]. This approach offers a multitude of benefits, including enhanced agricultural production, improved soil and water conservation, and increased carbon sequestration[30]. For coffee cultivation, agroforestry systems represent a pivotal adaptation strategy. They effectively moderate farm microclimates by reducing air temperatures, potentially by as much as 5°C, and augmenting available water resources through the strategic introduction of woody perennial support plants[29]. These diversified systems also contribute to increased and more stable farmer incomes by offering additional products, alongside providing various crucial ecosystem services such as enhanced biodiversity and natural pest control.

In the context of cocoa, climate-smart diversified cocoa agroforestry practices are instrumental in improving soil health, reducing erosion, and boosting overall crop productivity by fostering a more biodiverse and resilient ecosystem. These systems are also recognized for their vital role in carbon stocking and mitigating climate change. For small-scale forestry, agroforestry practices, including alley cropping and traditional home gardens, demonstrably enhance biodiversity and overall ecosystem resilience. Notably, traditional tree-based agroforestry systems in Southeast Asia have shown to facilitate a more rapid recovery from natural disasters, underscoring their adaptive capacity[29].

The consistent highlighting of agroforestry as a multi-benefit strategy across various perennial crops underscores its significance. It simultaneously addresses critical aspects of climate adaptation, such as microclimate regulation and water retention, alongside climate change mitigation through carbon sequestration, and livelihood diversification for farmers. This synergistic capacity positions agroforestry as a foundational and highly advantageous component of climate-resilient perennial crop systems, making it a "no-regrets" adaptation option that yields multiple positive outcomes for both the environment and human well-being.

3.1.1.2. Crop Diversification and Cultivar Selection

Crop diversification and the strategic selection of new or improved cultivars are crucial for enhancing the resilience of perennial crop systems. Diversifying crops and introducing a broader mix of coffee cultivars can significantly improve resilience, especially given the current global coffee production's reliance on only two main species with limited genetic diversity, which inherently makes the system vulnerable[31]. For instance, Robusta coffee exhibits greater tolerance to higher temperatures and is less susceptible to certain diseases compared to Arabica, offering a more resilient option in changing climates[31]. For cashew, the development and adoption of salinity, moisture, and environmental stress-tolerant varieties are recommended as vital mitigation measures against climate impacts[12].

Intercropping, a climate-smart agricultural practice involving the cultivation of multiple crops in the same field, especially with leguminous plants, can contribute significantly to climate adaptation and

[29] Ghanbari S, Jafari M, Ghasemi J, Eastin IL, Álvarez-Álvarez P, Sasanifar S, Azizi M and Eskandari L (2025) Adaptive agroforestry—mitigating climate change impacts by farmers' perception in different climate conditions in Iran. Front. For. Glob. Change. 8:1473355. doi: 10.3389/ffgc.2025.1473355

[30] Dobhal S, Kumar R, Bhardwaj AK, Chavan SB, Uthappa AR, Kumar M, Singh A, Jinger D, Rawat P, Handa AK and Ramawat N (2024) Global assessment of production benefits and risk reduction in agroforestry during extreme weather events under climate change scenarios. Front. For. Glob. Change. 7:1379741. doi: 10.3389/ffgc.2024.1379741

[31] Bracken, P., Burgess, P. J., & Girkin, N. T. (2023). Opportunities for enhancing the climate resilience of coffee production through improved crop, soil and water management. Agroecology and Sustainable Food Systems, 47(8), 1125–1157. https://doi.org/10.1080/21683565.2023.2225438

simultaneously reduce farming costs[32]. This practice also serves to diversify income streams for farmers, providing a buffer against single-crop failures and market volatility[33].

While the development and adoption of climate-resilient varieties represent a crucial long-term strategy for adaptation, their effectiveness is considerably amplified when integrated with agroforestry practices. Agroforestry provides immediate microclimatic benefits, such as temperature reduction and increased moisture retention, which are vital for the survival and productivity of both existing and newly introduced perennial crops[30]. Furthermore, agroforestry offers diversified income sources, which can be particularly beneficial during the multi-year transition period required for new perennial crop varieties to mature and become profitable. This combined approach creates a more robust and immediate adaptation pathway by mitigating short-term risks while building long-term resilience.

3.1.1.3. Soil and Water Management

Effective soil and water management practices are fundamental to building climate resilience in perennial crop systems. Implementing good agricultural practices is essential for maintaining soil quality and preventing erosion, which are exacerbated by extreme weather events. Key techniques include conservation agriculture, which minimizes soil disturbance, strategic crop rotation, balanced fertilization, and maintaining permanent soil cover through practices like mulching and cover cropping. For cashew crops, mulching, conservation agriculture, and various soil and water conservation measures are critical for mitigating the severe impacts of climate change-induced drought. Rainwater harvesting is also identified as a crucial practice to ensure water availability during critical periods.

Efficient irrigation strategies, such as drip irrigation and fertigation (applying fertilizers through irrigation water), are highly recommended to provide precise water and nutrient delivery during the sensitive fruit development stages of perennial crops. The advent of smart irrigation systems, powered by the Internet of Things (IoT) and integrating data from soil moisture sensors and weather forecasts, enables the delivery of water precisely when and where it is needed, leading to significant water conservation in drought-prone regions. Continuous monitoring of soil health, including organic matter and nutrient levels, is paramount for proactive soil management and improving overall soil fertility. Practices like cover cropping and reduced tillage are instrumental in increasing soil organic matter and enhancing carbon sequestration, contributing to both climate adaptation and mitigation.

The strong emphasis placed on soil health and efficient water management underscores their foundational role in climate adaptation. These practices underpin the success of nearly all other adaptation strategies, including the effectiveness of agroforestry systems and the viability of new, climate-resilient cultivars. Degraded soil conditions and inefficient water use can negate the benefits of even the most climate-resilient crops, highlighting the interconnectedness and hierarchical importance of these fundamental sustainable farming practices. Investing in robust soil and water management provides a resilient base upon which more complex adaptation strategies can be built and achieve their full potential.

3.1.1.4. Integrated Pest and Disease Management (IPM)

Climate change significantly alters the patterns and prevalence of pests and diseases, making robust Integrated Pest and Disease Management (IPM) critically important for perennial crops. For instance, cocoa cultivation faces increased threats from fungal diseases like black pod due to changing climatic conditions. IPM involves a science-based, holistic approach that combines various strategies, including prevention, biological control, cultural practices, and the targeted, minimal use of pesticides when

[32] Neufeldt H, Negra C, Hancock J, Foster K, Nayak D, Singh P. 2015. Scaling up climate-smart agriculture: lessons learned from South Asia and pathways for success. ICRAF Working Paper No. 209. Nairobi, World Agroforestry Centre. DOI: http://dx.doi.org/10.5716/WP15720.PDF
[33] Nguyen, TTN., Roehrig, F., Grosjean, G., Tran, DN., Vu, TM. 2017. Climate Smart Agriculture in Vietnam. CSA Country Profiles for Asia Series. International Center for Tropical Agriculture (CIAT); The Food and Agriculture Organization. Hanoi, Vietnam. 28 p.

necessary, thereby minimizing reliance on harmful chemicals. For coffee, IPM strategies can involve aligning plants' needs for fertilizer with natural inputs and reducing agrochemical use. This approach enhances soil microbial activity, which in turn increases the resilience of the entire soil system to climate variability.

The exacerbation of pest and disease issues by climate change transforms IPM from a standard best practice into a critical and dynamic component of climate adaptation. The changing climate introduces new pressures and alters the life cycles of pests and pathogens, making static pest control plans insufficient. This necessitates a growing need for real-time monitoring, predictive analytics (potentially facilitated by digital agriculture technologies), and rapid response systems to effectively manage evolving threats. Moving beyond traditional, reactive pest control, a proactive and data-driven IPM approach becomes essential for safeguarding perennial crop yields and quality in a changing climate.

3.1.2. Technological Solutions

Technological advancements are increasingly offering innovative solutions for climate change adaptation in perennial crop systems, enhancing precision, efficiency, and transparency across the agricultural supply chain.

3.1.2.1. Digital Agriculture (Sensors, Drones, AI, IoT)

Digital agriculture is revolutionizing food production by integrating advanced technologies to optimize crop production and resource use. Key precision agriculture tools include soil and crop sensors, which are embedded in fields to gather real-time data on soil moisture, pH levels, temperature, and nutrient content. This continuous data flow enables proactive soil management and highly precise fertilizer application, ensuring that inputs are optimized for plant needs and environmental conditions.

Drones equipped with multispectral cameras and remote sensing technologies are reshaping crop monitoring. These tools provide high-resolution imagery that can reveal plant stress, pest infestations, and nutrient deficiencies long before they are visible to the naked eye. Such early detection allows for timely intervention, significantly reducing potential crop losses. Internet of Things (IoT)-powered smart irrigation systems are transforming water management by integrating data from soil moisture sensors and weather forecasts to deliver the precise amount of water exactly when and where it is needed, thereby conserving precious water resources in drought-prone regions. Furthermore, autonomous machinery, embedded with IoT sensors and GPS, can adjust their behavior based on environmental inputs, ensuring uniform seed distribution and optimized harvesting, which boosts efficiency and reduces costs. These technologies also extend to supply chain optimization, with IoT devices monitoring post-harvest conditions during storage and transport to prevent spoilage and ensure product quality.

While digital agriculture tools offer unprecedented precision and real-time data, which are crucial for effective climate adaptation and resource efficiency, their transformative potential is currently limited by significant digital divides and infrastructure gaps prevalent in rural Southeast Asia. Many smallholder farmers lack access to reliable internet connectivity, electricity, and the technical literacy required to fully utilize these advanced systems. This implies that simply having the technology available is insufficient; substantial investment in rural connectivity, development of user-friendly interfaces, and accessible training programs are paramount to bridge this digital divide and enable widespread adoption by smallholders.

3.1.2.2. Traceability Systems (Blockchain, RFID)

Traceability systems are becoming indispensable in modern agriculture, enabling the tracking of products from the farm to the consumer's plate. These systems document the complete history of products and raw materials through all stages of production, transformation, and distribution.

Blockchain technology, in particular, is gaining traction for its ability to establish verifiable and immutable records of food provenance and production, directly addressing the rising global demand for transparency[34]. Its decentralized and unchangeable ledger ensures data accuracy and prevents tampering throughout the supply chain[35]. This enhanced transparency can significantly reduce food recall times, potentially by up to 80%, ensuring faster responses to contamination risks and limiting economic losses. Beyond food safety, blockchain enables verifiable sustainability practices by meticulously recording the ecological footprint of agricultural operations, from seed to harvest. This immutable ledger can incentivize farmers to adopt regenerative agriculture practices through verifiable carbon credits and sustainability premiums. Furthermore, blockchain can empower smallholder farmers by providing them direct access to markets, bypassing intermediaries, and securing fairer prices for their produce, thereby fostering a more equitable agricultural ecosystem.

Radio Frequency Identification (RFID) technology complements digital traceability by utilizing radio waves for real-time tracking of individual crops throughout their lifecycle[36]. This enables automated sorting, precise crop management, and early detection of pests and diseases, which can significantly improve yields and reduce post-harvest losses[37]. RFID enhances food safety and builds consumer trust by ensuring transparency from farm to fork. Cost-effective RFID solutions are emerging, with potential for seamless integration with artificial intelligence (AI), machine learning, and blockchain for even greater efficiency and data-driven insights.

Traceability systems, especially those leveraging blockchain and RFID, are evolving beyond mere food safety or supply chain efficiency tools. They are becoming crucial for verifying sustainable practices and ethical sourcing, which in turn allows farmers to access premium markets and potentially command higher prices for their products. This direct economic incentive is a powerful driver for the adoption of climate-smart agricultural practices, particularly as consumer demand for transparency and ethically produced goods continues to grow. By providing verifiable provenance and sustainability claims, these technologies create a market-driven mechanism that encourages and rewards climate adaptation efforts.

3.1.3. Sustainability Certification Standards and Sustainable Sourcing

Sustainability certification standards and sustainable sourcing initiatives play a pivotal role in driving climate change adaptation and resilience in perennial crop sectors by setting benchmarks for environmental, social, and economic performance. Further information will be provided in the next section (Section 4) on traceability of perennial crops.

3.1.4. Benefits of Certification for Farmers and Supply Chains

Sustainability certification offers a range of tangible benefits for both farmers and the broader supply chains of perennial crops. For farmers, certification serves as a practical framework to produce better crops, adapt to the impacts of climate change, enhance productivity, and ultimately reduce operational costs[34].

Crucially, certification provides expanded market access and helps businesses meet evolving consumer expectations for sustainably and ethically sourced products. Consumers are increasingly demanding more information about the origins of their food and the production practices employed. Studies indicate that

[34] Rainforest Alliance. Certification and Traceability. FAQ: 2020 Farm Requirements. https://knowledge.rainforest-alliance.org/docs/faq-2020-farm-requirements
[35] Blockchain applications in agricultural data traceability https://prism.sustainability-directory.com/scenario/blockchain-applications-in-agricultural-data-traceability/
[36] A Greener World. Certified Regenerative by AGW Standards. https://agreenerworld.org/certifications/certified-regenerative/certified-regenerative-standards/
[37] RFID in Agriculture. https://rfid4ustore.com/rfid-blog/rfid-in-agriculture/

certified farmers exhibit higher adoption levels of sustainable practices, including advanced pest and disease control, and improved soil and water management techniques. These farmers also report higher scores across ecological, social, and economic dimensions of sustainability.

The long-term advantages for certified farmers include increased yields, improved health outcomes for their families, enhanced food safety, and reduced financial risks associated with unpredictable environmental conditions. Furthermore, certification, particularly when coupled with robust traceability systems, enables producers to differentiate their products and command a premium in the market.

The economic benefits derived from certification, such as premium prices, expanded market access, and reduced operational costs, serve as a critical driver for farmers to adopt sustainable practices. For smallholder farmers, who often operate with narrow profit margins and high vulnerability to market fluctuations, these direct financial incentives are not merely an added bonus but a fundamental motivation for investing in and maintaining climate-smart agricultural methods. This demonstrates that market-based mechanisms can be powerful tools for accelerating widespread climate adaptation by aligning economic viability with environmental stewardship.

3.2. Availability of Adaptation and Resilience Programs in Southeast Asia

The landscape of climate change adaptation and resilience programs for perennial crops in Southeast Asia is characterized by a growing number of initiatives from diverse stakeholders, reflecting an increasing recognition of the climate threat to these vital agricultural sectors.

3.2.1. Government-Led Initiatives

Governments across Southeast Asia are increasingly integrating climate resilience into their national agricultural and forestry policies and development plans, indicating a strong top-down recognition of the climate threat to perennial crops. Vietnam, for instance, has demonstrated this commitment by developing National Sustainability Curricula for both Arabica and Robusta coffee. These curricula provide practical knowledge and best practices for farmers, explicitly incorporating climate change adaptation strategies. Furthermore, Vietnam's Green Growth Strategy (2021–2030) sets ambitious targets for greenhouse gas emission reduction and climate resilience within the agriculture sector, actively promoting low-emission practices and regenerative farming models[38]. The country's New Rural Development plan has also adopted the Climate-Smart Village (CSV) approach, a participatory model for building local resilience[33].

Cambodia's National Agriculture Development Policy (NADP) 2022-2030 outlines a vision to transform its agriculture into a modern, competitive, inclusive, climate-resilient, and sustainable sector.[101] This policy specifically targets perennial crops such as cashew nuts and pepper for climate-resilient and sustainable intensification, acknowledging their importance to the national economy and rural livelihoods. Regionally, the Association of Southeast Asian Nations (ASEAN) underscores the importance of scaling up sustainable agriculture and agro-ecology to help farmers adapt to climate change. ASEAN leverages existing platforms like the ASEAN Climate Change Initiative (ACCI) and the ASEAN Multi-Sectoral Framework on Climate Change: Agriculture, Fisheries and Forestry towards Food Security (AFCC) to foster regional cooperation on climate action[39].

While these high-level policy commitments and strategic frameworks demonstrate a clear availability of governmental intent and direction, a critical challenge lies in translating these policies into effectively implemented, actionable, and locally accessible programs at the grassroots level. Smallholder farmers,

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[38] ASEAN Briefing. Investing in Vietnam's Climate-Smart Agriculture Transformation. https://www.aseanbriefing.com/news/investing-in-vietnams-climate-smart-agriculture-transformation/

[39] ASEAN MULTI-SECTORAL FRAMEWORK FOR CLIMATE CHANGE: AGRICULTURE AND FORESTRY TOWARDS FOOD AND NUTRITION SECURITY AND ACHIEVEMENT OF SDGs. https://asean.org/wp-content/uploads/2012/05/ASEAN-Multisectoral-Framework-for-climate-change.pdf

who form the majority of producers in these sectors, often lack direct access to centralized government support due to geographical remoteness, limited outreach, and bureaucratic complexities. Therefore, the effectiveness of these initiatives hinges on robust implementation mechanisms that can bridge the gap between policy formulation and on-the-ground impact, ensuring that the intended benefits reach the most vulnerable communities.

3.2.2. International and NGO-Led Projects

A significant portion of climate change adaptation efforts in Southeast Asia is driven by international organizations and non-governmental organizations (NGOs), often in collaboration with local governments and communities. The prevalence of these multi-stakeholder projects signifies a growing understanding that comprehensive climate adaptation for perennial crops requires collaborative efforts that extend beyond the capabilities of single actors.

One prominent example is the **Climate-Smart Village (CSV) approach**, developed by the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). This approach is being integrated into national programs across Southeast Asia, with 33 CSVs established in the Philippines, Vietnam, Myanmar, Laos, and Cambodia. These CSVs empower local communities and enhance smallholder farmers' productivity and climate resilience through a participatory research-for-development model, which emphasizes local knowledge and context-specific solutions[40].

In Indonesia, the **LASCARCOCO Project** represents a joint investment by USAID, Olam Food Ingredients (ofi), Rikolto, Hershey's, and the Indonesian government. This project trains 6,500 cocoa and coffee farmers in sustainable agroforestry practices, promotes climate-friendly landscape management, and aims to create transparent, traceable supply chains, thereby improving environmental sustainability and rural welfare[41].

Cambodia benefits from the **SCALA Program**, facilitated by the United Nations Development Programme (UNDP). This program actively promotes climate-resilient practices and strengthens the cashew value chain through stakeholder consultations, investments in improved post-harvest infrastructure, and the provision of green loans from the Agricultural and Rural Development Bank (ARDB)[42].

In Vietnam, the **Green Climate Fund (GCF) Project FP125**, implemented by UNDP, aims to strengthen the resilience of smallholder agriculture to water insecurity in the Central Highlands and South-Central Coast regions. This substantial project secures water provision, supports the adoption of climate-resilient agriculture, and strengthens access to agro-climate information, credit, and markets for over 220,000 direct beneficiaries[43].

Furthermore, the ASEAN Forest Cooperation Organization (AFoCO) undertakes various initiatives aimed at restoring degraded forests, strengthening the resilience of forest ecosystems, and improving the livelihoods of forest-dependent communities. Examples include forest restoration projects in the Philippines, the application of Information and Communication Technology (ICT) for climate adaptation in the Mekong Region, and community-government restoration efforts for climate resilience in Indonesia[44].

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40 CGIAR. Climate-smart villages in Southeast Asia. https://www.cgiar.org/annual-report/performance-report-2019/climate-smart-villages-in-southeast-asia/
41 https://id.usembassy.gov/united-states-invests-in-indonesian-coffee-and-cocoa-producing-communities/
42 https://climatepromise.undp.org/news-and-stories/unlocking-private-sector-potential-climate-resilient-agriculture
43 https://www.greenclimate.fund/project/fp125
44 https://afocosec.org/programs-projects/projects/

Agri-Smallholder Resilience Fund (ASRF) in the Philippines, a blended debt financing model, aims to boost rural incomes and access to fresh produce by financing climate-smart agriculture and aquaculture projects, integrating agroforestry and mangrove restoration[45].

The widespread presence of these multi-stakeholder projects, involving international organizations, NGOs, and local governments, underscores a growing understanding that comprehensive climate adaptation for perennial crops requires collaborative efforts that leverage diverse expertise and resources. This multi-pronged approach is essential for effectively addressing the complex and interconnected challenges faced by smallholders, which span technical, financial, and social dimensions. No single entity can effectively tackle these multifaceted issues in isolation, making integrated partnerships a crucial strategy for building sustainable climate resilience.

3.2.3. Private Sector Engagement

The private sector is increasingly recognizing the imperative to invest in climate-resilient value chains, driven by both corporate sustainability goals and the pragmatic need to secure supply chains and mitigate risks in the face of escalating climate impacts. This represents a significant shift from traditional corporate social responsibility (CSR) initiatives to more strategic, business-integrated approaches to climate adaptation.

Major corporations are demonstrating this commitment through various initiatives. Mars, for example, through its "Cocoa for Generations"[46] strategy, aims to cultivate a modern, inclusive, and sustainable cocoa ecosystem. This involves direct investments in programs designed to combat climate change and protect forests within their sourcing regions. In a collaborative effort, Olam Food Ingredients (ofi) and Hershey's are key partners in the LASCARCOCO project in Indonesia. This initiative seeks to enhance environmental sustainability in cocoa and coffee production while simultaneously improving the welfare of rural communities through increased market access. A notable aspect of this partnership is the utilization of Olam's Farmer Information System (OFIS) application, which aims to create transparent and traceable supply chains, providing complete visibility of the environmental and social credentials of the products[41].

Nestlé's Nescafé Plan in Vietnam provides a compelling case study of private sector engagement at the farm level. The program offers comprehensive training to coffee farmers, distributes high-yield and disease-resistant coffee varieties, and introduces improved water management techniques. These interventions have led to demonstrable increases in yields and significant reductions in water consumption and chemical fertilizer use[47]. Furthermore, the SCALA program actively identifies entry points for private sector engagement in climate-smart value chains, facilitating partnerships that promote green loans from financial institutions like the Agricultural and Rural Development Bank (ARDB) to incentivize sustainable production practices.

Beyond direct corporate involvement, there is a growing trend of investment from tech investors, predominantly venture capital and private equity funds. These investors have channeled over $5.7 billion into adaptation tools and services for smallholder farmers in emerging markets since 2012, with Southeast Asia emerging as the most active region, attracting $1.9 billion of this funding[48]. This significant financial flow indicates a market-driven recognition of the need for climate resilience solutions.

The increasing involvement of the private sector, shifting from mere sustainable sourcing to active investment in climate-resilient value chains, signals a pivotal development in climate adaptation efforts.

[45] https://www.climatefinancelab.org/ideas/agri-smallholder-resilience-fund/
[46] https://www.mars.com/sustainability-plan/cocoa-for-generations
[47] https://www.wbcsd.org/resources/nestle-transforming-coffee-farming-in-vietnam/
[48] AgFunder. Climate Capital: Financing Adaptation Pathways for Smallholder Farmers. https://www.convergence.finance/resource/climate-capital-financing-adaptation-pathways-for-smallholder-farmers/view

This transformation is driven by a growing understanding that climate impacts pose a direct business risk, threatening raw material supply, increasing operational costs, and impacting brand reputation. Consequently, companies are adopting more proactive and financially integrated approaches to adaptation, viewing it not just as a social responsibility but as a strategic imperative for long-term business viability and supply chain security.

Table 1. Selected climate change adaptation projects and support mechanisms in Southeast Asia

Project/Initiative Name	Implementing/Funding Body	Target Countries/Crops	Type of Support
Climate-Smart Villages (CSVs)	CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), SEARCA, ASEAN Climate Resilience Network, IIRR, ADB, WFP, IDRC	Philippines, Vietnam, Myanmar, Laos, Cambodia / General Agriculture (including perennial crops)	Participatory research-for-development, Roving workshops, Simplified guides, Capacity building, Policy influence, Gender-sensitive initiatives, Youth participation
LASCARCOCO Project	USAID, Olam Food Ingredients (ofi), Rikolto, Hershey's, Government of Indonesia	Indonesia (North Sumatra, South Sulawesi, East Nusa Tenggara) / Cocoa, Coffee	Sustainable agroforestry training, Climate-friendly landscape management, Transparent & traceable supply chains (OFIS), Community engagement, Yield increase, Watershed/buffer vegetation conservation, Market access
SCALA Program	UNDP, Agricultural and Rural Development Bank (ARDB)	Cambodia / Cashew, Pepper	Stakeholder consultations, Promotion of climate-resilient practices, Improved post-harvest infrastructure, Green loans, Value chain strengthening, Local processing investment
GCF Project FP125	Green Climate Fund (GCF), UNDP	Vietnam (Central Highlands, South-Central Coast) / Smallholder Agriculture (including coffee, pepper, cashew, rubber, tea, fruits, rice, maize, cassava)	Water provision security, Climate-resilient agriculture adoption, Access to agro-climate information, Credit, Markets, Grants & Loans
AFoCO Initiatives	ASEAN Forest Cooperation Organization (AFoCO)	Philippines, Vietnam, Cambodia,	Forest restoration, Ecosystem resilience strengthening, Livelihood improvement, ICT for

		Indonesia, Myanmar, Laos, Timor-Leste, Bhutan	climate adaptation, Forest fire management, Biodiversity conservation
Agri-Smallholder Resilience Fund (ASRF)	Global Innovation Lab for Climate Finance, Mayani	Philippines / Climate-smart agriculture & aquaculture (integrating agroforestry, mangrove restoration)	Blended debt financing (concessional capital, risk management, index-based crop insurance, agronomic support), Income boost, Productivity increase, Women's participation
Nescafé Plan (Nestlé)	Nestlé	Vietnam / Coffee	Training, Distribution of high-yield/disease-resistant varieties, Water management techniques, Crop diversification, Reduced chemical use
Cocoa Life Indonesia (Mondelez)	Mondelez International	Indonesia / Cocoa	Training on best practices, Climate-smart farming techniques, Seedlings distribution, Financial literacy, Community empowerment, Increased yields & income

3.3. Accessibility of Adaptation and Resilience Programs for Smallholder Farmers

Despite the increasing availability of climate change adaptation and resilience programs, their effective accessibility by smallholder farmers in Southeast Asia remains a critical challenge. This section delves into the various barriers and the emerging support mechanisms designed to overcome them.

3.3.1. Financial Accessibility

Financial constraints represent one of the most significant impediments to smallholder farmers adopting climate change adaptation strategies.

3.3.1.1. Barriers to Financial Accessibility

Smallholder farmers, who account for a substantial portion of global coffee (70%) and cocoa (90%) production, frequently encounter severe financial limitations. Their pre-existing socioeconomic vulnerabilities and limited access to financing and resources significantly restrict their adaptive capacity. The high upfront costs associated with implementing new climate-smart practices, coupled with the delayed returns characteristic of perennial crops (new coffee plantings, for example, can take 2-3 years to yield), deter necessary investments[49].

[49] Le QV, Cowal S, Jovanovic G and Le D-T (2021) A Study of Regenerative Farming Practices and Sustainable Coffee of Ethnic Minorities Farmers in the Central Highlands of Vietnam. Front. Sustain. Food Syst. 5:712733. doi: 10.3389/fsufs.2021.712733

A substantial agricultural credit gap further exacerbates this issue; in the Philippines alone, it is estimated to be $6 billion. This gap is driven by a high perceived risk by lenders, a mismatch between traditional lending practices and the unique needs of smallholders, and a general lack of reliable supply chain data. Research indicates that in South and Southeast Asia, only a mere 1% of smallholders' credit needs for longer-term investments are currently met. Furthermore, farmers often exhibit a reluctance to apply for formal loans, citing concerns about productivity fluctuations and their ability to consistently repay debts[50]. This challenge is often amplified for women and low-income groups, who face even greater difficulties in accessing financial resources.

The persistent financial barriers, including high upfront costs, delayed returns on perennial crop investments, and systemic credit gaps, persist despite the existence of various funding mechanisms. This situation points to a fundamental mismatch between the structure of traditional financial products and the unique needs and risk profiles of smallholder farmers. Conventional lending models often fail to account for the long gestation periods of perennial crops, the inherent climate-related risks, or the informal nature of many smallholder operations. This highlights a profound need for innovative, tailored financial instruments that can effectively de-risk investments for smallholders and align with their specific cash flow cycles, thereby making climate adaptation economically viable and accessible.

3.3.1.2. Support Mechanisms for Financial Accessibility

To bridge the financial accessibility gap for smallholder farmers, a variety of innovative support mechanisms are emerging, often involving blended finance and value chain approaches.

Green Loans and Blended Finance: Financial institutions are increasingly offering specialized financial products. For instance, the Agricultural and Rural Development Bank (ARDB) in Cambodia provides green loans to farmers and cooperatives, specifically designed to support sustainable growth in the cashew value chain. These loans are contingent upon compliance with environmental safeguards, such as avoiding deforestation and adopting more sustainable land-use practices[51]. Similarly, the Agri-Smallholder Resilience Fund (ASRF) in the Philippines employs an innovative blended debt financing model. This model combines concessional capital with various risk management strategies, including index-based crop insurance and agronomic support, to improve the risk-return profile for rural smallholders and attract additional commercial investors[52].

Climate Finance Initiatives: Large-scale climate finance mechanisms are also contributing to financial accessibility. The Green Climate Fund (GCF) project FP125 in Vietnam, implemented by UNDP, provides significant grants and loans to empower smallholders to manage increasing climate risks by securing water provision and strengthening their access to credit and markets[53]. Furthermore, tech investors, primarily venture capital and private equity funds, are increasingly directing funding towards adaptation tools and services for smallholder farmers in Southeast Asia, recognizing the market potential in climate resilience solutions[48].

Value Chain Financing: There is a growing willingness among aggregators and buyers to experiment with value chain financing models to support small farmers, recognizing that stable supply chains benefit all actors. Bundling credit with crop insurance and technical assistance is a strategy that can significantly reduce the risk of crop failure for smallholders, thereby enhancing their resilience and business viability.

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50 Sustainable Cocoa Production in Indonesia. https://www.mcc.gov/resources/doc/evalbrief-061220-idn-cocoa-production/

51 Unlocking private sector potential for climate-resilient agriculture. https://climatepromise.undp.org/news-and-stories/unlocking-private-sector-potential-climate-resilient-agriculture

52 https://www.undp.org/cambodia/blog/toward-deforestation-free-agriculture-recommendations-sustainable-cashew-value-chain-stung-treng-province-cambodia

53 https://www.greenclimate.fund/project/fp125

The emergence of green loans, blended finance models, and value chain financing signifies a strategic shift in addressing the financial accessibility gap for smallholders. By directly linking these financial products to the adoption of climate-smart practices, a powerful, self-reinforcing incentive for adaptation is created. This approach moves beyond mere compliance, fostering proactive resilience building driven by the economic viability that these financial innovations enable. This indicates that financial innovation is a key factor in unlocking widespread adoption of climate adaptation strategies among smallholder farmers.

3.3.2. Knowledge and Technical Accessibility

Beyond financial resources, access to knowledge and technical expertise is a critical determinant of smallholder farmers' ability to adapt to climate change.

3.3.2.1. Barriers to Knowledge and Technical Accessibility

A significant and pervasive barrier to climate change adaptation remains the knowledge gap and limited access to technical assistance among smallholder farmers. Many farmers lack sufficient knowledge and understanding of complex agroforestry systems, despite their proven benefits. There is also a general deficit in access to specific climate change information and the practical capacity required to learn and effectively apply new techniques in their daily farming practices[21].

Agricultural extension services, which are crucial for disseminating knowledge and providing hands-on support, are often limited, particularly in remote or underserved regions. Consequently, smallholders frequently lack access to the necessary technology, resources, and up-to-date information, rendering them highly vulnerable to the evolving impacts of climate change[54].

This persistent problem is not merely a matter of information dissemination; it reflects a deeper challenge in capacity building. Even when programs and funds are available, farmers often lack the specific know-how, practical skills, or the foundational trust in new methods to implement them effectively. This underscores the critical role of effective, localized, and culturally sensitive extension services, coupled with robust peer-to-peer learning networks. Such approaches are essential to translate theoretical knowledge into practical application, fostering farmer ownership and long-term adoption of climate-resilient practices.

3.3.2.2. Support Mechanisms for Knowledge and Technical Accessibility

To address the knowledge and technical accessibility gaps, various support mechanisms are being implemented, emphasizing practical training and participatory approaches.

Training Programs and Technical Assistance: Numerous projects are directly providing training and technical assistance to farmers. For example, the LASCARCOCO project trains cocoa and coffee farmers in sustainable agroforestry practices and climate-friendly landscape management. Nestlé's Nescafé Plan offers comprehensive training on high-yield, disease-resistant coffee varieties and improved water management techniques, demonstrating tangible benefits like increased yields and reduced water/chemical use. Similarly, Cocoa Life Indonesia continuously trains farmers on best practices to enhance farm productivity and climate resilience, including climate-smart farming techniques and seedlings distribution.

National Curricula: Governments are developing standardized educational resources. Vietnam's National Sustainability Curricula for Arabica and Robusta coffee provide standardized knowledge and good

[54] Climate Smart Agriculture for the Small-Scale Farmers in the Asian and Pacific Region. https://cgspace.cgiar.org/server/api/core/bitstreams/8d1e9e7d-ec4e-4e89-b88c-51fc6d3c7a59/content

practices for producers and extension services, aiming to boost quality and value while supporting climate change adaptation[55].

Climate-Smart Villages (CSVs): The CSV approach, through its participatory research-for-development methodology, and the use of roving workshops, provides practical experiences with climate-smart agriculture to community leaders and implementers. These initiatives also develop simplified guides translated into local languages, making complex information more accessible.

Knowledge Hubs: Regional bodies are also promoting knowledge sharing. ASEAN is encouraged to develop a regional knowledge hub for climate adaptation and mitigation practices in agriculture, equipped with a built-in system for information exchange, to facilitate wider dissemination of best practices[56].

While training programs and technical assistance are undeniably vital, their effectiveness is significantly enhanced when they are designed to be participatory, context-specific, and actively integrate local knowledge. This approach moves beyond a simple top-down dissemination of best practices. Instead, it fosters the co-creation of knowledge and solutions, leading to greater farmer ownership and more sustainable adoption of adaptation programs. By valuing and building upon existing local expertise, these initiatives become more relevant and enduring, ensuring that interventions are not only technically sound but also culturally appropriate and accepted by the communities they serve.

3.3.3. Market and Policy Accessibility

Market and policy factors significantly influence the economic viability and widespread adoption of climate change adaptation practices for perennial crops.

3.3.3.1. Barriers to Market and Policy Accessibility

Market volatility poses a substantial barrier for farmers attempting to implement climate adaptation strategies, as fluctuating prices can undermine the economic returns of their investments[21]. For instance, despite efforts to enhance cashew production in Cambodia, limited local processing capacity means that most cashews are exported in raw form. This significantly reduces profit margins and hinders domestic job creation, thereby limiting the economic benefits that farmers can derive from their harvests.

Furthermore, the processes for obtaining and maintaining sustainability certifications can be complex and costly, presenting a significant barrier for smallholder farmers who often lack the resources and administrative capacity to navigate these requirements[57]. The absence of a robust national traceability system further impedes farmers, particularly smallholders, from achieving certification for national standards or accessing lucrative export markets that demand verifiable product origins and sustainable practices[58].

Market volatility and limited local processing capacity significantly undermine the economic incentives for climate adaptation, even when farmers successfully adopt new, resilient practices. This situation highlights the need for holistic value chain interventions that extend beyond on-farm practices. Investing in post-harvest processing facilities and strengthening market linkages are crucial steps to ensure that farmers can capture more value from their climate-resilient efforts. By enabling local value addition and connecting

55 Global Coffee Platform. National sustainability curriculum for Arabica in Vietnam set to boost quality and value. https://www.globalcoffeeplatform.org/latest/2021/national-sustainability-curriculum-for-arabica-in-vietnam-set-to-boost-quality-and-value/

56 Oxfam. Harmless harvest: How sustainable agriculture can help ASEAN countries adapt to a changing climate. https://oxfamilibrary.openrepository.com/bitstream/handle/10546/556778/bp-harmless-harvest-sustainable-agriculture-asean-250515-en.pdf;jsessionid=D8FDD106656B2366A2F2C2E6DE8BA4A8?sequence=1

57 Aninver. Sustainable agriculture: definition, advantages and policies. https://aninver.com/blog/sustainable-agriculture-definition-advantages-and-policies

58 USDA Organic. Guide for Organic Crop Producers. https://www.ams.usda.gov/sites/default/files/media/GuideForOrganicCropProducers.pdf

farmers to more stable and premium markets, adaptation becomes economically sustainable, providing a stronger incentive for continued investment and practice.

3.3.3.2. Support Mechanisms for Market and Policy Accessibility

To overcome market and policy barriers, various support mechanisms are being implemented, often leveraging technology and strategic partnerships.

Market Linkages and Value Addition: Projects are actively working to connect sustainable, climate-smart perennial crop production with 'green' premium markets, ensuring that farmers receive fair compensation for their environmentally responsible practices. Significant efforts are also being made to develop domestic processing industries for cashew nuts in countries like Cambodia. This aims to capture value-added benefits locally, thereby increasing profit margins for farmers and creating domestic employment opportunities.

Policy Frameworks: National agricultural development policies play a crucial role in creating an enabling environment. For example, Cambodia's National Agriculture Development Policy (NADP) 2022-2030 explicitly aims to transform the agricultural sector into a modern, competitive, and climate-resilient system, providing a strategic framework for market and policy interventions.

Digital Traceability Tools: The adoption of advanced traceability systems, including blockchain and RFID technologies, is increasingly vital. These systems enhance transparency across the supply chain, allowing consumers to verify product origin and validate sustainable practices. By providing verifiable provenance and sustainability claims, these tools directly address market accessibility barriers, enabling producers to charge higher prices and access sustainability-driven markets. This creates a powerful economic incentive for farmers to invest in and consistently maintain climate adaptation practices, as their efforts are recognized and rewarded in the marketplace.

Traceability systems are not merely about compliance or food safety; they are increasingly vital for enabling market access and premium pricing for sustainably produced perennial crops. By providing verifiable provenance and sustainability claims, these tools directly address market accessibility barriers and create a powerful economic incentive for farmers to invest in and maintain climate adaptation practices. This direct link between technology, transparency, and market advantage is a crucial mechanism for driving widespread adoption of climate-resilient agriculture.

3.3.4. Institutional and Social Factors

The success of climate change adaptation programs for smallholder farmers is deeply intertwined with underlying institutional and social factors, which can either facilitate or impede accessibility and sustained impact.

3.3.4.1. Vulnerabilities of Smallholders

Smallholder farmers are disproportionately vulnerable to the adverse effects of climate change due to a confluence of factors. Their high reliance on subsistence agriculture, coupled with limited financial resources and pre-existing socioeconomic vulnerabilities, makes them particularly susceptible to climate shocks. Climate impacts, such as reduced yields and increased input costs, directly translate into reduced household income, increased food prices, and even food shortages, often forcing farmers to cut essential household expenses. This creates a vicious cycle where climate stress exacerbates poverty, further eroding adaptive capacity. Furthermore, a lack of secure land tenure can significantly hinder long-term investments in perennial systems like agroforestry, as farmers may be reluctant to invest in land they do not securely own or control.

The deep-seated socioeconomic vulnerabilities of smallholders mean that climate adaptation cannot be effectively addressed in isolation from broader rural development and poverty reduction goals. Interventions that focus solely on agricultural practices without considering the underlying economic and social fragility of farming households may yield limited or unsustainable results. Programs must therefore adopt a holistic approach, addressing fundamental issues such as food security, equitable land tenure, and access to basic social services. By creating a stable and supportive foundation for smallholder livelihoods, these broader development efforts can significantly enhance the capacity and willingness of farmers to adopt and sustain effective climate resilience strategies.

3.3.4.2. Community Engagement and Participatory Approaches

Community engagement and participatory approaches are fundamental to ensuring the effectiveness and long-term sustainability of climate change adaptation programs for smallholder farmers. These approaches empower local communities and leverage their invaluable indigenous knowledge.

Community-led and participatory approaches are not merely a matter of good governance; they are crucial for the effectiveness and sustainability of adaptation programs. The Climate-Smart Villages (CSVs), for instance, exemplify this by employing a participatory research-for-development approach that actively involves local communities in identifying and implementing context-specific solutions. Farmers often possess extensive local knowledge regarding their environment and traditional coping mechanisms, which can be invaluable in addressing the effects of climate change. Increasing the roles of stakeholders within the community, including through community-based organizations (CBOs), is critical for enhancing farmers' capacity and fostering continuous social learning and adaptation.

Furthermore, successful programs integrate gender-sensitive initiatives and promote youth participation, recognizing that different demographic groups within a community may have unique vulnerabilities, knowledge, and roles in climate-smart agriculture. By involving all segments of the community, adaptation strategies become more equitable and comprehensive.

By leveraging local knowledge, building social capital, and fostering collective action, these participatory approaches lead to the development of more relevant, accepted, and enduring solutions compared to top-down, externally imposed interventions. When communities are involved in the design and implementation of programs from the outset, they are more likely to take ownership of the solutions, leading to higher adoption rates and sustained benefits in the face of climate change.

4. Traceability of perennial crops in the context of adaptation

The Growing Imperative for Sustainability and Transparency in Agricultural Supply Chains

The increasing global imperative for sustainability and transparency in agricultural supply chains is driven by a confluence of factors, notably evolving consumer demand and regulatory pressures. Consumer surveys consistently indicate a strong desire for transparency: while 91% of consumers value knowing the origin of their food, only a small fraction (12%) wholeheartedly trust its safety[59]. This significant trust deficit underscores the urgent need for enhanced traceability and verifiable production standards.

Sustainability certifications serve as crucial assurances for buyers, verifying that products in their supply chains are environmentally sound, ethically produced, and meet escalating consumer expectations for responsible sourcing[60]. This market-driven demand creates a powerful economic incentive for producers

[59] Traceability in Agriculture. https://www.croptracker.com/resources/traceability-in-agriculture.html
[60] UNEP. Crop certification: Going green unlocks global markets for farmers. https://www.unep.org/news-and-stories/story/crop-certification-going-green-unlocks-global-markets-farmers

to adopt certified practices, as it can unlock access to sustainability-driven consumers and international markets. The clear articulation that consumer demand for transparency and sustainably sourced products is a primary force behind the adoption of both traceability systems and certification schemes highlights a powerful market-pull dynamic. As consumers become more informed and conscious, their purchasing decisions exert pressure on the supply chain to provide verifiable sustainability credentials. This, in turn, creates a direct economic incentive for farmers and producers to invest in certification and traceability, leading to increased market access and potential for premium pricing for certified products. This demonstrates how consumer preferences are actively reshaping agricultural practices and supply chain structures.

4.1. Global Perennial Crop Certification Landscape

4.1.1. Overview of Major Certification Schemes

The global landscape of perennial crop certifications is characterized by a diverse array of schemes, each with unique strengths and areas of focus. These organizations play a critical role in defining, verifying, and promoting sustainable practices across various perennial commodities.

Certified Regenerative by A Greener World (AGW)

Certified Regenerative by A Greener World (AGW) focuses on a comprehensive set of agricultural practices designed to improve or maintain the health of soil, water, air, and biodiversity over time. This represents a holistic approach to environmental stewardship, moving beyond mere compliance to active ecological restoration. A core requirement of this certification is the development of a measurable Regenerative Plan, which is crafted in collaboration with a qualified expert and subject to annual review. The expectation is for continuous, incremental improvement in sustainability metrics, acknowledging the dynamic nature of agricultural ecosystems and the long-term commitment required for regenerative processes. The certification applies to the entire production of a defined product from a specific land area, necessitating continuous adherence to the standards throughout the production cycle. Key principles include minimizing soil erosion, optimizing soil structure, biological activity, and fertility, ensuring sustainable water use, and actively managing biodiversity through the integration of wildlife habitats, hedges, ponds, and species-rich pastures. The emphasis on a "measurable Regenerative Plan" that is "tailored for the success of the holding" and expects "incremental and measurable improvement" signifies a departure from static compliance models. This dynamic, performance-based approach, coupled with a focus on "mitigating negative impacts of human and livestock disruption," suggests a deep understanding of ecosystem complexity and the long-term nature of regenerative processes. This model is particularly well-suited for perennial systems, which are inherently complex, long-lived, and require continuous management and improvement over decades. It allows for flexibility in diverse agro-ecological zones and encourages innovation, aligning seamlessly with the long-term vision of perennial agriculture.

Regenerative Organic Certified® (ROC)

Regenerative Organic Certified® (ROC) is overseen by the non-profit Regenerative Organic Alliance (ROA), a consortium of experts in farming, ranching, soil health, animal welfare, and farmer and worker fairness. This multi-stakeholder governance aims to ensure robust and balanced standards that address multiple dimensions of sustainability. The certification is structured around three foundational pillars: Soil Health & Land Management, Animal Welfare, and Farmer & Worker Fairness. This integrated approach recognizes the interconnectedness of environmental, social, and ethical dimensions of agriculture, promoting a holistic view of sustainable production. A prerequisite for ROC certification is holding USDA Organic certification or an equivalent international organic standard. This builds upon existing organic frameworks, leveraging established compliance mechanisms and potentially streamlining the certification process for already organic producers. ROC employs a tiered system—Bronze, Silver, and Gold levels—

each requiring a progressively greater number and scope of regenerative organic practices. This tiered approach is designed to facilitate continuous improvement and broader participation, making the initial commitment less daunting for farms at varying stages of their sustainability journey. Annual recertification audits are mandatory at all levels, ensuring ongoing compliance and progress. For perennial systems specifically, the standard requires the maintenance of native vegetation or seeded mixes as ground cover between perennial plants, promoting biodiversity and soil health. The tiered system of ROC is a strategic design choice that directly addresses the challenge of widespread adoption. By offering different entry points, it acknowledges that farms are at varying stages of their sustainability journey and may not be able to achieve the highest level immediately. This incremental approach fosters a culture of continuous improvement, which is vital for the long-term nature of perennial crop systems. This model can significantly facilitate wider adoption of regenerative practices, especially for small and medium-sized farms, by making the initial commitment more accessible.

SCS Sustainably Grown® Certification

SCS Sustainably Grown® Certification is broadly applicable to agricultural crop production operations of all sizes worldwide, encompassing both conventional and organic farming systems. This wide scope makes it a versatile tool for various agricultural contexts, promoting sustainability across a broad spectrum of producers. It holds significant market recognition, being acknowledged by major retailers such as Costco, Walmart, Aldi, and Lidl, and is aligned with leading US and European sustainability initiatives. This market acceptance provides a strong incentive for producers to seek certification, offering a competitive advantage in a sustainability-conscious marketplace. The certification framework is comprehensive, structured around three core categories: Business Integrity (covering responsible management systems, legal compliance, and crucial traceability and transparency), Sustainable Farming Practices (including crop and pest management, soil conservation, water stewardship, climate neutrality, biodiversity protection, energy efficiency, and integrated waste management), and Ethical Stewardship (addressing fair work agreements, equitable wages and benefits, prohibition of child/forced labor, non-discrimination, and community engagement). Specific requirements include annual risk assessments for water quality, mandatory implementation of mitigation measures, and subsequent assessment of their efficacy. It mandates strategies to increase soil organic matter (e.g., compost, cover crops, reduced tillage, animal grazing) and requires regular testing to monitor soil organic matter and carbon levels. Producers must assess their operations' effects on natural ecosystems, implement strategies to mitigate adverse impacts and improve biodiversity, and establish or maintain buffer zones adjacent to natural habitats and water bodies. The broad market recognition of SCS Sustainably Grown® by major retailers and its alignment with prominent sustainability initiatives clearly indicate its strong market-driven orientation. This certification acts as a direct link between sustainable agricultural practices and market access, providing a tangible economic incentive for producers. The explicit inclusion of "Traceability and Transparency" as a core component demonstrates a proactive integration of supply chain visibility into the sustainability framework, recognizing its importance for consumer trust and regulatory compliance.

Rainforest Alliance Certification

Rainforest Alliance certification specifically covers a range of perennial crops, including bananas, cocoa, coffee, tea, various fruits, nuts, and palm oil. This focus on high-volume perennial commodities highlights its significant impact on global supply chains. The overarching mission is to foster a world where both people and nature thrive in harmony, achieved through the implementation of strict environmental, social, and economic standards. A notable development was the merger of the UTZ certification program with the Rainforest Alliance in 2018, leading to the gradual phasing out of the UTZ label in favor of a unified Rainforest Alliance seal. This consolidation aims to simplify the certification landscape for consumers and producers, potentially amplifying the reach and impact of sustainable sourcing. The 2020 Sustainable

Agriculture Standard, which underpins the certification, comprises detailed Farm Requirements (focused on protecting landscapes, improving farmer livelihoods, and advancing human rights) and Supply Chain Requirements (promoting transparency and responsible business practices throughout the value chain). Key sustainability areas explicitly addressed within the standard include deforestation prevention, upholding human rights, ensuring living wages, promoting climate-smart agriculture, and conserving biodiversity. For traceability, the standard requires geolocation points for plots of land, with even stricter requirements for compliance with EU regulations, such as higher decimal precision for coordinates and a "no deforestation after 31 December 2020" rule. The strategic merger of UTZ and Rainforest Alliance signifies a concerted effort to consolidate and strengthen sustainable certification for major perennial commodities. This move aims to reduce complexity for producers and consumers, potentially amplifying the reach and impact of sustainable sourcing. The explicit integration of "deforestation" and "climate-smart agriculture" within the 2020 standard demonstrates a proactive adaptation to pressing global environmental challenges, particularly relevant for perennial crops often cultivated in tropical, biodiverse regions.

International Sustainability and Carbon Certification (ISCC)

ISCC is a globally recognized sustainability certification system that encompasses a wide range of sustainable feedstocks, including agricultural and forestry biomass, biogenic wastes and residues, circular materials, and renewables. This broad scope makes it highly versatile across various perennial crop types. It operates as a "no-deforestation standard," demonstrating a strong commitment to protecting forests, high-carbon stock lands, and biodiversity. This principle is fundamental to its environmental integrity. ISCC offers a voluntary add-on specifically for regenerative agriculture practices, which focuses on enhancing soil health, water health, biodiversity, and carbon sequestration. This shows an adaptive approach to emerging sustainability trends. The core ISCC Principles guide its certification process, including the exclusion of biomass production from high biodiversity or high carbon stock areas (Principle 1), promotion of good agricultural practices and environmental protection (Principle 2), ensuring safe working conditions (Principle 3), adherence to social standards (Principle 4), compliance with all applicable laws and international treaties (Principle 5), and commitment to good management practices and continuous improvement (Principle 6). ISCC aligns with the European Union Deforestation Regulation (EUDR) through its dedicated EUDR Add-on, which mandates deforestation-free production (post-December 31, 2020), compliance with local laws, robust due diligence processes, and strict chain of custody requirements. ISCC's ability to cover "all sustainable feedstocks" and its explicit, detailed alignment with the EUDR through an "Add-on" positions it as a highly adaptable and forward-looking certification scheme. This dual focus on broad applicability and specific regulatory compliance is critical for global agricultural supply chains. The voluntary regenerative agriculture add-on further demonstrates its responsiveness to evolving sustainability paradigms, particularly relevant for perennial crops that are integral to regenerative systems.

Forest Stewardship Council (FSC)

FSC is an international non-profit organization established in 1993, dedicated to promoting responsible management of the world's forests through timber certification. Its market-based approach aims to drive sustainable forestry practices globally. FSC certification signifies that forest operations meet rigorous environmental, economic, and social standards, ensuring the protection of plants, animals, and people dependent on forests. The foundation of all FSC standards is its 10 Principles and Criteria (FSC P&C), which are globally applicable to all forest types and management units. Beyond timber, FSC also certifies a wide variety of non-timber forest products (NTFPs), many of which are perennial. These include cork, bamboo, natural rubber, various nuts and seeds, honey, mushrooms, fruits, and resins. This demonstrates a comprehensive approach to forest resources. The 10 Principles cover a broad spectrum of sustainability aspects: compliance with laws, maintaining/improving worker well-being, upholding Indigenous Peoples' rights, enhancing local community well-being, efficient use of multiple forest products/services, conserving biological diversity and ecosystem services, implementing robust management plans, conducting thorough monitoring and assessment, maintaining natural forests (prohibiting their replacement by plantations), and ensuring plantations complement, rather than replace, natural forests. FSC's primary focus on timber might initially seem tangential to "perennial crops." However, its explicit and extensive certification of "non-timber forest products" (NTFPs) directly integrates many perennial crops into its sustainable forest management framework. The emphasis on harvesting NTFPs "without cutting down trees" while "generating new sources of income" highlights a key sustainability benefit and alignment with agroforestry principles. FSC provides a critical framework for integrating the sustainable harvesting of perennial NTFPs into broader forest management strategies.

Programme for the Endorsement of Forest Certification (PEFC)

PEFC operates a forest certification scheme that promotes the sustainable management of forests and ensures traceability of forest-based products from sustainable sources to the final product through its Chain of Custody certification. Notably, PEFC was founded in 1999 specifically to address the unique requirements of small- and family forest owners who faced difficulties accessing alternative certification systems. This highlights its commitment to inclusivity within the forestry sector. PEFC endorses national forest management standards in over 48 countries globally, indicating a decentralized yet harmonized approach to sustainable forestry. Its definition of sustainable forest management emphasizes socially just, ecologically sound, and economically viable outcomes, aligning with the three pillars of sustainability. Key requirements include maintaining and enhancing ecosystem biodiversity, protecting ecologically important forest areas, prohibiting forest conversions, recognizing the free, prior, and informed consent of indigenous peoples, promoting gender equality and equal treatment of workers, ensuring the health and well-being of forest communities, respecting human rights in forest operations, and prohibiting genetically modified trees and most hazardous chemicals. PEFC is actively aligning its standards, such as PEFC ST 1003:2024, with the European Union Deforestation Regulation (EUDR) to ensure compliance and market access. The scheme explicitly certifies "non-wood forest products" and "non-wood products from TOF (Trees Outside Forests) areas," which include various perennial products. PEFC's foundational mission to serve "small- and family forest owners" is a critical aspect, as this demographic often faces significant barriers to certification due to cost and complexity. Its endorsement of national standards allows for local adaptation while maintaining global credibility, making it highly scalable. This broad global reach and adaptability to local contexts make it a powerful force for sustainable forest management, which inherently includes many perennial non-timber forest products.

GLOBALG.A.P.

GLOBALG.A.P.'s Integrated Farm Assurance (IFA) for flowers and ornamentals is a global standard designed to promote safe and responsible farming practices across all production stages. The standard's applicability is broad, covering major production systems (open field, greenhouses, hydroponics) and a wide range of perennial products, including cut flowers, house plants, trees, bulbs, and turf. It offers flexible certification options for various farm sizes and types, including individual producers (single-site and multi-site) and producer groups, specifically accommodating smallholders. GLOBALG.A.P. actively supports the UN Sustainable Development Goals, aligning its efforts with broader global sustainability agendas. GLOBALG.A.P.'s explicit mention of "perennials" within its IFA for flowers and ornamentals is significant because it highlights that sustainability certification extends beyond food crops to other high-value perennial sectors like floriculture and horticulture. Its flexibility in certifying individual producers and producer groups, including smallholders, indicates an understanding of the diverse operational structures in agriculture. This demonstrates the growing scope of sustainability certifications to encompass the full spectrum of perennial crop applications.

Table 2. Key Global Perennial Crop Certification Schemes: Scope and Core Principles

Organization Name	Primary Perennial Crops Covered	Core Sustainability Focus (Environmental)	Core Sustainability Focus (Social)	Core Sustainability Focus (Economic)	Key Differentiator/Note
Certified Regenerative by A Greener World (AGW)	Broad agricultural crops, including perennials (e.g., olive farms)	Soil health, water quality, air quality, biodiversity, carbon sequestration, erosion minimization	Human/societal factors, fair work agreements, equitable wages, no child/forced labor, non-discrimination, community engagement	Farm profitability, resilience, market access	Holistic, adaptive, measurable Regenerative Plan; continuous improvement expected; applicable to all farm sizes
Regenerative Organic Certified® (ROC)	Broad agricultural crops (requires USDA Organic or equivalent), including perennial systems (e.g., ground cover between perennials)	Soil health & land management (increasing organic matter, carbon sequestration, crop rotations)	Animal welfare, farmer & worker fairness (economic stability, fairness)	Economic stability for farmers/workers, market access	Tiered system (Bronze, Silver, Gold); builds on existing organic certification; multi-stakeholder governance
SCS Sustainably Grown® Certification	All agricultural crop production operations globally (conventional and organic), including perennials	Crop & pest management, soil conservation, water stewardship, climate neutrality, air quality, biodiversity protection, energy efficiency, waste management	Fair work agreements, equitable wages/benefits, no child/forced labor, non-discrimination, workforce health & safety, community engagement	Brand support, market access, supply chain risk mapping, innovation recognition	Robust, comprehensive framework; recognized by major retailers (Costco, Walmart, Aldi, Lidl); strong traceability emphasis
Rainforest Alliance	Bananas, Cocoa, Coffee,	Deforestation prevention,	Human rights, living wage,	Improved productivity,	Merger with UTZ; 2020 Sustainable

Certification	Tea, Flowers, Fruit, Herbs & Spices, Non-Timber Forest Products, Nuts, Palm Oil	climate-smart agriculture, conserving biodiversity, landscape protection	living income, gender equality, improved farmer livelihoods	reduced costs, secured supply, brand credibility	Agriculture Standard; focus on high-volume tropical perennials; strict geolocation for traceability
International Sustainability and Carbon Certification (ISCC)	All sustainable feedstocks (agricultural & forestry biomass, biogenic wastes/residues, circular materials, renewables), including perennials	No-deforestation, high-carbon stock protection, biodiversity, soil health, water health, carbon sequestration, GHG emission reduction	Safe working conditions, social standards, worker/community rights	Economic viability, market access	Broad scope; EUDR alignment (EUDR Add-on); voluntary regenerative agriculture add-on; multi-stakeholder development
Forest Stewardship Council (FSC)	Timber, Non-Timber Forest Products (NTFPs) like cork, bamboo, natural rubber, nuts, honey, mushrooms, fruits, resins	Forest conservation, biodiversity protection, ecosystem services, prevention of forest conversion, responsible plantation management	Worker well-being, Indigenous Peoples' rights, local community well-being	Economic viability, market access, reputation protection	Holistic forest management; extensive NTFP coverage; 10 Principles and Criteria; global recognition
Programme for the Endorsement of Forest Certification (PEFC)	Forest-based products (wood & non-wood forest products), including perennials from Trees Outside Forests (TOF)	Sustainable forest management, biodiversity, prohibition of forest conversions, GHG emission reduction	Worker rights (ILO conventions), indigenous peoples' consent, gender equality, community well-being	Economic viability, market access	Global reach; designed for small/family forest owners; endorses national standards; EUDR alignment; Chain of Custody focus
GLOBAL G.A.P.	Flowers, ornamentals (cut flowers, house plants, trees, bulbs,	Safe & responsible farming practices, resource	Worker health & safety, social responsibility	Market access, efficiency, cost reduction, product quality	Broad applicability for production systems & farm sizes (incl. smallholders);

	perennials, turf), fruits, vegetables	optimization, environmental protection			supports UN SDGs; strong focus on Integrated Farm Assurance

4.1.2. Common Principles and Criteria

Despite the diversity in their specific focus and commodity coverage, global certification schemes for perennial crops exhibit significant convergence on core sustainability principles. This alignment reflects an emerging global consensus on the essential elements of responsible agricultural production.

Environmental Stewardship

A consistent and paramount focus across certifications is the maintenance and improvement of soil quality. This includes strategies for increasing soil organic matter, minimizing erosion, optimizing soil structure, and enhancing biological activity and fertility. Common practices promoted are crop rotation, cover cropping, mulching, reduced tillage, and balanced fertilization, all crucial for long-term perennial system health. The emphasis on these practices underscores a recognition that healthy soil is the fundamental building block of sustainable agriculture, particularly for perennial systems that rely on undisturbed soil for extended periods.

Water stewardship is another universally emphasized area, focusing on preserving water quality and preventing resource depletion. This involves minimizing impacts on surface and groundwater from chemical residues and erosion, promoting aquifer recharge, and implementing efficient irrigation practices based on crop needs and water availability. Many standards require risk assessments and mitigation measures for water contamination, reflecting a commitment to responsible water resource management.

Biodiversity protection is integral to nearly all schemes. This includes maintaining and enhancing ecosystem biodiversity, protecting ecologically important forest areas, and conserving habitats for wildlife and pollinators. The establishment of buffer zones adjacent to water bodies and natural habitats is a common requirement to minimize off-site disturbance and protect sensitive ecosystems. The focus on biodiversity underscores a broader understanding that agricultural systems are part of larger ecosystems and their health depends on the surrounding natural environment.

A critical environmental principle, particularly for perennial crops often associated with land-use change, is the prohibition of deforestation and conversion of high carbon stock areas. Standards like RSPO, ISCC, FSC, and PEFC explicitly ban or severely restrict new land clearing in primary forests, highly biodiverse areas, peatlands, and other high carbon stock lands after specific cut-off dates. This reflects a global commitment to mitigate climate change and protect critical ecosystems by preventing the expansion of agriculture into valuable natural habitats.

Finally, climate action, including the reduction of greenhouse gas (GHG) emissions and enhancement of carbon sequestration, is increasingly integrated into certification criteria. This involves monitoring fossil fuel use, promoting renewable energy, and encouraging practices like agroforestry and reduced tillage that turn agricultural lands into carbon sinks. This demonstrates a shift towards recognizing agriculture's role not just in reducing its footprint but actively contributing to climate change mitigation.

Social Responsibility

Social responsibility is a fundamental pillar across various perennial crop certifications. A key area is the protection of worker rights, including fair work agreements, equitable wages and benefits, and the prohibition of child, forced, or coerced labour. Many standards align with International Labour Organization (ILO) conventions, ensuring safe and healthy working conditions, non-discrimination, and freedom of association. This comprehensive approach to labour conditions aims to create dignified and equitable employment opportunities within the agricultural sector.

Community relations and respect for human rights are also consistently emphasized. This involves upholding the legal and customary rights of Indigenous Peoples and local communities, ensuring their participation in processes that affect them, and addressing grievances. Some certifications explicitly require ethical business behaviour, transparency, and the absence of corruption. These provisions aim to ensure that agricultural operations contribute positively to local communities and do not infringe upon their rights or livelihoods.

Economic Viability

While driving environmental and social improvements, certification schemes also recognize the necessity of economic viability for producers. Common economic principles include optimizing productivity and efficiency, reducing costs (e.g., through reduced inputs or improved management), and enhancing market access for certified products. Many certifications aim to provide a competitive advantage, allowing farmers to differentiate their products and potentially command higher prices in sustainability-conscious markets. The focus on economic benefits ensures that sustainable practices are not only ecologically sound but also financially sustainable for farmers, promoting long-term resilience of the agricultural sector.

4.1.3. Adoption Rates and Market Trends

The adoption of sustainable agriculture certifications for perennial crops shows a growing trend, driven by increasing consumer demand and evolving market dynamics. While specific, comprehensive global data for all perennial crops remain somewhat fragmented, existing information highlights significant progress and emerging patterns.

In the broader context of organic farming, which often includes perennial crops, there has been a substantial increase in certified areas globally. For instance, in the EU, the total agricultural land under organic production expanded by 79% between 2012 and 2022, reaching an estimated 16.9 million hectares. Countries like Croatia, Portugal, Bulgaria, France, Hungary, Romania, and Italy have seen particularly rapid expansions in their organic areas. This growth in organic certification, which requires a 2-3 year conversion period before full certification, indicates a strong underlying trend towards more sustainable practices, many of which are inherently beneficial for perennial systems[61].

For specific perennial commodities, certification has seen notable uptake. Data from 2019 indicates that over 209,000 farmers participated in the Rainforest Alliance certification scheme for cocoa in Côte d'Ivoire, Ecuador, and Ghana, producing more than 200,000 tonnes. In the same year, Rainforest Alliance certified tea production involved 936,000 tea farmers and 734,000 workers, with top producing countries including India, Kenya, and Sri Lanka[60]. This demonstrates substantial engagement in high-volume perennial crop sectors.

Regenerative agriculture certifications, while newer and less prominent than established organic or non-GMO labels, are gaining traction in the U.S. market. Certifications like Regenerative Organic Certified, Certified Regenerative by A Greener World, and Regenefied are appearing on food products.[58] Regenefied, for example, certifies farms, ranches, and food products across six countries, encompassing one million acres of farmland and 20 food brands. A notable example is King Arthur Baking Company's Climate Blend flour, which uses perennial wheat grown in North Dakota and Montana, certified by

[61] EuroStat. Developments in organic farming. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Developments_in_organic_farming

Regenefied. Despite lower consumer awareness compared to organic labels (7% for ROC, 5% for Regenefied), surveys suggest a significant consumer curiosity about regeneratively grown products (54%), indicating strong future growth potential[62].

Studies confirm that certified farmers tend to adopt a higher level of sustainable practices, including pest and disease control, weed, soil, and water management, compared to non-certified farmers[63]. Certified farmers also report higher scores in ecological, social, and economic sustainability, suggesting that certification contributes directly to the adoption of improved practices and long-term sustainability of operations. Economic factors, such as efficiency and cost reduction, market demand, and financial incentives, play a significant role in influencing farmers' decisions to adopt sustainable agricultural practices[64]. This implies that as market demand for certified perennial crops continues to grow, and as the economic benefits of certification become clearer, adoption rates are likely to accelerate further.

4.2. Traceability Systems for Perennial Crops

Traceability systems are fundamental to ensuring transparency, safety, and sustainability throughout the agricultural supply chain, particularly for perennial crops which have complex, multi-year production cycles.

4.2.1. Traditional Traceability Methods

Traditional traceability methods in perennial crop agriculture primarily rely on manual record-keeping and basic identification systems[65]. These systems aim to track produce from the field to the immediate buyer, typically utilizing lot codes, unique numbers or alphanumeric combinations assigned to a distinct portion of a crop. A lot might be defined as all of the same crop harvested from the same field on the same day, though farms may further subdivide lots for more granular tracking[65].

Growers often use existing farm and planting maps to establish field numbers, which are then referenced in harvest logs to track harvest and packing dates. For farms with fewer employees, harvest crews might be grouped, with their activities linked to the lot number. Labelling individual containers with lot numbers, even if not federally mandated for every piece of produce, is a common practice to enhance traceability efficiency, especially when products are commingled. Simple tools like grocery store labelling guns, markers, or self-adhesive mailing labels are employed for this purpose.

For direct market sales, where buyers are often anonymous, systems are developed to track what was taken to market, its origin, and harvest date, documenting volume, date, and location of sale. On-farm markets also maintain records of daily sales and inventory. These traditional methods, while foundational, often involve binders, spreadsheets, and physical file systems for data storage. They enable basic tracking for purposes like settling customer complaints, managing inventory (e.g., first-in, first-out), and estimating income[65].

4.2.2. Advanced and Digital Traceability Solutions

The agricultural sector is increasingly adopting advanced digital technologies to establish verifiable records of food provenance and production, addressing the rising global demand for transparency and efficiency. These innovations are transforming traceability for perennial crops.

Blockchain Technology

[62] The Organic and Non-GMO Report. Regenerative ag certifications gaining traction in U.S. market. https://non-gmoreport.com/regenerative-ag-certifications-gaining-traction-in-us-market/
[63] Gikunda, R. M., & Lawver, D. E. (2020). Effect of Certification on Adoption and Sustainability of Organic Agricultural Practices. Journal of International Agricultural and Extension Education, 27(1), 64-78. DOI: https://doi.org/10.5191/jiaee.2020.27105
[64] Feliciano, D. (2022). Factors influencing the adoption of sustainable agricultural practices: the case of seven horticultural farms in the United Kingdom. Scottish Geographical Journal, 138(3–4), 291–320. https://doi.org/10.1080/14702541.2022.2151041
[65] Cornell University. https://cals.cornell.edu/national-good-agricultural-practices-program/resources/educational-materials/decision-trees/traceability

Blockchain technology is a leading innovation in agricultural traceability, offering a secure, open, and irreversible ledger for all transactions and processes in the supply chain[35]. This immutable record ensures data accuracy and prevents tampering, providing full transparency and reliable documentation of every item's journey from "farm to fork"[66].This comprehensive tracking is critical for perennial crops, which often have long and complex supply chains.

The core strength of blockchain lies in its decentralized nature, immutability of data, and the use of smart contracts. This allows for seamless information flow across diverse systems and multiple actors, from small-scale farmers and primary processors to distributors, retailers, and consumers, even if they use different data formats and software. Every product, from harvest to waste, carries a digital identity, meticulously chronicling its complete life cycle[67].

Blockchain significantly enhances food safety by enabling rapid identification and removal of contaminated products during foodborne illness outbreaks, reducing recall times by up to 80% compared to conventional systems. This targeted recall capability minimizes public health risks and limits economic losses from widespread recalls and brand damage. Beyond safety, blockchain provides unprecedented consumer confidence, allowing consumers to access a comprehensive, verifiable history of their food, including origin, cultivation methods, processing details, and transportation, with a simple scan of a QR code.

Furthermore, blockchain serves as an indispensable instrument for environmental sustainability. By meticulously recording every input and output, it provides unparalleled visibility into the ecological footprint of agricultural practices. This facilitates the verification of sustainable practices, supports farmers in qualifying for carbon credits and environmental programs, and drives the adoption of regenerative agriculture. The technology also promotes fair labour procedures and ethical sourcing, allowing producers to potentially charge higher prices for their products due to verifiable provenance. Case studies illustrate its application, such as Walmart's collaboration with IBM to track leafy greens in seconds, and Nestlé's use for dairy product traceability from New Zealand farmers to Middle East plants. While these examples might not be exclusively perennial, the underlying technology's benefits are directly transferable.

The trajectory of blockchain in agriculture depends on overcoming its inherent complexities through unified industry action and supportive policy. User-friendly, accessible solutions tailored for diverse agricultural contexts are crucial to bridge the digital divide and empower smallholder farmers with market access and fairer economic returns.

Radio-Frequency Identification (RFID)

Radio-Frequency Identification (RFID) technology offers a powerful solution for tracking perennial crops, moving beyond traditional methods like barcodes by utilizing radio waves to wirelessly transfer data between tags and readers[37]. Unlike barcodes, RFID tags do not require a direct line of sight, can be read from several feet away, and can be reprogrammed to hold up to 2KB of data, including location, date, and time. This enables real-time tracking and automated data collection, significantly reducing manual data entry and human errors.

RFID tags provide each crop or batch with a unique digital identity, enabling precise tracking throughout its lifecycle, from planting to harvest, storage, and packing. This allows for automated sorting and grading, enhancing consistency and efficiency. RFID-enabled sensors actively monitor critical environmental factors such as soil pH, nutrient levels, moisture, and temperature, providing vital insights into crop health

[66] Folio3. Blockchain in Agriculture: Paving the way for unbreakable Farm-to-Fork traceability. https://agtech.folio3.com/blogs/blockchain-in-agriculture/
[67] UNDP, Blockchain for Agri-Food Traceability (Singapore: UNDP Global Centre for Technology, Innovation and Sustainable Development, 2021).

and optimizing irrigation and fertilization schedules. This real-time monitoring facilitates early detection of pests and diseases, helping prevent significant crop losses and safeguarding yields[37].

RFID also enhances supply chain and inventory management, allowing farmers to track products from farm to market, quickly respond to issues, and optimize storage and transportation logistics. In organic agriculture, RFID ensures transparency by recording key data during planting, picking, and transportation, building consumer trust. Examples include vineyards installing RFID tags on grapevines linked to soil moisture sensors for precision agriculture. he future of RFID in agriculture is bright, with integration with AI, machine learning, drones, and robots enhancing predictive capabilities and further automating field scanning[37].

Internet of Things (IoT), Sensors, Drones, and AI/ML

Beyond blockchain and RFID, a suite of interconnected digital agriculture technologies is revolutionizing perennial crop management and traceability. The Internet of Things (IoT) integrates advanced sensors, drones, GPS, and satellite imagery into traditional farming practices to optimize crop production and resource use[68].

- **Sensors:** Soil and crop sensors, embedded in the field, gather real-time data on soil moisture, pH levels, temperature, and nutrient content. Plant-based sensors assess chlorophyll content and stress indicators, enabling proactive soil and plant health management. Smart irrigation systems, powered by IoT and data from these sensors, weather forecasts, and crop databases, deliver precise amounts of water where and when needed, conserving resources.
- **Drones and Remote Sensing:** Drones equipped with multispectral cameras and remote sensing technologies provide high-resolution imagery that reveals plant stress, pest infestations, and nutrient deficiencies long before they are visible to the naked eye. Aerial imagery allows for early intervention, reducing crop losses, while NDVI (normalized difference vegetation index) maps guide targeted interventions. Thermal imaging detects water stress and irrigation needs, enabling precise scheduling.
- **Artificial Intelligence (AI) and Machine Learning (ML):** AI and ML analyse the vast amounts of data collected by sensors and drones, providing recommendations for fertilizer application, drainage improvements, and predictive capabilities for crop diseases and yields. This enables a shift from reactive to proactive farm management.
- **Autonomous Machinery:** Tractors, planters, and harvesters embedded with IoT sensors and GPS can operate autonomously, adjusting their behaviour based on environmental inputs to ensure uniform seed distribution, optimized harvesting, and fuel efficiency.
- **Supply Chain Optimization:** IoT devices also monitor post-harvest conditions during storage and transport, tracking temperature, humidity, and shock exposure to ensure produce quality and prevent spoilage. Real-time alerts help logistics providers take corrective action immediately.

These technologies feed data into integrated farm management systems, allowing farmers to monitor all operations from a smartphone or dashboard, facilitating precision timing for irrigation, fertilization, and harvesting, resulting in higher efficiency and reduced costs. Companies like Perennial are leveraging advanced digital soil mapping models to achieve high accuracy with fewer samples, significantly reducing costs for sustainability programs and carbon markets. This full-service Measurement, Reporting, and

[68] Alliance of Bioversity International and CIAT. How Digital Agriculture Boosts Crop Yields and Efficiency. https://alliancebioversityciat.org/stories/digital-agriculture-boosts-crop-yields-efficiency

Verification (MRV) solution is compatible with any crop and program globally, streamlining and standardizing sustainability efforts.

4.2.3. Benefits of Robust Traceability Systems

Robust traceability systems for perennial crops offer a multitude of benefits across the entire agricultural supply chain, extending from enhanced food safety to improved market access and operational efficiency.

One of the most critical advantages is **enhanced food safety and public health assurance**. Traceability allows for the rapid identification and isolation of contaminated products in the event of a foodborne illness outbreak, thereby reducing the spread of illness and minimizing the impact on public health[65]. This capability can reduce food recall times by up to 80% compared to conventional systems, protecting consumers and limiting economic losses from lengthy recalls and brand damage. The ability to identify a specific lot of contaminated product means that only the affected items need to be recalled, rather than an entire region's supply, saving significant resources and preventing unnecessary waste.

Unprecedented consumer confidence and transparency are direct outcomes of effective traceability. With digital traceability, consumers gain access to comprehensive information about each food product, including its origin, production methods, and journey through the supply chain. This level of transparency builds trust and can lead to increased customer loyalty. Consumer movements like 'Eat Local' underscore the demand for more information about where and how food is grown, placing the onus on farmers to maintain clear records.

Regulatory compliance and global market access are significantly facilitated by robust traceability. Meeting stringent traceability requirements opens new market opportunities and ensures compliance with international food safety regulations, such as the EU's General Food Law and the USA's FSMA[69]. For specialty crop growers, organic producers, or Global G.A.P. suppliers, traceability is essential for proving compliance with specific standards regarding seeds, approved processes, and chemical applications. This can expedite processes for insurance claims and provide market-compliant paper trails.

Superior quality assurance and consistency are also improved. By tracking products through all stages of production, problem areas can be better identified and addressed, leading to higher product consistency. Real-time monitoring via RFID and IoT allows for rapid identification of quality issues, leading to up to 50% higher product consistency.

Finally, **significant economic benefits for producers and retailers** are realized. Traceability streamlines recall processes, reduces production downtime, and protects long-term brand reputation. It decreases costs from contamination events and unlocks new market opportunities among consumers and retailers who require demonstrable quality and transparency. Producers can command a premium on traceable products, and the precise records enable more accurate reporting for sustainable certification and qualification for carbon credits and environmental programs. This ability to link employees and work crews to production practices also allows for more efficient labour management and improved productivity incentives. Overall, adopting traceability systems is a strategic move that enhances operational efficiency, food safety, regulatory compliance, and consumer trust[69].

4.2.4. Challenges in Implementing Traceability Systems

Despite the numerous benefits, implementing comprehensive traceability systems for perennial crops presents several significant challenges, spanning technological, infrastructural, and operational dimensions.

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[69] Qaltivate. Traceability in agriculture: challenges, technologies and benefits. https://qaltivate.com/blog/traceability-in-agriculture-challenges-technologies-and-benefits/

One of the primary obstacles is the **high implementation cost**, which can deter smaller farmers from adopting advanced traceability solutions[69]. This financial barrier creates a disparity in technological advancements across the agricultural sector, potentially leaving smallholders at a disadvantage in a market increasingly demanding transparency.

Data interoperability and fragmentation pose a substantial technical challenge. The agricultural ecosystem comprises a multitude of actors, each potentially employing different data formats, software, and operational protocols. Achieving a cohesive, end-to-end traceability system necessitates that these disparate platforms communicate and exchange information without friction, which often requires developing and adopting universal data standards and protocols. Without this, traceability efforts can be conducted in silos, multiplying work and leaving systems open to fraud[69].

Lack of verification and transparency can undermine the credibility of traceability systems. Some systems may not be based on robust, ground-truth data, or the verification of data may be insufficient[70]. Business confidentiality is often cited as an obstacle to transparency, particularly in the absence of regulatory interventions compelling disclosures. For example, in some regions, palm oil plantation concession maps are not publicly available, making it difficult to verify the legal status of production. Poor transparency about the structure, methods, and data sources used ultimately undermines a system's credibility and any sustainability claims made.

The **complexity of implementation** itself can be daunting for many farmers. Setting up traceability systems requires precise data entry and consistent monitoring. Mismanagement or incorrect implementation can lead to incomplete or inaccurate traceability records, defeating the purpose of the system. This is particularly true for indirect supply chains, which often remain more opaque than direct ones[69, 70].

Furthermore, **security vulnerabilities** can undermine trust in traceability systems and expose stakeholders to potential fraud and data manipulation. Implementing robust cybersecurity measures and educating stakeholders about best practices in data protection are crucial for maintaining the integrity of these systems. The risk of "laundering" non-compliant products into certified supply chains remains significant if systems are not robust enough to detect or exclude double-counting of farm polygons or to estimate reasonable production volumes for each polygon[69, 70].

Finally, the effectiveness of traceability systems in driving change in producer countries can be limited if they are primarily designed by actors in consumer countries without sufficient local context and incentives. To be truly transformative, traceability systems need to be linked to positive incentives for sustainable production, identifying and rewarding producers who are genuinely sustainable[70].

4.3. Future Outlook

4.3.1. Trends in Perennial Crop Certification

The trend towards increased adoption of sustainable agriculture certifications, including those relevant to perennial crops, is expected to continue and accelerate. The significant growth in organic farming areas globally, particularly in the EU, signals a broad shift in agricultural practices that naturally benefits perennial systems. The European Commission's target of 25% of agricultural land under organic farming by 2030 further underscores this policy-driven momentum[61].

70 https://www.fern.org/fileadmin/uploads/fern/Documents/2024/Transformative_traceability_How_robust_traceability_systems_can_help_implement_the_EUDR_and_fight_the_drivers_of_deforestation.pdf

While newer, regenerative agriculture certifications are gaining traction, with consumer curiosity indicating a strong market potential, their prominence is set to increase as awareness grows[62]. The tiered approach of schemes like Regenerative Organic Certified, which allows for continuous improvement, is likely to facilitate broader participation and mainstreaming of regenerative practices, including perennialization. This incremental pathway makes certification more accessible for farms at different stages of their sustainability journey.

The increasing alignment of certification standards with major regulatory frameworks, such as the EU Deforestation Regulation (EUDR)[71], will further drive adoption, particularly for perennial commodities traded internationally. This regulatory pull, combined with growing consumer and market demand for transparent and sustainable sourcing, will make certification an increasingly essential prerequisite for market access rather than a niche differentiator.

4.3.2. Policy and Industry Collaboration

To fully realize the potential of perennial crops for sustainable agriculture, concerted policy interventions and enhanced industry collaboration are essential.

Policy Recommendations:

- **Harmonized Regulatory Frameworks:** Governments should work towards harmonizing regulatory frameworks that support sustainable agriculture and traceability. This includes developing clear standards for data ownership and secure data sharing, which are crucial for blockchain-based systems[35]. Policies should proactively enable innovation rather than lagging behind.
- **Financial Incentives and Support:** Policymakers should provide targeted financial incentives, subsidies, and technical assistance to farmers transitioning to perennial crop systems and adopting certification and traceability technologies. This addresses the significant initial costs and knowledge gaps that can deter adoption, particularly for smallholders[69].
- **Integration of Perennial Crops into Agricultural Policies:** Agricultural policies often overlook the unique role of perennial crops. Policies should explicitly promote biodiversity-friendly farming, stricter land-use planning, and financial mechanisms that encourage sustainable perennial cultivation, recognizing their long-term ecological and economic benefits[72].
- **Public Traceability Systems:** Investing in robust, mandatory, and comprehensive public traceability systems is crucial to mitigate risks like double-counting of farm polygons and to ensure interoperability across the supply chain. Information derived from these systems should guide further actions to improve regulatory frameworks and prevent deforestation[70].

Industry Collaboration:

- **Cross-Value Chain Partnerships:** Stronger partnerships are needed across the entire value chain, from producers and distributors to retailers and technology providers, to build a more transparent, efficient, and accountable food system. This collaboration is essential for addressing challenges like data fragmentation and ensuring seamless information flow[35].

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[71] European Commision. Regulation on Deforestation-free Products. https://environment.ec.europa.eu/topics/forests/deforestation/regulation-deforestation-free-products_en
[72] Exploring the role of perennial crops in sustainable agriculture and global policy. https://showcase-project.eu/news/exploring-role-perennial-crops-sustainable-agriculture-and-global-policy

- **Standardization of Data:** Industry stakeholders must collaborate to develop and adopt universal data standards and protocols to ensure interoperability between different traceability systems[69]. This will promote smoother integration and data flow, reducing complexity and costs.
- **Investment in Research and Development:** Continued investment in research and development is necessary to breed new perennial crop species with desirable attributes like high and consistent yields, and to further refine sustainable cultivation practices. This includes addressing challenges such as seed size, lodging, and pest management specific to perennial systems.
- **Capacity Building and Education:** Industry and certification bodies should invest in educational programs and training for farmers on sustainable methods and the implementation of traceability systems. This addresses the knowledge and education gaps that can be a barrier to adoption, especially in remote regions[57].

5. Agricultural risk transfer solutions and index-based insurance in Southeast Asia

Perennial crops, with lifespans extending over several decades, inherently demand long-term agricultural planning. This characteristic implies that any effective insurance solution must also consider long-term climate projections and provide sustained risk coverage over many years, aligning with the extended investment horizon of these crops.

Empirical findings from a case study in Ghana indicate that interest in index insurance among cocoa farmers was higher among those with younger trees[73]. This phenomenon is potentially attributed to the critical need for securing income and repaying significant upfront investment costs during the early, non-productive or low-productive years of a perennial crop's life cycle. This finding contrasts with some studies on annual crops, where interest in insurance might increase with crop age due to declining yields as trees grow older and yields decline. The distinct investment lifecycle of perennial crops, characterized by substantial upfront capital and delayed returns, suggests that IBI products need to be flexible enough to address varying risk profiles and payout structures across the crop's lifespan. The economic value and risk exposure of a perennial crop change significantly over its life cycle. Young trees represent a high-risk, high-investment phase with no immediate returns, while mature trees provide stable income but might face declining yields or new disease risks. A uniform IBI product might not adequately address these evolving needs. Therefore, insurers could explore tiered or modular products where coverage limits, premium rates, or even the types of perils covered adapt to the crop's age and its associated financial risk profile, ensuring more relevant and attractive insurance solutions throughout the crop's long productive life.

5.1. Implementation of Index-Based Insurance for Perennial Crops in Southeast Asia

5.1.1. Regional Trends and Pilot Initiatives

There has been a significant increase in global interest in developing satellite-based IBI solutions, particularly after 2015, with Asia and Africa identified as the regions showing the most interest. Within Southeast Asia, several countries are actively experimenting with index-based crop insurance, including Weather Index Insurance (WII) and Area Yield Index Insurance (AYII). While these products are generally considered more suitable for small-scale cereal producers, there is a strong recommendation for public and private sector stakeholders in all ASEAN Member States (AMS) to incorporate research and

[73] Lydia Afriyie-Kraft, Astrid Zabel, Lawrence Damnyag,Index-based weather insurance for perennial crops: A case study on insurance supply and demand for cocoa farmers in Ghana, World Development Perspectives, Volume 20, 2020, 100237, ISSN 2452-2929, https://doi.org/10.1016/j.wdp.2020.100237.

development (R&D) into these alternative index insurance products, with a view towards their gradual introduction for other crops over time.

The Southeast Asia Disaster Risk Insurance Facility (SEADRIF)[74] is noted as a potential regional mechanism that could offer AMS an opportunity to pool catastrophe climatic risks in agriculture, such as excess rain, flood, typhoon, and drought. Despite the rising global interest in IBI, particularly in Asia, its application to perennial crops in Southeast Asia appears to be in a nascent stage, primarily characterized by R&D and pilot programs. This suggests a significant "protection gap" for these high-value, long-lived assets, indicating a need for targeted R&D and policy support to realize IBI's full potential for perennial crops.

5.1.2. Case Studies: Coffee, Cocoa, Cashew, and Small-Scale Forestry

Coffee

In Vietnam, a notable pilot initiative is the Coffee Climate Protection Insurance (CCPI)[75], launched for smallholder robusta coffee farmers in the provinces of Lam Dong and Dak Lak. This scheme is designed to manage risks associated with drought, heatwave, and excessive rainfall. Similarly, Laos has developed three new parametric insurance products specifically for its coffee industry, aiming to manage drought and extreme rainfall risks, including high cumulative soil moisture and high cumulative rainfall. These adaptation measures are further supported by seasonal climate forecasts, which aid in better risk management and planning. These pilots, by incorporating multi-peril coverage and leveraging seasonal forecasts, represent a crucial step towards more sophisticated IBI for coffee. This highlights the ongoing need for localized climate data and robust farmer engagement to ensure that the insurance products accurately reflect the specific risks faced by coffee growers and are understood by them.

Cocoa

While specific Southeast Asian case studies for cocoa IBI are limited in the provided material, insights from a Ghana case study offer valuable perspectives on insuring perennial crops like cocoa[76]. This study revealed a high interest in index insurance among cocoa farmers, with over 90% of the sampled households expressing willingness to participate. Key determinants for this interest included ownership of the cocoa farm, regular access to extension services, and the age of the cocoa farm, with higher interest observed for younger trees. The study also emphasized the need for specific index design for cocoa, considering optimal rainfall ranges (e.g., 1500-2000mm for healthy growth) and the risks of fungal infestations from excessive rainfall (above 2500mm). The high demand but significant supply-side challenges (e.g., insufficient data, low profitability for insurers, farmer perceptions of insurance as "free money," and poor organizational structures for reaching farmers) underscore the complex interplay of socio-economic, technical, and institutional factors that affect IBI adoption in perennial crops. Addressing these challenges requires not only product innovation but also substantial investment in farmer education and institutional capacity building.

Cashew Nuts

While cashew nuts are recognized as a high-value plantation crop of socio-economic importance, specific detailed studies focusing on index-based insurance for cashew nuts in Southeast Asia are less prominent in the literature. Some general agricultural insurance schemes in the region, such as Forte in Cambodia, do cover crops like cashews. However, the broader challenges for index-based crop insurance in Southeast Asia, such as low farmer awareness about product benefits and limited preparedness of insurers to develop such products, likely extend to cashew cultivation. The limited specific literature on cashew IBI, despite its socio-economic importance, points to a research gap. This suggests that existing

[74] https://seadrif.org/

[75] CGIAR Research Program on Climate Change, Agriculture and Food Security. 2021. Coffee Climate Protection Insurance (CCPI) scheme led by the private sector in the Central Highlands, Vietnam covered 200 hectares of farms of coffee producers protecting them from the risk of drought and excessive rainfall. Reported in Climate Change, Agriculture and Food Security Annual Report 2021. Outcome Impact Case Report. https://hdl.handle.net/10568/121227

IBI models, primarily designed for cereals, may not fully address the unique risks, phenological stages, and data requirements of cashew, necessitating dedicated research and development efforts to create tailored products.

Small-Scale Forestry

The provided literature generally acknowledges the popularity of forestry and plantation crops in several Southeast Asian countries, including Indonesia, Malaysia, Thailand, Myanmar, Lao PDR, and Cambodia. Furthermore, forestry/plantation crop fire insurance, along with allied perils, is available on a restricted basis in Indonesia, Malaysia, and Vietnam. However, there is a notable scarcity of specific detailed studies or case examples on index-based insurance for small-scale forestry within Southeast Asia. The existing research on IBI largely focuses on cereal crops, with fewer studies dedicated to perennial crops in general, and even fewer specifically on forestry. The scarcity of specific literature on small-scale forestry IBI, despite the prevalence of plantation crops, indicates a significant gap in both research and product development. This suggests that the unique long-term nature, diverse species, and varied risk profiles of small-scale forestry may not be adequately addressed by current IBI frameworks, requiring tailored approaches that consider the multi-decade growth cycles and specific perils relevant to timber and other forest products.

5.2. Challenges and Limitations

5.2.1. Basis Risk

Basis risk remains one of the most commonly cited limitations and significant challenges for index-based insurance. It is defined as the difference between an index's estimate of an individual farmer's losses and their actual losses. This mismatch means that payouts may occur when no losses happen, or, more critically, no payout may be triggered despite actual losses on the farm, which can worsen a farmer's situation and diminish the appeal of IBI.

Mitigation strategies for basis risk are crucial for deepening the market for index-based insurance. The use of remote sensing (RS) data, particularly satellite-based vegetation health indices, has been identified as a key way to reduce basis risk. These products require reliable, broad coverage, and long historical data archives. High spatial resolution data can indirectly reduce spatial basis risk by capturing commodity dissimilarities within complex landscapes. Longer time series and higher temporal resolution satellite data, capable of mapping crop key growth phases, can also contribute to reducing temporal basis risk. Other suggestions include careful design of the trigger, improving data quality and diversity of data sources (merging gauge and satellite data), ample rain gauge installation, community-based data to set index thresholds, and financial alleviation mechanisms like premium decreases after periods without payouts. Basis risk, particularly spatial and temporal, remains a critical barrier to IBI adoption. Its reduction hinges on integrating advanced remote sensing, sophisticated crop modelling, and localized data to improve the correlation between the index and actual farm-level outcomes.

5.2.2. Data Availability, Quality, and Infrastructure Gaps

The effective design and implementation of IBI products, especially those leveraging remote sensing, are heavily reliant on the availability of reliable, broad coverage, and long historical data archives. However, significant data availability, quality, and infrastructure gaps persist in Southeast Asia.

Challenges include a general lack of historical yield data, particularly at the local level, which is crucial for designing and rating Area Yield Index Insurance (AYII) programs. Small-sized farm holdings further complicate data collection and the design of workable crop insurance schemes. For AYII, the infrastructure and manpower required to conduct extensive crop cutting experiments across a country are substantial, contributing to delays in indemnity settlement. For Weather-Based Index Insurance (WII), limitations include the sparse location of weather stations, a general lack of weather data, and issues with real-time data transfer, all of which constrain the accuracy and efficiency of payout settlements. In some cases, there is a discrepancy in data perception between local agencies and reinsurers, as observed in the Ghana cocoa case, where local agencies reported sufficient data while reinsurers highlighted issues with completeness and quality. These data scarcity and quality issues are systemic, limiting the precision and reliability of IBI design. While the increasing reliance on satellite data is a strategic response to overcome ground-based data constraints, its full potential requires robust ground validation and seamless integration with traditional data sources to ensure accuracy and build trust.

5.2.3. Farmer Awareness, Trust, and Uptake

Despite the theoretical benefits and years of experimentation, the uptake of index-based insurance products in low- and middle-income countries (LMICs), including Southeast Asia, has often been disappointingly low. A primary obstacle identified across various case studies is the low awareness of farmers about the potential benefits of weather index-based insurance products and their relatively low premiums. Many farmers in the region are unfamiliar with agricultural insurance and hesitate to trust the insurance product and the underlying index data.

Uptake rates for IBI products have varied widely, from as low as 29% in Mali to 100% in cases where the insurance was offered for free. Reasons for this low uptake often include the perception of insurance as "free money" when heavily subsidized, high illiteracy levels among farmers, and a general lack of perceived value unless bundled with other benefits like subsidized credit or technical assistance. Low farmer uptake, despite IBI's theoretical benefits, points to a critical communication and trust deficit. Effective scaling requires not just product innovation but also comprehensive financial literacy programs, proactive community engagement in product design, and transparent payout mechanisms to build and sustain farmer confidence.

5.2.4. Policy and Regulatory Frameworks

The policy and regulatory environment significantly impact the growth and sustainability of agricultural insurance in Southeast Asia. A major challenge is the heavy dependence on premium subsidies, which can place a substantial fiscal burden on governments in countries like the Philippines, Thailand, Indonesia, and Vietnam. While subsidies can increase uptake, offering 100% premium subsidies (effectively free insurance) is fiscally unsustainable in the long term and can promote moral hazard, where farmers have less incentive to manage their risks.

Furthermore, limited incentives for private insurers pose a challenge. In some countries, government policy channels premium subsidies exclusively through state monopoly insurers, crowding out private sector competition and making it difficult for private insurers to compete on price or scale up their innovative index-based products without subsidies. Traditional indemnity-based products, which still dominate in some areas, are often unsuitable for very small-scale and subsistence farmers due to their high administration costs associated with field-level inspections and yield assessments. Lastly, countries in the early stages of agricultural insurance development, such as Lao PDR, Myanmar, and Malaysia, often lack the technical knowledge and expertise within insurance companies to design, rate, and implement agricultural insurance products and programs effectively. The policy landscape, characterized by heavy subsidies and limited private sector participation, creates a complex environment for sustainable IBI growth. A strategic shift towards Public-Private Partnerships (PPPs) and a cautious, gradual reduction of subsidies are crucial for market maturation and long-term viability, fostering a more competitive and innovative insurance ecosystem.

5.3. Socio-Economic Impacts and Benefits

5.3.1. Enhancing Resilience and Stimulating Investment

Agricultural insurance plays a crucial role in managing risks and building resilience against natural disasters, aligning with major global initiatives such as the Sendai Framework for Disaster Risk Reduction, the COP21 Paris Agreement, and the G7 InsuResilience. Index-based insurance, in particular, aids smallholder farmers in strengthening their resilience to the impacts of weather extremes, such as drought or flood. Beyond mere protection, it also stimulates investments in productivity in favourable years to optimize profitability.

Access to index insurance generally increases agricultural investment. Studies show that farmers offered IBI cultivated, on average, 8% more land and invested 16% more in seeds, 9% more in pesticides, and 8% more in fertilizer. This financial protection helps farmers recover from disasters and lowers various forms of risk, preventing them from resorting to costly coping strategies like high-interest borrowing or reducing investments in children's education, which can compromise future household welfare. By reducing exposure to risk, IBI products can lead to higher investments by both crop and livestock farmers in profitable yet risky opportunities, thereby raising incomes over time and helping households emerge from the cycle of poverty that makes them vulnerable to disasters in the first place. Index-based insurance's impact extends beyond simple risk transfer to fostering a virtuous cycle of increased investment, enhanced productivity, and improved household welfare, thereby contributing to long-term poverty reduction and climate adaptation.

5.3.2. Cost-Effectiveness and Efficiency

Index-based insurance stands out as a cost-effective and efficient option for farmers to transfer climate risk. Its inherent design significantly reduces the need for expensive loss assessments, which are typically required by traditional multi-peril options. The automatic triggering of claims based on predefined indices removes the need for field investigations, leading to substantial reductions in administration and operational costs for insurers. This efficiency allows for lower premiums, making insurance more affordable and accessible to a wider base of smallholder farmers. This streamlined approach minimizes overheads, allowing for greater market penetration and broader access to vital risk protection.

6. Current projects funded by Adaptation Fund in the region

Projects funded by the Adaptation Fund across Southeast Asia highlight several systemic and region-wide challenges in climate change adaptation. Water insecurity is a prominent issue, driven by prolonged droughts, erratic rainfall, and over-extraction of groundwater for agriculture, particularly in high-demand crops like rice (Cambodia, Lao PDR) and coffee (Vietnam). Coastal communities face increasing sea-level rise, saltwater intrusion, and soil erosion, while urban and peri-urban areas struggle with outdated or insufficient drainage and housing infrastructure. Institutional gaps are widespread: local governments often lack the technical and financial capacity to plan or implement adaptive responses, and climate data systems (especially for groundwater and weather) are fragmented or lacking. Furthermore, vulnerable groups, particularly women, youth, indigenous peoples, and informal workers, frequently lack access to resources, decision-making spaces, or capacity-building opportunities, leaving them disproportionately exposed to climate risks. Although many projects begin addressing these challenges, gaps persist in scaling climate finance, monitoring gender outcomes, and mainstreaming adaptation in core development policy.

While not all projects are agriculturally focused, several specifically target crops that are both economically important and climate-sensitive. Rice is a primary focus in Cambodia, Lao PDR, and Indonesia due to its central role in food security and its vulnerability to both drought and flooding. Coffee and cocoa are highlighted in Vietnam and Indonesia as key export crops requiring groundwater and facing threats from shifting rainfall and disease. Corn is also mentioned in Indonesia, particularly in upland and indigenous areas. In coastal and island areas, particularly the Philippines and Indonesia, seaweed cultivation is a major livelihood and a focus of resilience efforts due to its exposure to rising sea temperatures and fluctuating salinity. In addition, some projects promote diversification through forest-food systems (Indonesia), livestock, fisheries, and artisanal activities like mat making or aquaculture as climate-smart alternatives. These targeted crop interventions are often linked to broader goals of securing livelihoods, enhancing value chains, and reducing poverty under a changing climate.

The projects in Southeast Asia region take a diverse but complementary approach to climate resilience, with interventions spanning across sectors such as water and sanitation, agriculture, coastal and urban infrastructure, disaster preparedness, and institutional policy. Many projects emphasize climate-resilient infrastructure, such as upgrading drainage, embankments, housing, and early warning systems, especially in flood-prone and urban areas like Cambodia, Lao PDR, and Indonesia. Others focus on ecosystem-based adaptation (EbA), restoring mangroves, watersheds, and coral reefs to buffer communities against floods, droughts, and erosion. Some target livelihoods and value chains, particularly in seaweed farming, fisheries, and sustainable agriculture, integrating renewable energy and inclusive business models. Importantly, capacity building, knowledge sharing, and governance reforms are central components across nearly all projects. These include integrating climate adaptation into planning processes, developing gender-responsive tools, and enhancing vertical coordination from community to national levels. Collectively, these multi-sectoral approaches reflect the complexity of adaptation needs in the region.

For a summary of recent AF-funded projects in Southeast Asia, please see Annex 1.

University of Southern Queensland

unisq.edu.au

info@unisq.edu.au